Risk perception as a function of age – a psychological investigation

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Summary

This thesis explored how older drivers' perception of risk differs from that of younger age groups. Its aim was to enhance knowledge that can inform the development of measures to maintain the driving safety of older drivers for as long as possible.

Fast aging populations in the Western World (Lanzieri, 2011), the recognition of the importance of mobility for quality of life (Whelan et al., 2006), and the role of the car as a relatively safe mode of transport for older people (OECD, 2001) provide a strong impetus for research on older drivers. Collision statistics show that older people are comparatively safer than young drivers, and this is frequently attributed to 'self-regulation', which describes older drivers' voluntary adaptation of driving to match changing cognitive, sensory and motor capacities to the requirements of the driving task (Charlton et al., 2006). However, international research also indicates the over-representation of older drivers in particular collision types (e.g. Baldock & McLean, 2005), including collisions at intersections and in give-way situations. Study One therefore explored collision involvement rates of young, middle-aged and older drivers and patterns of 62 individual contributory factors in collisions from STATS19, Great Britain's police-recorded injury collision database. As contributory factors have only been collected as part of STATS19 since 2005, the study had unique access to a large dataset, including two years of data and 472,451 cases. Older drivers had higher collisions rates than middle-aged drivers, when rates were based on person miles travelled, and collision rates of older drivers increased in the study's sample with the beginning of the 7th life decade. The analysis of contributory factor patterns found some factors to be recorded particularly frequently against older drivers, but also to play a role in young and middle-aged driver collision. This included failures in manoeuvring, failures in judgement and failures in attending properly to the traffic situation. A number of contributory factors were almost exclusive to older drivers, including factors that pointed towards deteriorations of the visual system, general health problems and heightened feelings of anxiety in traffic.

However, contributory factors cannot deliver a comprehensive model of drivers' perception of risk and driving decision making. The thesis therefore progressed with the review of the literatures on motivational models of driver behaviour, of drivers' awareness and reaction to age-related changes, and of systematic biases in risk perception and driving skills to join up empirical findings and theoretical frameworks and develop testable hypotheses for Study Two. The study used the Task-Capability Interface Model (Fuller, 2005) as the conceptual framework to explore the psychological processes through which thirty young, middle-aged and older drivers appraised risk and how this shaped their decisions and behaviour in a driving simulator. On urban roads, older

drivers compared to young drivers rated the difficulty of the driving task, their feelings of risk and the likelihood of a collision as significantly higher in all experimental conditions, suggesting that older drivers preferred a lower range of task difficulty, potentially because of age-related reductions in capability. Older drivers also adopted significantly lower preferred and maximum driving speeds on urban roads in a free drive condition. Age-related decreases in capability were, however, not reported by the older driver group in a self-assessment questionnaire.

The study's support for the importance of "feeling of risk" as the central parameter for driving decisions led to the review of the literature on affect and decision making. Research suggests that affective cues, including physiological responses, assist and improve cognitive processes, even when they are non-conscious (Bechara & Damasio, 2005). For older drivers, the role of the physiological component of feelings of risk particularly interesting, as studies on emotional reactivity (e.g. Kunzmann et al., 2005) indicate that autonomic reactivity diminishes with age. If physiological responses to risk attenuate with age and drivers are hypothesised to target an optimal range of arousal (i.e. feeling of risk), do older drivers arrive at correct assessments of task difficulty? Study Three explored differences in the affective appraisal of eight video-recorded pairs of high and low difficulty driving situations between 34 young, middle-aged and older drivers through measurement of skin conductance, heart rate variability and subjective ratings of risk. Self-reports of capability did not show significant differences between the three age groups. However, older drivers rated perceived difficulty and feelings of risk significantly higher than middle-aged and young drivers for both high and low difficulty version of the driving situations. The empirical evidence from this thesis therefore points towards an age-related general lowering of the preferred task difficulty range, without concomitant perception of capability reductions. The analysis of age effects for skin conductance and heart rate variability was hampered by the loss of physiological data for a third of the older driver sample and thus low statistical power. For the biggest participant group, the middle-aged drivers, the pattern of results for SCL and Heart Rate Variability across the eight situation pairs tracked the rating data: high difficulty versions were associated with greater skin conductance changes and greater Heart Rate Variability. Further studies with larger participant samples need to test whether physiological signals correspond with subjective measures or dissociate from them in different age groups.

As a result of the thesis, it is suggested that further research into the role of the affective component of risk perception in older drivers is undertaken. The implications of the findings from the research for practical support for older drivers are discussed, including, in particular the question of how correct driver calibration can be encouraged.

Dedication

To my parents, with love and gratitude for their encouragement and support throughout my life. And to my grandmother, who lost a lot and taught me that education is something no one can ever take away from you.

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Presentations and publications arising from this thesis

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Lang, B., Parkes, A. M. & Fernandez-Medina, K. (2013). Driving choices for the older motorist – the role of self-assessment tools. London: RAC Foundation Report.

Lang, B., Parkes, A. M. & Gormley, M. (2013). Feeling of risk as a determinant of driving behaviour - a simulator study. In L. Dorn (Ed.) Driver Behaviour and Training, Vol. VI., Aldershot: Ashgate.

Lang, B., Parkes A. M. & Gormley, M. (2011, August). *Accident involvement of older drivers in Britain.* Paper presented at the TRB Conference 'Emerging Issues In Safe And Sustainable Mobility For Older People', Washington DC, USA.

Lang, B. & Parkes, A. M. (2009, June). *Contributory factors in British injury accidents – accident patterns of older drivers.* Paper presented at the 21st World congress of the International Traffic Medicine Association (ITMA) conference, The Hague, Netherlands.

CONTENTS

1 Setting the scene

With an ever-growing population of older people in the United Kingdom (UK) and many other countries of the Western World, research into the role of mobility in older life, into older drivers' travel patterns and into the risks associated with their continued driving is crucial. Such research can inform the development of bespoke solutions that help maintain older drivers' safe mobility for as long as possible.

This first chapter of the thesis provides an overview of demographic and licensure trends and the current international research concerned with the relevance of mobility and particularly of driving and well-being, travel patterns and change of those patterns as a function of age. The review goes on to explore older drivers' crash involvement and their crash patterns. Aging, the onset of medical conditions and their effect on drivers' fitness are discussed before exploring how older drivers may regulate their driving to match the demands of the driving task with their capabilities. Chapter 2 presents the results of the analysis of police recorded collision statistics for Great Britain and in particular the role of contributory factors in older driver injury accidents.

1.1 Why should we be interested in older drivers?

Low birth rates coupled with increases in longevity and a generation of post-World War II baby boomers moving towards retirement mean that the UK's population is aging (Baster, 2012; Lang, Parkes, Fernandez-Medina, 2013). Whilst 15% of the population were 65 years or older in 1984, this proportion is projected to rise to 23% in 2034 (ONS, 2011). It is particularly those aged 85 and over, the "oldest old", for whom the increases are and will be the greatest (Whelan, Langford, Oxley, Koppel, & Charlton, 2006). Compared to 1984, when approximately 660,000 people fell into this category, the number has increased to 1.4 million in 2009 and is projected to reach 3.5 million in 2034, accounting for 5 percent of the total population in the UK.

The observed change of the population's age structure in the UK over recent decades has coincided with social, economic and environmental transformations that have altered the material and social circumstances of older people, as in their housing, pensions, closest relationships, means of transport and proximity to basic services (Warnes, 1992, Warnes & Fraser, 1992). Land-use planning over past decades has promoted out of town developments that have increased the reliance on the car, especially in areas not well served by public transport (Box, Gandolfi & Mitchell, 2010). The centralisation of services and the increasing distances between the home and the work place further promote this trend (Sammer, 1991). Walking and use of public transport has decreased in Britain and the reliance on the car for transport has increased with significant increases in car ownership rates; in 2009 only 25% of households did not own a car compared to 40% in 1981 according to the British National Travel Survey (2009). At the same time, a significant proportion of today's and tomorrow's older people have higher incomes, more education and better health (Coughlin, Mohyde, D'Ambrosio & Gilbert, 2004) leading to more active older lifestyles compared to previous cohorts and extended driving careers (Holland, 2001).

In addition to the increase in the proportion of older people, driving-licence holding trends reflect cohort changes in people's driver training and experience through the life course and indicate a considerable increase in British licensing rates over recent decades (Box, Gandolfi, & Mitchell, 2010). Women are more likely than before to acquire a driving licence: Whilst only 4% of females and 32% of men aged 70 and older held a full car driving licence in 1975, these proportions had increased to 41% and 78% respectively in 2010 according to National Travel Survey data (Department for Transport, 2010). This equates to just over four million British licence holders aged 70 and older (Office for National Statistics, 2010). In the 60-69 age group, licensure rates in 2009 were 90% for men and 67% for women respectively, suggesting that prevailing differences in licensure rates will disappear as younger people, of whom most will have driven throughout their adult lives move into retirement age. Similar trends have been observed in many other countries, and further increases in licensing rates are expected until at least 2030 (OECD, 2001).

Licensure arrangements in the UK thereby require non-professional drivers aged 70 years or older to renew their driving licence every three years. To renew, older drivers need to submit a self-declaration of medical fitness to the Driver and Vehicle Licensing Authority (DVLA). No external fitness to drive assessment is necessary. Drivers, irrespective of their age, are also legally required to notify the Drivers Medical Branch at the DVLA of any disability (either physical or medical condition) which is or may become likely to affect their fitness as a driver. The DVLA can subsequently (completely or temporarily) revoke the licence or refer the driver to one of 17 accredited Mobility Centres in the UK to undergo a comprehensive fitness to drive assessment.

1.2 Defining the "older driver"

Whilst the importance of research on older drivers is evident, there is no agreement as to when people start to be *"older"* drivers (Cobb & Coughlin, 2004). Kostyniuk and Shope (2003, p.408) remark that *"there is no precise age at which a driver becomes an 'older driver'".* Age in its chronological sense as time elapsed since birth is ruled out by Coughlin (2001, p. 2) who states that the *"chronological age is not a perfect indicator of who is an older driver."* Hakamies-Blomqvist (1998) points out that whilst the probability of older-driver-like characteristics increases with chronological age, aging patterns are subject to considerable variation between individuals. She instead discusses the introduction of biological, psychological or social definitions of aging and proposes the use of changes on important performance variables that could mark the transition to older driving.

The difficulty of defining the onset of "older driving" is reflected throughout the international literature, where different ages are adopted arguably arbitrarily as starting points, e.g. 55 years, 60 years or 65 years. Whilst some researchers define the cut-off point by the age associated with discernable changes in collision risk (e.g. Center for Urban Transportation Research (2005) in the US or Clarke, Ward, Bartle & Truman (2010) in the UK), others define it socially, i.e. by linking it to the entry into retirement age as this transition is typically associated with changes to driving patterns and purposes. However, most frequently no explicit rationale is provided to justify the classification of drivers as "older drivers".

In the absence of an accepted chronological criterion for older drivers, age categories used in this thesis:

- followed age classifications already used in data sources such as UK population data or National Travel Data and differentiated between the "younger old", aged 60-69 years and "older old" aged more than 70 years, for the purpose of collision data analysis;
- counted drivers aged 65 or older as "older" in the two experimental studies, reflecting the transition into retirement age and associated changes in driving patterns.

1.3 Mobility and well-being

The term "mobility" hearkens back to the Latin "mobilitas" (=speed, agility, instability). Mobility comprises residential and circular mobility (Franz, 1984), the former referring to changes of location of residence, the latter referring to travel away from and back to residential locations. With the exacerbation of problems caused by circular mobility, such as congestion or greenhouse gas emissions, it has developed into an important field for research since the eighties. Several definitions of (circular) mobility have been suggested. Suen and Sen (2004) for example define mobility as being able to travel where and when a person wants, being informed about travel options, knowing how to use them, being able to use them, and having the means to pay for them.

Mobility is essential to maintain independence, to access work or education, to cultivate social contacts, to access services and to engage in leisure activities (Mathey, 1983).

Driving in particular, is a pre-requisite for older peoples' participation in, and maintenance of, social activity and contacts (Mollenkopf et al., 1997), which is in turn associated with greater satisfaction with life (Thomae, 1991), better health (e.g. Adelman, 1994; Coke, 1992) and greater longevity (Mollenkopf et al., 1997). Driving cessation and the associated mobility loss have been found to be associated with an increase in depression, loss of self-confidence and status, and, in extreme cases, even early death in international research (Harper & Schatz, 1998; Yassuda, Wilson & von Mering, 1997; Kostynuik & Shope, 1998; Harris, 2000; Rabbitt, Carmichael, Shilling & Sutcliffe; 2002; Persson, 1993).

Mobility needs are prevalent in all age groups. For many people, including older people, driving represents not only a means of transportation, but a symbol of independence, self-reliance and feeling of control of their life (Whelan, Langford, Oxley, Koppel & Charlton, 2006). The relationship between quality of life, well-being and mobility has received considerable attention over the last decade and is discussed in the context of driving cessation later on.

1.4 Travel patterns

A range of international studies shows that age influences patterns of driving activity, destinations and mileage driven (Whelan et al., 2006). Compared to other age groups, older people make fewer journeys and travel fewer miles (Rosenbloom, 2004). Retirement has a significant impact on driving patterns in older drivers as commuting to and from work and of 'at-work' journeys become superfluous (OECD, 2001).

Older drivers' car journeys tend to be shorter, closer to home, and are undertaken for different purposes compared to younger drivers. The types and frequencies of recreation and social trips change with increasing age (Eberhard, 1996). For older women the most common trip is to go shopping; for older men social, recreational and medical visits are more common (Benekohal, Michaels, Shim & Resende, 1994; Rosenbloom, 2004).

Mollenkopf et al. (1997) conducted a questionnaire survey with 2000 older people (55 years and older) in Finland, Germany and Italy to explore mobility needs of older people. Activities most frequently included shopping and walks, followed by visiting friends or family. The researchers found that older people frequently walked to visit friends and family if they lived close by. A large proportion, however, also reported using the car. Those respondents who did not have a car or who were restricted in their mobility by health conditions expressed the greatest dissatisfaction with their level of mobility. Those who had access to a car reported engaging in social activities more frequently. With increasing age, mobility decreased in the sample. Reasons for reduced mobility were most frequently health problems, but also included the lack of services in walking distance, cost and stress associated with travel.

Differences between the travel patterns of older men and women are currently very distinct, but have been predicted to disappear in future cohorts of older drivers (Hakamies-Blomqvist & Siren, 2003). Surveys on the current travel behaviour of older men and women in Europe (Siren, Heikkinen & Hakamies-Blomqvist, 2001) and the US (Collia, Sharp & Giesbrecht, 2003) have identified the following differences:

1. Women travel and drive less than men in terms of both, frequency and distance;
2. Women travel shorter distances;
3. Women are more likely to report[1] medical conditions that impact on their fitness to drive;
4. Women give up driving earlier than men;
5. Women's reason for giving up driving are mostly due to social factors (lack of experience (e.g. if the husband has done the majority of the driving) and finances); men give up mostly due to health factors;
6. Women are more likely to use other transport options than men.

The authors conclude that at present older men and women have substantially different driving patterns and cannot be treated as a homogenous group. However, sex differences in travel patterns are not restricted to old age as studies into the travel patterns of males and females of employment age also find differences in travel patterns that are to a large degree attributable to employment status, household structure and child care arrangements (Nobis & Lenz, 2004).

1.5 Health and collision risk

Whilst it is agreed that chronological age or a particular medical diagnosis does not determine an individual driver's fitness (Folkerts, 1993), is it also a fact that aging brings about deteriorations in brain size, sensory, motor and cognitive functioning even in healthy older adults. A longitudinal MRI study with 140 healthy older (mean age at baseline was 64 years) adults in the US carried out by Raz et al. (2005) furthermore suggest age-related structural changes of the brain that exceeded those found in cross-sectional studies, with accelerated shrinkages in the hippocampus and the cerebellum. None of the participants showed gross cognitive decline, and the authors found significant individual differences in the magnitude and variability of the change observed.

[1] The study did not explore whether the higher reporting was due to a higher prevalence of medical problems or due to a greater willingness to admit to medical difficulties.

Stutts and Wilkins (2003, p.431) summarise the linkage between age-related change and collision risk in older drivers as follows:

"The reality of aging ... is that many of the sensory, physical, and mental skills needed to safely operate a motor vehicle deteriorate. As a group, older adults have poorer visual acuity, reduced night time vision, poorer depth perception, and greater sensitivity to glare; they have reduced muscle strength, decreased flexibility in the neck and trunk, and slower reaction times; they also are less able to divide their attention among tasks, filter out unimportant stimuli, and make quick judgments."

Whilst the evidence suggests age-related changes in these capacities, aging is also a process characterised by considerable inter-individual differences. In their review of age-related declines in driver capabilities, Lang et al. (2013) concluded that age-related decline varies considerably between individuals, and the rate of decline in one particular capability is not necessarily accompanied by similar declines in others. In the same vein McKnight and McKnight (1999) suggest that: *"Age related declines in ability tend to be inter-correlated and the relationship between any one ability and driving could be mediated by other variables. For example, the association of certain visual or perceptual deficiencies with accidents could be due, wholly or in part, to cognitive declines within the same people. While many of the individual studies reviewed addressed several age and driving-related capabilities, few have addressed more than a portion of the full range. As a consequence, we know less of the interrelationships among declines in the various abilities than about the declines themselves. Attempts to combine results from different studies are thwarted by the differences in populations studied and methods of measurement employed."* (p. 446). In their study of 22 visual attentional, perceptual, cognitive and psycho-motor abilities and a highly structured road test with 407 drivers aged 62 years and above, the authors found significant correlations (r=0.4-0.5) between unsafe driving incidents and deficiencies in attentional, perceptual, cognitive and psycho-motor capacities and visual capacities (r=0.3). However, inter-correlations among measured abilities were moderate or high, and the authors suggested that while the different abilities may be distinguished from one another in the degree of their decline, and therefore the relation of declines to driving performance, age-related deficit appeared to pervade all aspects of ability to some extent, and there is no way of knowing which ability declines are actually contributing to accidents.

Similar results were presented by Anstey, Horswill, Wood and Hatherly (2012) in an Australian study with 297 older drivers aged 65-96 years to investigate how cognitive and visual function independently and jointly explain performance on validated measures on the Capacity to Drive Safely. Participants completed the Mini Mental State Examination (MMSE) and a range of cognitive and visual tests, followed by the Useful

Field of View Test (UFOV), the Hazard Perception Test (HPT) and the Hazard Change Detection Task (HCDT) (for a full descriptions of these test, see Anstey et al, 2012). All individual cognitive and visual measures showed negative bivariate correlations with age and a large proportion of variance in the outcome measures was explained by age: The cognitive and visual measures shared between 83% and 95% of variance in the outcome measures, with cognitive factors explaining significantly more variance than visual factors. Visual function measured by standard measures of acuity and contrast sensitivity was uniquely associated with performance on the Hazard Perception Test, but not the other outcome measures, once the cognitive factors and age had been accounted for. Processing speed and executive function measures shared common variance, were inextricably linked and had the largest effect on UFOV and the HCDT, which led the authors to conclude that processing speed and executive function were the strongest correlated of integral driving skills in later life. The authors concluded that further advances in driver screening require the development of more sophisticated models of how factors inter-relate to influence driving performance under different conditions.

The evidence therefore suggests that age-related reductions in performance levels can lead to increases in the difficulty experienced in some tasks; however, whether that difficulty is a cause for concern depends on the precise combination of capabilities required and the consequences of error or slowed responses. Several other reviews of aging processes point to a complicated picture of variable rates of decline and associations with important real life tasks (Koppel, Charlton & Fildes, 2009; Reger, Welsh, Watson, Cholerton, Baker & Craft, 2004; Parasuraman & Nestor, 1991; McGwin, Chapman & Owsley, 2000). Whilst age-related decline in cognitive and perceptual abilities are therefore well documented, the application of a general trend in age-related decline to understanding the impact on driving performance is complex, and a large proportion of older drivers maintain a good standard of driving performance (Dobbs, Heller & Schopflocher, 1998).

Cognitive function

Executive function and processing speed have been suggested as the key cognitive abilities that contribute to performance decrement when driving (Daigneault, Joly & Frigon, 2002; Deary, Johnson, & Starr, 2010; Anstey et al. 2012; Wagner et al., 2011; Salthouse, 2010; Dawson et al., 2010; Mathias & Lucas, 2009; Selander et al., 2011). Andrews and Westerman (2012) explore the relationship between cognitive decline and driving performance by using a distinction of 'fluid' abilities and 'crystallised' abilities proposed by Horn and Cattell (1967). Fluid abilities such as problem-solving, complex reaction time, reasoning and spatial ability are posited to be important for responding to novel situations and tasks where completing the task cannot rely on prior knowledge or experience alone. Crystallised abilities comprise acquired knowledge, skills and life experiences. Fluid abilities appear to decline steadily from early adulthood while crystallised abilities are maintained or in fact increase into adulthood (Salthouse, 2010). Several causal mechanisms have been proposed for the age-related decline in fluid abilities such as processing resource capacity, reductions in processing speed, deficiencies in inhibitory processing and increases in neural noise (Salthouse, 1991; Hasher & Zacks, 1988). However, while types of cognitive processing that are theoretically important to safe and competent driving have been related to ageing, this relationship is not so clear in the real world.

Other age-related decline on the cognitive functions that have been related to driving performance include attention, (Lopez-Ramon, Castro, Roca, Ledesma, & Lupiañez, 2011; Dawson, Uc, Anderson, Johnson & Rizzo, 2010), working memory (MacPherson, Phillips & Della Sala, 2002; Grady & Craik, 2000) and visual perception (Dennis & Cabeza, 2008).

Sensory function

Studies of age-related decline in visual function, in particular visual acuity and visual field loss, have been associated with crash risk in older adults (Higgins & Wood, 2005; Owens, Wood & Owens, 2007; Wood et al., 2009). For visual acuity, poor dynamic acuity (the ability to perceive a moving target) shows a stronger relationship to driving errors than static visual acuity. Visual acuity follows an inverted u-shaped curve over the course of life, with adults over 50 starting to show declines. However, Janke (1994) points out that there is considerable variability in acuity at older ages. Owsley (2004) suggests that whilst visual acuity is the most frequently tested aspect of vision, its association with collision risk is weak and cannot effectively identify high-risk older drivers. Owsley argues that visual acuity is only one component and that other factors, especially the simultaneous use of central and peripheral vision together with the capacity to detect and process critical ingredients from a visually cluttered array while in motion, are not tested by conventional screening instruments. According to the author, the fact that driving is a complex visual-cognitive task makes the diagnosis of eye disease alone insufficient to identify people at elevated risk for collision involvement. Visual information processing skills are thus of higher relevance rather than visual-sensory thresholds. Similar conclusions have been drawn Ball, Owsley, Sloane, Roenker and Bruni (1993). Anstey et al. (2012) emphasise the need for the combination of visual tests with cognitive ability measures and conclude:

"...this does not imply that age can be used as an indicator of driving ability. At the individual level, assessment of actual visual and cognitive function is likely to be a fairer

and more accurate indicator of driving ability than chronological age. There are large individual differences in abilities even at older ages and individual assessment is required to determine a person's actual visual and cognitive abilities." (p. 770)

Regarding the age-related decline of the aural system Dobbs (2005) showed in a meta-analysis of existing research that deafness, even when profound, is not a barrier to car driving. The link between deafness and driving performance was found to vary across studies and there was no strong association with increased collision risk.

Physical function

Age-related decline of physical functions that have consistently been found to relate to driving ability include lower and upper limb mobility and head and neck range of motion (Janke, 1994; NHTSA 2008). Lower limb function is needed to shift the foot from the accelerator to the brake in emergency situations. Research has shown that elderly drivers who commit more pedal errors (failing to stop or accelerating inappropriately) were at higher risk of collision involvement (Freund, Colgrove, Petrakos & McLeod, 2008).

Medical conditions

In addition to non-pathological aging processes, older adults are more likely to suffer from chronic medical conditions and to consume medications for their treatment, both of which can further compromise their ability to drive (Dobbs, 2002; Janke, 1994; Johansson & Lundberg, 1994; Pleis & Coles, 2002). In Great Britain, 38.3 % of the UK residents over the age of 60 reported suffering from a limiting long-term illness defined as 'any health problem or handicap which limits a persons' daily activities, including those which are due to old age' in the 1991 Census (ONS, 1991). For a sample of 999 persons aged 65 years or more Ayis, Gooberman-Hill, Ebrahim and MRC Health Research Collaboration (2003) even reported prevalences of 68.1% for self-reported long-standing illness (LSI) and 40.0% for limiting long standing illness (LLSI).

Medical conditions that have been suggested to increase drivers' collision risk, such as epilepsy or alcoholism are not necessarily associated with aging; however, some specific illnesses, such as the dementias become more prevalent with age. The effect of medical conditions on driving performance has been investigated for several disease-specific groups, including traumatic brain injury, stroke, diabetes, sleep apnoea and, in particular, dementia (Cox, Merkel, Kovatchev & Seward 2000; McGwin, Sims, Pulley & Roseman, 1999; Heikkila, Korpelainen, Turkka, Kallanranta & Summala, 1999; Fox, Bowden & Smith, 1998). The disproportionate amount of work undertaken with this latter group probably relates to the fact that dementia is a group of diseases characterised almost exclusively by deficits in cognitive function, with little interference from the effects of physical disability that may confound any results.

The prevalence of dementia in the population aged 65 years or older in England reduced to 6.5% according to a study recently published in the Lancet (Matthews et al., 2013). Between 30-40% of drivers with dementias are likely to be involved in a road collision (Owsley, 2004). Drivers with impaired cognition, regardless of aetiology, are reported to be at least twice as likely to be involved in collisions as healthy older adults, with the exact measure of risk varying across studies (Owsley, 2004). Hakamies-Blomqvist et al. (2004) have reported that while dementias result in cognitive impairment that can reduce some important driving skills, they are degenerative conditions that in their early stages are often both mild in impact and difficult to detect. O'Neill, Bruce, Kriby and Lawlor (2000) have shown in quasi-prospective studies that the risk in the first two years of dementia approximates that of the general population.

For many medical conditions, conclusive evidence for reduced driving performance or increased collision risk is still limited (OECD, 2001), because of the differential effects of medical conditions on functional abilities (Langford & Koppel, 2006; Marottoli & Richardson, 1998), but also for methodological reasons: Hakamies-Blomqvist, Siren and Davidse (2004) point out that the safety implications of medical conditions, including arthritis, heart disease, arterial hypertension, diabetes and the various forms of dementia are difficult to assess, because some conditions lead to reduced driving exposure and hence reduced opportunity of being involved in collisions.

An interesting study that explored the association between medical warnings for unfit drivers on collision involvement was recently conducted in Ontario, Canada (Redelmeier, Yarnell, Thiruchelvam & Tibshirani, 2012). Physicians in Ontario are required to provide warnings to patients who are suffering from a condition that makes it dangerous for the person to operate a motor vehicle. The study investigated the collision involvement of 100,075 patients who had received a medical warning from a total of 6,098 physicians over a three year baseline prior to the warning and for one year after the warning. The observed annual collision rate per 1000 persons reduced by 45% after the warning from 4.76 to 2.73 ($p<0.001$) for patients as drivers, but not for patients as pedestrians or passengers. Whilst the study addressed a diverse set of medical conditions and comprised all driver age groups rather than older drivers specifically, approximately a third of the patients included in the study were 75 years of age or older. The reduction in collision involvement observed after the issuance of a warning was accompanied by an increase in emergency department visits for depression and a decrease in return visits to the responsible physician. This led the authors to conclude, that medical warnings could help to reduce traffic collision involvement of unfit drivers, but would potentially come at the price of exacerbated mood disorders and a deterioration of the doctor-patient relationship.

In Great Britain, the list of medical conditions that are regarded as increasing drivers' risks and thus excluding drivers from traffic participation are listed in the Driving Vehicle Licensing Agency's (DVLA) medical guide, which is regularly updated by medical professionals (DVLA, 2013). General Practitioners (GP) in the UK may report a driver to the DVLA if in doubt over their fitness to drive and when there is a concern that the driver may pose a risk to other road users. However, as the "GPs primary role is to provide for the patient's health rather than to police licensing" (Fildes et al., 2000, p. 21) this optional notification of the DVLA aims to protect doctor-patient confidentiality and serves to avoid the potential damage to the doctor-patient relationship that may arise from the notification of the licensing agency without the older driver's consent. Furthermore, Breen, Moore and O'Neill's (2007) report provides evidence that psychiatrists have poor knowledge of the guidelines issued by the DVLA and that relatively few patients are advised that they should not drive. Thus, fitness to drive issues may also not be at the forefront of GPs minds when seeing patients. A recent study by the Department for Transport into GPs' knowledge and attitudes to giving advice on fitness to drive indicated that they would benefit from computer-prompts and would welcome information materials that could be distributed to patients and the general public (Hawley, 2011). The family, friends and social network of the older driver are an important trigger for decisions to adapt or cease driving or to seek a specialist fitness to drive assessment. Research presented by Musselwhite (2011) indicated that older drivers who made the decision to cease driving themselves were more accepting and happier with the outcome. They also reported a higher quality of life than those who were pressured to give up driving by family members or medical professionals.

1.6 Collision involvement

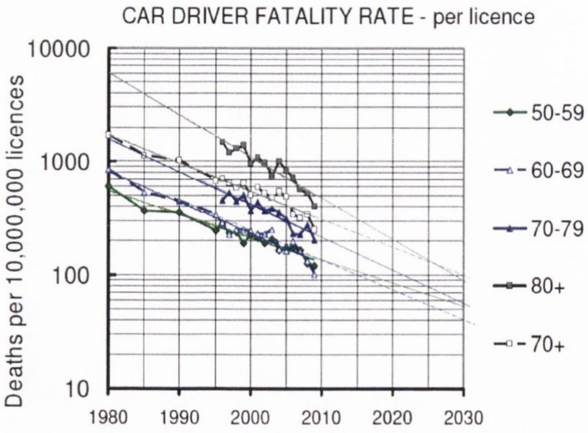
Fair assessments of older drivers' collision risk are fraught with difficulty. On the one hand older drivers have the highest risk of injury accident involvement per distance driven (OECD, 2001). On the other hand, this does not mean that they are unacceptably unsafe. Data (based on the US Fatality Analysis Reporting System (FARS) for 1997 presented by the OECD working group in 2001 showed that per capita fatality rates were high during the first years of the driving career, declined for drivers aged 25-64 years and then increased thereafter. Drivers aged 75 years and older had fatality rates close to those of the youngest drivers. Fatality risks of different age groups were subsequently compared using two different exposure measures. The age-related risk increase in fatalities was relatively small if risk was calculated per licensed driver. Drivers aged 85 years and older had just over double the risk of being killed or injured in a road collision relative to the safest driver group. If fatality risk was, however, calculated on the basis of distance driven, there was a sharp, age-related risk increase in deaths, such that the oldest drivers had around twelve times the risk of being killed relative to the safest driver group.

The working group identified the following methodological difficulties (OECD, 2001), particularly with fatality rates per distance driven:

1. Fatalities only represent a relatively small proportion of the total road safety burden and provide an inadequate indicator of total collision risk, especially for older drivers. Injury collision analyses, even those encompassing casualties of all severity, have a sampling bias: the so called frailty-bias (see Section 1.6.1), which exaggerates any apparent age-related risk increase.
2. While distance driven is generally regarded as a robust exposure measure, it fails to take into account several important factors, such as the amount and location of driving, the net effect of which is also to exaggerate age-related risk increase (see Section 1.6.2).

The working group concluded that neither of the exposure measures allowed straightforward conclusions about whether drivers' individual overall collision involvement changed with age. It argued that older drivers' apparent over-representation in fatality and perhaps serious injury data could not be interpreted as an increased collision risk as a result of the methodological difficulties outlined above. A similar comparison of the collision rates of different driver age groups, either calculated per head of population, per licensed driver or per kilometre driven was presented by Baldock and McLean (2005). South Australian collision data included damage only collisions that had occurred between 1994 and 1998 and which had exceeded $1000 worth of damage. The findings confirmed that older drivers had relatively few collisions overall, but higher collision rates per distance driven. The authors recommended that the overall collision number per age group and collision rates per licensed driver should be used as the most important indicator of collision involvement.

Projections for both indicators for older drivers in Britain up to 2030 have been presented by Mitchell (2011). Figure 1-1 (left) illustrates that whilst fatality rates per 10 million licensed drivers increase with age (as a result of increasing frailty), they are projected to decrease in years to come. In terms of absolute numbers of fatalities, considerably fewer older drivers die compared to young drivers (Figure 1-1, right).



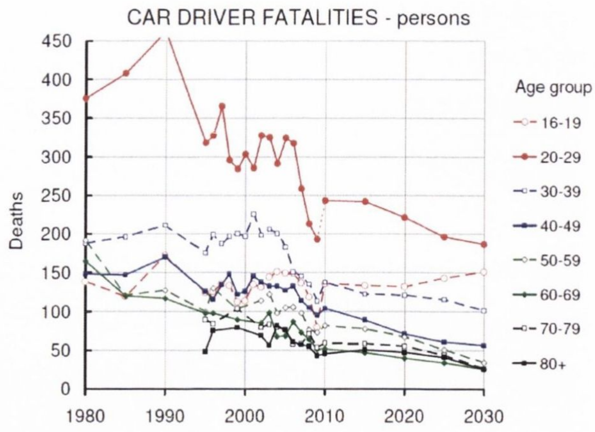


Figure 1-1: Projections of older road driver fatality rates (left) and fatality numbers (right) up to 2030 (Source: Mitchell (2011), slide 33 & 34).

1.6.1 The frailty bias

Older adults' biomechanical tolerance to injury is lower than that of younger people, primarily due to reductions in bone strength and fracture tolerance (Dejeammes & Ramet, 1996; Welsh, Morris, Hassan & Charlton, 2006). Therefore the energy required to produce an injury reduces as a person ages (Langford, 2002) and thus increases the likelihood of serious injuries among older drivers in a collision. Some authors (Li, Braver & Chen, 2003) suggest that after statistical correction, older drivers' over-representation in fatalities could be explained mainly by frailty.

The most valid approach to correcting for frailty is to consider total collision involvement, including injury and non-injury collisions. However, collision data collected by authorities such as the police is frequently limited to injury collisions. The less severe a collision, the less likely it is to appear in official databases (Evans, 2000; Hakamies-Blomqvist, 2003; Maycock, 1997). Baldock & McLean (2005) compared damage-only (more than $1000 damage) collision rates to injury and fatality rates (all calculated per licensed driver) of different driver age groups (16-85+ years) and found that damage-only collision rates continuously decreased with driver age, whereas injury collision rates and even more so fatal collision rates followed a U-shaped distribution with the lowest rates for the 45-54 year olds.

1.6.2 The low mileage bias

According to Janke (1991) drivers travelling greater distances will typically have lower collision rates per kilometre compared to those driving shorter distances. This phenomenon occurs independent of age and is due to the fact that low mileage drivers do more of their driving on local roads and streets, which have more potential conflict points and thus higher collision rates per unit distance. As older drivers typically drive less distance per trip and make fewer trips, this may lead to an apparent high risk based on per distance collision rates.

Hakamies-Blomqvist, Raitanen and O'Neill (2002) demonstrated the low mileage effect using a Finnish travel survey with 1080 participants. They categorised older and middle-aged drivers according to their extent of annual driving and then compared per-kilometre crash rates for the two age groups, controlling for the different annual driving distances. When older drivers were compared with younger drivers who had driven equivalent annual mileages, there was no age-related increase in crashes per distance driven. Fontaine (2003) using French data of 913 drivers and Langford, Methorst and Hakamies-Blomqvist (2006) using Dutch data from 47,502 drivers replicated the findings. Langford et al. (2006), based in Australia, concluded that different driver age groups could only be compared in terms of per distance crash rates after allowances had been made for driving distance differences. When this had been done, older drivers were as safe as or safer than other age groups. Whilst Staplin, Gish and Joyce (2008) have cautioned against the reliance on self-reported driving distances in the context of the low mileage bias, Langford, Koppel, McCarthy and Srinivasan (2008) confirmed the existence of a somewhat smaller low mileage bias after re-analysing previous data and using odometer reading of travels distance instead of self-reported driving distance.

1.7 Collision patterns

Older drivers' typical collision patterns have been described in several publications (OECD working group, 2001; Hakamies-Blomqvist, 1993; McGwin & Brown, 1999; Clarke et al., 2010). Additionally, accident patterns and trends of older road users have been compared for a number of European countries, including France, Spain, the Czech Republic, the United Kingdom and Denmark in the European Research Project CONSOL (Reeves, Lang, Parkes, Bernhoft, Senk & Gabaude, 2013). The authors found that Killed and Seriously Injured (KSI) rates per million driver decreased steadily since 1994 in the UK, Denmark and the Czech Republic, whereby the age group of the 65-69 year olds had the lowest KSI rates. Casualty rates per million population show steady decreases in all three countries since 1994, and people aged 65 and older had consistently the lowest casualty rates of all road user ages groups.

Compared to other age groups, older drivers are rarely involved in single-vehicle collisions, where the loss-of-control is due to risky overtaking or speeding. Instead, a large share of older driver crashes involves collisions with other vehicles, whereby the older driver is typically at fault (McGwin & Brown, 1999). A considerable proportion of older driver collisions occur at intersections with where the older driver is turning against oncoming or crossing traffic with right-of-way. Ferguson, Ulmer and Weinstein (1998) compared fatal collision reports of 1164 drivers of 85 years and older with 661 drivers, aged 40-49 years. Drivers aged 85 years or older were 10.62 times more at risk of a multiple-vehicle collision at intersections than the younger reference group, and the authors found that particularly stop-sign controlled or uncontrolled intersections represented a high fatality risk for older drivers. The high percentage of angle collisions where the older driver is hit from the side by an oncoming vehicle is another factor that explains why older drivers tend to be the ones injured in the collision (Austin & Faigin, 2003). Collisions occurring while turning and changing lanes are also more common amongst older drivers. The collision patterns of older drivers are similar in a wide range of Western countries (Fildes, Corben, Kent, Oxley, Le & Ryan, 1994; Clarke, Forsyth & Wright, 1998; McGwin, Owsley & Ball, 1998; Zhang, Lindsay, Clarke, Robbins & Mao, 2000; Larsen & Kines, 2002; Abdel-Aty & Radwan, 2000; Li et al., 2003).

Different explanations have been offered to account for older drivers' propensity for junction collisions, including problems with visual search, the impossibility to self-pace the driving task in a junction and high task demands:

- Clarke et al. (2010) in the UK propose that the high proportion of visual search difficulties may occur because of increased levels of 'situationai blindness' or because of a reduced 'useful field of view' (UFOV) which has been found to reduce performance in a hazard perception tasks used by Horswill et al. (2008).
- Most older drivers are sensitive to functional impairments and adapt by employing protective strategies in the self-paced driving task (see Section 1.8). The strategies such as slowing down, choosing greater gaps or processing information serially instead of simultaneously help to reduce task difficulty. Whilst self-pacing is possible in most driving situations, junctions may not allow self-pacing to the required degree and thus put older drivers under pressure to drive in a way that may exceed their capabilities.
- Junctions are inherently more complex than most other driving situations as they may involve several other road user types, a greater number of lanes and traffic signals. Junctions are thus more likely to demand divided attention and simultaneous processing resulting in high task demands may exceed older drivers' capabilities and thus increase their collision risk in these situations.

Older drivers' greater likelihood to be at fault in a collision as demonstrated by McGwin & Brown (1999) in the US and Clarke et al. (2010) in the UK has been subject to some debate. Dulisse (1997) points out that by virtue of their presence on the road drivers bear some responsibility for any collision. Hakamies-Blomqvist (1993) argues that because of their greater frailty older drivers may have fewer opportunities to defend their pre-collision actions and that authorities may be biased against very young and very old drivers in attributing blame. Whilst acknowledging the fact that collisions are typically multi-causal, the concept of collision responsibility has been used for a number of purposes, particularly to highlight specific human and other failures. The data sources used in such research studies have included police traffic collision reports (Claret, del Castillo, Moleon, Cavanillas, Martin & Vargas, 2003; Williams & Shabanova, 2003), linked databases (Cooper, 1990; Yanik & Monfotron, 1991; Verhaegen, 1995) and in-depth collision investigations (Hakamies-Blomqvist, 1993). Some studies attributed driver errors such as misperception, misjudgements or failures to give-way as contributing particularly to older driver collisions (Cooper, 1990; Preusser et al., 1998; Schlag, 1993).

1.8 Self-regulation

Janke (1994, p.15) summarises the link between aging, functional decline and reduced driving skills and collision involvement as follows:

"The weight of the evidence with regard to driving competence or skill appears to indicate that the most likely state of affairs is a reduction in elders' driving skills resulting from various declines that come with age, but begin at different ages in different individuals. However, this reduction in skill does not necessarily translate into a high crash rate over any given period of time for elderly drivers as a group, because of the group's characteristic compensatory behaviours and voluntary limitations of their driving." Such behaviours are summarised under the term "self-regulation", which implies that *"drivers make adjustments in their driving behaviour that adequately match cognitive, sensory and motor capacities"* (Charlton et al, 2006, p.363).

In their review of the literature, Lang et al. (2013) found that several studies have demonstrated that older drivers are generally sensitive to the effects of aging and health on their driving competence, and perform self-regulatory adjustments of their driving patterns to avoid travelling under conditions which are perceived to be threatening or may cause discomfort (Rabbitt et al. 2002; Evans, 1988; Eberhard, 1996; Smiley, 2004; Meng & Siren, 2012). Stutts (1998) for example found that older drivers in the US with poorer cognitive and/or visual function drove fewer miles and avoided high-risk situations such as night driving, rush-hour traffic or bad weather conditions. The proportion of older drivers who report self-regulatory avoidance of certain driving situations, however, varies considerable between studies and is likely to reflect differences in study samples (Charlton & Molnar, 2011). Females report to self-regulate more than men. Significant associations have been found between self-ratings of confidence, health status, previous collision performance, performance in an on-road driving test on the one hand and reported avoidance of difficult driving situations on the other (Marottoli & Richardson, 1998; Lyman et al., 2001; Baldock, Mathias, McLean & Berndt, 2006; Raitanen, Toermaekangas, Mollenkopf & Marcellini, 2003). Older drivers typically choose to reduce their exposure by reducing their annual mileage, making shorter trips and making fewer trips by linking trips together (Benekohal et al. 1994; Rosenbloom, 1995, 2004). Older drivers have also been found to restrict long distance travel, take more frequent breaks and drive only on familiar and well lit roads (Ernst & O'Connor, 1988; Smiley, 2004).

Whilst most research into self-regulation is based on the premise that older drivers' adoption of self-regulatory behaviours depends on their insight into age-related deteriorations, a comprehensive review on self-regulation and common changes in older drivers' driving patterns by Charlton et al. (2003) argues that the behavioural adaptations observed in many older drivers are not necessarily compensation mechanisms. They suggest that reduced driving can equally be explained as more mature judgements about road use, lifestyle choices, and personal preferences brought about by changes in employment status, place of residence and proximity of services. The authors also suggest that the greater flexibility of older drivers compared to younger age groups with regards to mobility decisions allow them to avoid driving in situations other drivers are required to drive in by their circumstances (e.g. work) but may prefer to avoid, too, if they were given the choice.

Although self-regulation does not entirely prevent older driver collisions, it appears to be effective in that the "*moderate functional changes related to normal aging do not appear to lead to a discernible increase in collision risk.*" (OECD, 2001, p.49). Despite this positive overall outlook on older drivers' ability to match their capability with the demands of the driving task, there is a small proportion of older drivers who have been shown not to adopt protective driving patterns. Stalvey and Owsley (2000) in the US studied 401 collision-involved current drivers of 65 years and older who had some form of visual impairment. The majority of drivers (82%) did not acknowledge their impairment or its effect on handling difficulty driving situation despite the belief that they would notice if such changes occurred (89%). Over three quarters of this high-risk group did not self-regulate by avoiding driving situations that placed the highest demand on visual processing abilities, and the majority rarely performed specific alternative driving strategies. However, their ratings of self-efficacy for compensatory strategies were high. The participants perceived the seriousness of collision involvement, i.e. the likelihood of being injured, but perceived their susceptibility to be involved in a collision as comparatively low. The authors suggested that interventions increasing self-awareness of functional limitations were the prerequisite for the development and adoption of self-regulatory strategies. Stutts, Wilkins and Schatz (1999) reported similar findings in another US based study. Whelan et al. (2006) suggested that in Australia an estimated ten percent of older drivers do not self-regulate, whereby the authors did not comment on whether this results from a lack of self-awareness or the wish to continue driving despite evident fitness to drive problems.

1.9 Driving cessation, its causes and effects

Self-regulation and driving cessation are clearly linked. The cessation process, described as a "cessation continuum" by Dellinger et al. (2001) occurs in stages as a gradual progression of self-imposed (self-regulatory) restrictions on driving that culminate in cessation. Gilley, et al. (1991, p. 944) noted that *"cessation of driving is not likely to be an all or none phenomenon, but rather the eventual end point of a gradual reduction of driving activity".* This is, however, not to imply that cessation decisions may not appear to be made rather abruptly.

In a review of the literature on the effects of driving cessation or reduction for people aged 65 years and older Harrison and Ragland (2003) established that driving reduction or cessation can be associated with a number of adverse consequences, including reduced out-of-home activity, increased dependence on caregivers or others for transportation, loss of independence, loss of personal identity, increased depressive symptoms and decreased life satisfaction. However, Ragland, Satariano and MacLeod (2005) pointed out that the association between health status and driving cessation was not necessarily causal, but may be moderated by a third variable, such as health status. The researchers explored the association between driving cessation and depression in the US in a longitudinal study with 1953 drivers aged 55 years and older. They found driver status to be strongly linked with depression and cessation to lead to increases in depression, thus suggesting a causal direction between cessation and increases in depressive symptoms. No association between cessation and depression was found at baseline, and variables such as health status were controlled for. The findings were replicated in a second US-based longitudinal study by Fonda, Wallace and Herzog (2001) with 3543 drivers aged 70 years and older.

A number of studies in Europe and abroad have examined factors associated with driving cessation and/ or reduction by older drivers (Hakamies-Blomqvist & Wahlstrom, 1998; Chipman 1998; Kington et al., 1994; Marottoli et al, 1993; Persson 1993; Campbell et al., 1993). Commonly cited factors include practical reasons such as a reduced need for driving or difficulties with some driving situations, medical reasons such as changing health including poor vision (especially at night time) or medical conditions such as arthritis and psychological reasons such as a general "lack of confidence" or a feeling that one is "too old to be driving" (Raintanen et al. 2003, Charlton et al, 2006, Ragland et al. 2004). Economic factors can be a concern for many older drivers, especially women living in rural areas and in single family households. A survey with 1889 US respondents aged 55 year and older who had either recently stopped or restricted their driving, (Ragland, Satariano & MacLeod, 2004) found problems with eyesight to be a leading cause for men and women to avoid driving. The strength of the association increased with age. For respondents aged 75 years and older, 40 percent of the women and 29 percent of males mentioned this factor. Specific medical conditions were only reported by small proportion of respondents. The second most frequent factor reported was "no reason to drive", followed by concerns about being involved in a collision and the possible consequences.

Stutts et al. (2001) carried out a series of focus groups as well as a national telephone survey in the US with 2510 current or previous drivers aged 65 years and older. The researchers found driving to be very important to older adults, for practical as well as emotional and psychological reasons. A sub-sample of 171 former drivers was interviewed about the decision to stop driving. Deciding to stop was found to be extremely difficult for older drivers as well as their families. Approximately 72% of drivers reported to have stopped driving all at once, whereas the others reduced their driving gradually. For those who stopped abruptly, crash involvement, health problems and licence cancellation were the most frequently reported reasons for stopping. Those who gradually reduced their driving mentioned their dislike of the driving environment and poor reflexes as deciding factors. Whilst one third of the respondents believed that they had stopped earlier than they should have, 9% felt that they had stopped later than they should have. Younger males and females of any age were more likely than older male drivers to report that they had stopped driving too early (both 44%) The majority of respondents believed they had stopped at the right time. Those who reported to have stopped driving prematurely were typically younger women in good health who had never enjoyed driving, did not feel comfortable driving and had someone available to drive them when necessary.

1.10 Summary

Research suggests that in comparison with other age groups, older drivers' collision involvement is generally low. However, casualty rates for older drivers per million population and even more so per mile driven are relatively high. As discussed previously, this finding can be partly explained by older peoples' greater frailty and thus their higher likelihood to suffer injury or death as a result of being involved in road collisions.

Furthermore, older drivers are likely to reduce their driving which consequently increases their per mile collision rates (low mileage bias), as most of their driving is carried out on road types where collisions are more likely to occur (e.g. roads in built-up areas). Reasons given for the reduction in driving include the reduced need for a car as a result of retirement and the extinction of work journeys, an increasing dislike of driving, particularly in females, and perceived functional impairments or perceived deficiencies in driving performance. Age-related decline in cognitive and sensory abilities are subject to considerable inter-individual variability and group-based findings say little about an individual's capability to drive safely. Overall, the research suggests that the majority of older drivers successfully adjust their driving to changing circumstances. Mechanisms employed to reduce risk typically include (a) the reduction of driving speed and increase of safety margins and (b) the avoidance of high-risk driving situations such as night-time driving. Whilst the former strategies can reasonably be expected to benefit performance in driving situations that permit self-pacing, avoidance would be the more successful strategy in complex driving situations such as junctions and intersections that involve multiple road users. The fact that older drivers are over-represented in junction collisions has been interpreted as a result of the demands of these situations exceeding older drivers' capacity.

With the number and proportion of older drivers predicted to increase for the foreseeable future as a result of increased longevity and decreasing birth rates and an unwavering popularity of the car as an age-attuned mode of transport for the elderly, research into how the safe mobility of older drivers can be maintained is clearly important.

2 Study 1: Analysis of contributory factors in police-recorded collision data in Great Britain

2.1 Introduction and research aim

According to the literature, age-related increases in fatality rates are comparatively small if calculated on a per licensed driver basis. However, older drivers' fatality rates calculated per person mile of travel have been shown to be considerably higher than those of middle-aged drivers (OECD, 2001). Similar findings have been presented by McGwin and Brown (1999). These authors found a U-shaped distribution of fatality rates based on person miles travelled. Middle-aged drivers of both sexes in this study had distinctly lower rates than young (16-34 years) and old (75+years) drivers. The fatality rates of the oldest drivers even exceeded those of the youngest age group. In comparison, fatality rates based on the number of licensed drivers followed a much flatter W-shaped distribution where the oldest drivers' fatality rates were comparable to 35-44 year old drivers. For both rate types, male drivers had higher rates than female drivers.

McGwin and Brown (1999) also reported all severity collision rates. Calculated on a per licensed driver basis, collision rates decreased steeply from the 15-24 year old to the 25-34 year old driver category and subsequently continued to decrease to the oldest driver group (75+), however, considerably less steeply. Collision rates based on person miles travelled again showed a U-shaped distribution which was flatter than the one found for fatality rates, but still indicated considerable increases for the older age groups (65+). With exception of the youngest age group female drivers had higher all severity collision rates than male drivers.

Several studies comparing the higher fatality rates of young, middle aged and old drivers have concluded that the higher fatality rates of older drivers reflect their greater frailty and lower injury resilience rather than their susceptibility of being involved in a collision and that the risk of injury they pose are predominantly to themselves rather than to others (Ryan, Legge & Rosman, 1998; Li, Braver & Chen, 2003; Dellinger, Kresnow, White & Sehgal, 2004; Baldock & McLean, 2005; Langford & Koppel, 2006). Comparisons of the collision rates of different age groups should therefore comprise all severity collision rates.

A considerable body of international research is also available on the type of collisions older drivers are significantly over-represented in (see Section 1.7), including collisions at intersections or in give-way situations during daylight hours in dry conditions.

Attention failures, failure to detect other road users and failures in judging the speed of other road users or the time required to complete a manoeuvre have been proposed as possible causes of older drivers' over-representation in intersection collisions (e.g. Larsen & Kines, 2002) and there is evidence to suggest that the younger old commit more evaluation errors whereas the older old fail to detect other road users more often (Braitman, Kirley, Ferguson & Chaudhary, 2007). With the considerable number of international studies on characteristic collisions patterns for older drivers it seems reasonable to expect that age-specific patterns should also emerge in the contributing factors of these collisions. This chapter presents the findings of the comparison of age-related patterns in factors contributing to police-recorded injury collisions in Great Britain.

Contributory factors have been recorded as a regular feature of Great Britain's injury collision database, STATS 19, since 2005. Prior to this, the collection of contributory factors varied considerably between local police forces. Because the standardised collection of STATS 19 data commenced comparatively recently and because of the complexity of the dataset relatively little use had been made to date of the data source at the time of this study. The analyses summarised in this chapter aim to improve our understanding of the specific circumstances of older driver collisions and aim to shed light on potential difficulties these drivers may encounter prior to the collision. The identification of contributory factor patterns will inform the development of further research hypotheses with the ultimate aim of supporting the development of measures that promote older drivers' safety.

Previous research has shown the existence of distinct collision patterns for young drivers (e.g. OECD, 2006; Maycock, 2002). Young drivers[2] have been shown to be over-represented in single vehicle collisions during the hours of darkness, associated with excessive speeds and the loss of control. Whilst the current emphasis is on the older driver, it is of intrinsic interest to compare where contributing factors in older driver collisions are similar to those of young drivers and where they differ. Such comparisons can inform conclusions on the appropriateness of different interventions as a means of effectively reducing collision rates in both target groups.

Research questions

The analysis conducted here broadly addressed two questions:

1. Since they have only recently been introduced into the STATS 19 database, how reliable and valid are the contributory factor data?

[2] Young drivers are usually defined as young adults between 18 and 25 years of age.

2. How do young, middle-aged and older drivers differ with regard to their collision performance, their injury collision patterns and associated contributory factors?

The STATS 19 database

STATS 19 is the reported injury collision database that was established in Great Britain in 1949. Data are collected in England, Scotland and Wales by police using a standardised STATS 19 data gathering form (see Appendix A for a copy of the STATS 19 form). Training of police officers regarding the completion of the form is generally given during probation. For each reported collision police officers have to complete the details for all vehicles that were involved in or contributed to the collision, regardless of whether the vehicle was damaged or not. Furthermore, officers have to complete the details for any person injured or killed in the road collision. Detailed explanation of the STATS 19 variables and definitions of the collision parties and vehicles that must be included in STATS 19 are summarised in the STATS 20 manual (Department for Transport, 2004).

Contributory factors in STATS 19

Whilst many police forces have used local collision coding systems in parallel to the completion of the STATS 19 form, it was only in 2005 that all police forces in Great Britain began reporting contributory factors as an integral part of the STATS 19 collection system, based on a prototype system developed by TRL in 1996 (see Broughton, Markey & Rowe, 1998; Broughton, Keigan, Knowles & Smith, 2010a)[3]. The contributory factor system allows the recording of up to six factors per collision by the attending police officer at the end of the STATS 19 form (see Appendix A, bottom of Figure A-1). These are attributed to vehicles (V) (their drivers or riders), casualties (C) or uninjured pedestrians (U). Where the road environment was a contributory factor to the collision (e.g. road surface poor/defective) this is recorded against all vehicles affected by this condition. As collisions can have more than one contributory factor attributed to them, percentages do not necessarily add up to 100%. Contributory factors are disclosable in court and their recording requires some supporting evidence. For each of the contributory factors recorded in the STATS 19 form the police officer will indicate whether the contribution of the factor was "very likely" or "possible". The STATS 19 form for reporting contributory factors includes 77 contributory factors in total which grouped into nine categories:

1. Road environment contributed (Codes 101-109);

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[3] According to Broughton, Keigan, Knowles & Smith (2010a) & Broughton, Keigan, Knowles & Smith (2010b) the main difference between the prototype system and the current system was the removal of two-tiers of factors differentiating between **what** had happened in the collision and **why**.

2. Vehicle defects (Codes 201-206);
3. Injudicious actions (Codes 301-310);
4. Driver error or reaction (Codes 401-410);
5. Impairment or distraction (Codes 501-510);
6. Behaviour or inexperience (Codes 601-607);
7. Vision affected (Codes 701-710);
8. Pedestrian only (Codes 801-810);
9. Special codes (Codes 901-903 and 999 (other[4])).

As this brief description of STATS 19 documentation illustrates, collision records can represent complex data sets where multiple vehicles and casualties are involved. Broughton, Keigan, Knowles and Smith (2010b) suggest that this might explain why Contributory Factors have not been extensively used since becoming available, despite their potential to provide additional information relevant to road safety researchers and practitioners. In the same report, the authors state that whilst checks of the coding of Contributory Factors indicate that data consistency is generally good, the possibility of inconsistencies has to be borne in mind.

The STATS 19 data file for analysis

The STATS 19 data subset that was extracted from the STATS 19 database for the comparison of contributory factor patterns between driver age cohorts comprises information on the drivers of passenger cars involved in injury collisions in 2005 and 2006. Specifically, the data includes:

1. The collision description;
2. The description of the car involved in the collision;
3. Information on the driver of the car involved in the collision;
4. Information on the casualty if the driver of the car was injured in the collision;
5. Contributory factors associated with the car or its driver involved in the collision.

Taxi drivers were excluded from the data file and only passenger cars were retained for analysis as the focus of the current study was non-professional car drivers.[5] Since

[4] Code 999 is "Other – Please specify below", but the text that should be recorded on the form is not entered in the national STATS 19 database. Hence, the 999 codes in the STATS19 data can represent officers' failure to use the system properly or an incompleteness of the form.

[5] STATS19 includes a vehicle code "8" for car and "9" for taxi. Whilst taxis were excluded from the data file, category 8 may arguably still include some "professional" drivers such as chauffeurs.

contributory factors have been recorded since 2005, STATS 19 data was available for two years when the analysis commenced in 2008; 2005 provided 241,775 cases and 2006 provided 230,676 cases, indicating a slight decrease in injury accidents for non-professional passenger car drivers in the second year. The total number of cases for analysis was thus 472,451 cases. The initial screening of the data comprised the calculation of simple descriptives using SPSS. This procedure ensured that incorrect data (e.g. drivers aged 6 years) were excluded from the analysis. In particular, variable codes that did not exist according to the STATS 20 manual were re-coded into missing values. Re-coding into missing values was performed in 29 cases for contributory factor 1, nine cases for contributory factor 2, ten cases for contributory factor 3, six cases for contributory factor 4 and three cases for contributory factor 5.

Whilst the STATS 19 data file only includes car drivers of all age groups and should thus preclude codes associated with pedestrians involved in the collision, the review showed that pedestrian codes (codes 801-810) had actually been erroneously allocated. 8529 erroneous pedestrian codes occurred in 2005 and 7862 in 2006. Such incorrect codes constitute less than one percent of all cases and were excluded from analysis.

The contributory factor group "special code" (codes 901-904 and 999) comprises exceptional circumstances such as "vehicle in course of crime" that are of no interest to the research question. All special codes were therefore excluded from analysis. 7408 cases of special codes on the six contributory factors were found for year 2005 and 2006 and were deleted from the dataset.

After re-coding of erroneous code into missing values, exclusion of pedestrian and special codes, 62 separate contributory factors and seven contributory factor groups remained in the database and 15,994 cases (3.4% of all cases) were excluded.

Of the total of 472,451 drivers in the data file (2005 and 2006 combined), 57% cases did not have any contributory factors associated with them which implies that the reporting police officer felt that these drivers had not contributed to the collision. For the 42% that had contributing factors recorded against them, the largest proportion had one contributory factor against them. For less than one percent of the cases a total of six contributory factors had been recorded (see Table 2-1).

Table 2-1: Number of contributory factors associated with drivers, shown for the total sample and for 2005 and 2006 separately.

No of CFs associated with collision	Frequency All cases	% All cases	Frequency 2005	% 2005	Frequency 2006	% 2006
0 contributory factors	269316	57.0	139944	57.9	129372	56.1
1 contributory factor	72922	15.4	37023	15.3	35899	15.6
2 contributory factors	69013	14.6	34701	14.4	34312	14.9
3 contributory factors	37687	8.0	18530	7.7	19157	8.3
4 contributory factors	15184	3.3	7416	3.1	7768	3.4
5 contributory factors	5446	1.2	2755	1.1	2691	1.2
6 contributory factors	2883	0.6	1406	0.6	1477	0.6
Total	472451	100	241775	100	230676	100

As the data contained in the STATS 19 database at least nominally[6] represent the entire population of such collisions, the analysis of contributory factor patterns used descriptive rather than inferential statistics. Any differences identified between groups within the data reflect the true differences in injury collisions rather than differences drawn from a sample distribution.

The National Travel Survey

To compare the collision involvement rates of different driver age groups in addition to the contributory factor patterns exposure data are required. However, accurate exposure data is difficult to obtain. In Britain, one source of exposure data of private motorists is the National Travel Survey, a continuous survey that commenced in 1988, following ad-hoc surveys since the mid-1960s. It gathers personal travel information for Great Britain based on respondents' completion of travel diaries for a one-week period. Travel information requested includes trip purpose, mode of travel, time of travel and trip length. Additionally, personal information including age, sex, driver licence holding, working status and ownership of cars is collected. The 2005 National Travel Survey used a sample of 8400 households and for the first time applied a weighting procedure to reduce non-response bias and the drop-off in the number of trips reported over the course of the reporting week. A "trip" in the National Travel Survey is defined as a "*one-way course of travel having a single main purpose. Outward and return halves of a return trip are treated as two separate trips. A trip cannot have two separate purposes,*

[6] Some injury collisions that occur in Great Britain may either not be reported to the police or may be reported by not be recorded by the police and may therefore not be included in the database; however, the number of such incidents is not known.

and if a single course of travel involves a mid-way change of purpose then it, too, is split into two trips." (Department for Transport, 2005, p. 51).

The National Travel Survey is a household survey, and various trips types are excluded resulting in an underestimation of car mileage which is approximately 20% (Broughton, personal communication, 12th February, 2010). However, as this underestimation is unlikely to vary by driver age, this may affect the absolute rates, but should not bias the differences between the rates of different driver age groups in the following calculation of collision involvement rates.

2.2 Method

2.2.1 Reliability and validity check

Exploring the reliability and validity of the STATS 19 data (see Section 2.3.1) comprised two tasks:

- The comparison of the number of incorrectly recorded Contributory Factor codes in STATS 19 in the first two consecutive years of their gathering, 2005 and 2006
- The comparison of police-recorded STATS 19 Contributory Factors with Contributory Factors recorded for the same collisions by trained collision investigators from the On-The-Spot (OTS) database held at TRL. The On-The-Spot (OTS) project was funded by the Department for Transport and the Highways Agency and investigated road traffic collisions in depth to build a comprehensive database about the causes of collisions and injuries. OTS investigators were immediately deployed to the scene of approximately 500 road collisions each year, covering the south of Nottinghamshire and the Thames Valley region. Investigations focused on all types of vehicles, the highway, human factors, and the injuries sustained. Data collection included the completion of STATS 19 collision forms including contributory factors by TRL collision investigators in parallel to the police force's completion of the same form. This means that for a small number of collisions, direct comparisons between STATS 19 data as completed by the police and STATS 19 data as completed by a trained collision investigator were possible. To obtain as large a sample as possible for comparison, data from 2005 and 2006 were combined for this analysis.

2.2.2 Collision involvement and patterns, differentiated by age

This part of the analysis comprised the following three tasks:

- Collision involvement rates of car drivers were calculated as collision involvement rates per licensed driver and as collision involvement rates per person mile of travel, based on UK population data, UK National Travel Survey data and STATS 19 data for 2005 (see Section 2.3.2). Age differentiation applied in the analysis comprised the following seven age groups: 17-20; 21-29; 30-39; 40-9; 50-59; 60-69; 70+ years.
- Collision patters for were explored using STATS 19 data for 2006 (see Sections 2.3.3 and 2.3.4), using four age categories: 17-30; 31-60; 61-70; 71+ years.
- Patterns of Contributory Factors were explored using STATS 19 data for 2006 (see Section 0), using four age categories: 17-30; 31-60; 61-70; 71+ and eight age categories: 17-20; 21-30; 31-40; 41-50; 51-60; 61-70; 71-80; 80+ years.

2.3 Findings

2.3.1 Reliability and validity of the data

As contributory factors have been introduced as part of the STATS 19 form only in 2005, some inaccuracies in data recording are to be expected. Two arguments have been put forward that challenge the reliability of contributory factors in the dataset (e.g. Broughton, personal communication, 15th March 2007). Firstly, police officers who complete the STATS 19 form at the scene of a collision will have limited experience with the data coding; thus, erroneous codes should occur more frequently in earlier years of data than later years. Secondly, police officers may regard the contributory factors as an additional burden rather than valuable information and may thus not complete the form carefully. An informal interview with a former police officer established that contributory factors are not necessarily recorded in their order of importance and that the notion of a hierarchy of importance in the six contributory factors should not be assumed.

Erroneous codes

As explained in Section 2.1, the present STATS 19 data for 2005 and 2006 should not include codes associated with pedestrians involved in the collision (codes 801-810), and the reduction of erroneous coding can be interpreted as an improvement in data recording. As a first step of the reliability analysis, the number of erroneous pedestrian codes recorded was compared against the number of correct codes for 2005 and 2006, resulting in an error rate of 3.92% for 2005 and 3.59% for 2006, thus indicating a slight improvement in the accuracy of recording for 2006 (see Table 2-2).

Table 2-2: Frequency of incorrect pedestrian codes compared to the frequency of all other contributory factor codes for 2005 and 2006.

	2005		2006	
CF	Pedestrian Codes	Other Codes	Pedestrian Codes	Other Codes
1	2443	101188	2135	100897
2	2782	63046	2598	63593
3	1782	32511	1690	33365
4	911	13290	842	13688
5	413	5453	397	5433
6	199	2077	200	2140
	Σ 8529	Σ 217,565	Σ 7862	Σ 219,116
	Error rate: 3.92 %		Error rate: 3.59%	

STATS 19 and OTS data comparison

The direct comparison of contributory factors associated with drivers or their vehicles for the years 2005 and 2006 included 495 injury collisions in both, STATS 19 and OTS. Of these 373 collision reports completed by the OTS team had contributory factors recorded against them, while only 317 of the police reports included such detail. This finding could suggest that police officers are less likely than collision investigators to record the more descriptive information on injury collisions.

As for the STATS 19 data recorded by the police, pedestrian (Codes 801-810) and special codes (Codes 901-003 and 999) were excluded from the OTS data set (34 cases), resulting in 1109 recorded contributory factors in the 373 collisions.

The most relevant question for the current analysis of contributory factor patterns, however, is whether the distribution of the contributory factors recorded by the police forces is comparable to that recorded by trained collision investigators. If this was found to be the case it would suggest that the contributory factor patterns identified for different driver age groups provide an accurate picture of important collision circumstances. To test this, contributory factor distributions as recorded by OTS investigators and by police officers for the 495 collisions for which both data sources were available, were compared (see Figure 2-1 and Table 2-3). Simple proportion tests of difference with pooled standard deviations were conducted to ascertain for each category, whether the recording patterns between Police and OTS were significantly different. Whilst the X^2 test of independence does not perform well when cell frequencies are low, this does not affect simple proportion tests. To account for the multiple comparisons and the consequently higher likelihood of a type-one error, a Bonferroni correction of the alpha level was performed, with $a=0.05/7$ ($a=0.0071$). Significant differences at the 7‰ level were marked with one star in the graph below.

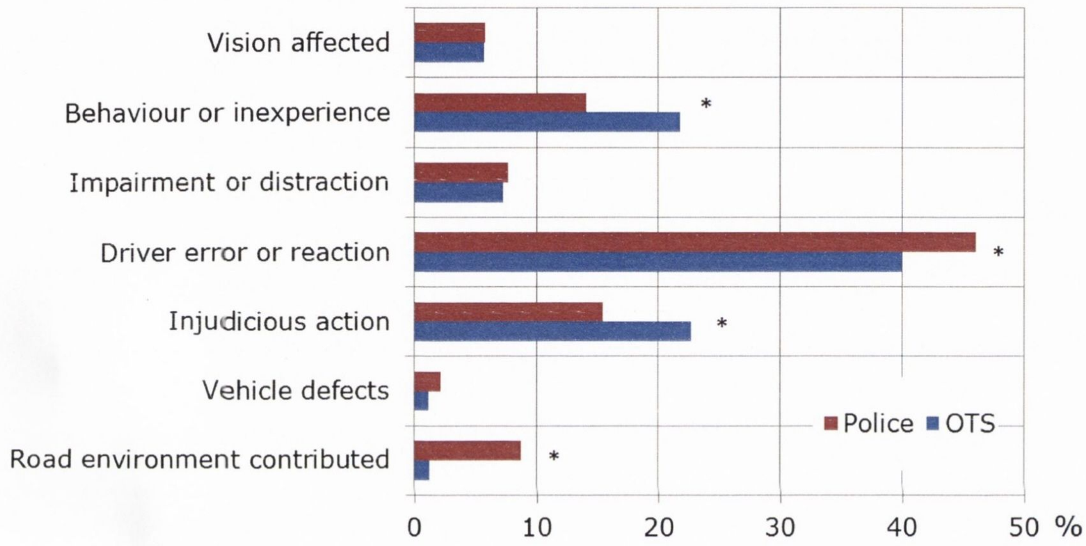


Figure 2-1: Pattern of contributory factors recorded for the same collisions in 2005 and 2006 (*n*=495) by OTS collision investigators and police officers. Differences significant at the *p*=0.007 level are marked as (*).

The results indicated several systematic differences between the judgements of OTS investigators and police officers; OTS collision investigators were more likely to allocate responsibility to the driver than police officers as indicated by the higher percentages in contributory factor class "injudicious actions" ($z=5.59$, $p<0.001$), "behaviour or inexperience" ($z=6.15$, $p<0.001$). In contrast, police officer recorded "road environment contributed" ($z=10.46$, $p<0.001$) and "driver error or reaction" ($z=3.71$, $p<0.001$), a more proximal and descriptive class of contributory factors, more often. For the remaining three other contributory factor classes, differences between police officers and OTS investigators were not significant ("vision affected": $z=0.12$, p=0.45; "impairment or distraction": $z=0.48$, $p=0.32$; "vehicle defects": $z=2.29$, $p=0.01$).

Table 2-3: Percentage distribution of contributory factor classes as recorded by OTS collision investigators and the police for 495 collisions in 2005 and 2006.

	Contributory factor class	OTS		Police		
		f	%	f	%	Simple proportion test
1	Road environment contributed	14	1.26	61	8.73	z=10.46, p<0.001
2	Vehicle defects	13	1.17	15	2.15	z=2.29, p=0.01
3	Injudicious action	252	22.72	108	15.45	z=5.59, p<0.001
4	Driver error or reaction	443	39.95	322	46.07	z=3.71, p<0.001
5	Impairment or distraction	81	7.30	54	7.73	z=0.48, p=0.32
6	Behaviour or inexperience	242	21.82	98	14.02	z=6.15, p<0.001
7	Vision affected	64	5.77	41	5.87	z=0.12, p=0.45
	Total	1109	100	699	100	

To further explore the differences between OTS and police-recorded data, comparisons between the two datasets were made for the 62 retained individual contributory factors. Because the overall number of contributory factors is considerable, the relative frequencies of individual contributory factors are small. A difference of 1% or more was considered as important, and such differences occurred for the individual contributory factors displayed in Table 2-4. Table A-1 in Appendix A displays the results for all 62 contributory factors.

Consistent with the findings for the comparison of the contributory factors classes, OTS investigators recorded more frequently risky driving behaviours such as following too closely, excessive speeds for the prevailing conditions or driving recklessly or in a hurry. Police officers on the other hand recorded contributions of the road environment more frequently as well the occurrence of failures of judgement in drivers such as failing to look properly or failing to judge other road users' path or speed.

Table 2-4: Individual contributory factors for which the difference in OTS and Police records exceeded 1%.

Class	Individual CF	OTS (in %)	Police (in %)
1	Slippery roads	0.7	5.2
1	Road layout	0.3	1.3
3	Disobeyed "Give way" or "stop" sign or markings	4.1	2.3
3	Exceeding speed limit	5.1	3.0
3	Travelling too fast for conditions	7.5	5.0
3	Following too close	4.1	3.0
4	Failed to look properly	10.1	13.7
4	Failed to judge other person's path or speed	5.4	7.3
4	Impaired by alcohol	1.5	2.7
6	Careless, reckless or in a hurry	13.6	7.2
7	Rain, sleet, snow or fog	0.3	1.3
7	Vehicle blind spot	1.3	0.3

According to an experienced OTS investigator at TRL, police officers' greater tendency to allocate responsibility to the road environment can be explained by that fact that contributory factors may be used in court. Police officers may therefore be slightly more cautious with the allocation of responsibility to the driver.

2.3.2 Collision involvement rates

To calculate collision involvement rates for car drivers, population estimates for England, Scotland and Wales for the year 2005 were obtained from the Office for National Statistics (2010). The population figures for the different age groups (17 to 70+ years) were subsequently adjusted to account for the proportion of actually licensed drivers in these age groups[7]. Data on the proportions of licensed drivers in the seven age groups in 2005 were obtained from the National Travel survey 2005 (Department for Transport, 2005). Data from both sources are shown in Table 2-5.

[7]The National Travel Survey does not include provisional licence holders. These drivers are not accounted for in the current analysis.

Table 2-5: Population in Great Britain in 2005 (Office for National Statistics, 2010) and percentage of licensed drivers in Great Britain in 2005 (Department for Transport, 2005).

	Population in GB in 2005			% of licensed drivers in GB in 2005			Number of licensed drivers in GB in 2005		
	♂	♀	Total	♂	♀	Total	♂	♀	Total
17-20	1,587,400	1,500,000	3,087,400	37	27	32	587,338	405,000	987,968
21-29	3,331,100	3,302,200	6,633,300	69	62	66	2,298,459	2,047,364	4,377,978
30-39	4,248,700	4,308,100	8,556,800	86	77	82	3,653,882	3,317,237	7,016,576
40-49	4,156,500	4,245,800	8,402,300	90	79	84	3,740,850	3,354,182	7,057,932
50-59	3,647,200	3,738,700	7,385,900	90	73	82	3,282,480	2,729,251	6,056,438
60-69	2,751,400	2,920,600	5,672,000	88	61	74	2,421,232	1,781,566	4,197,280
70+	2,771,600	3,999,200	6,770,800	73	35	51	2,023,268	1,399,720	3,453,108

Collision involvement rates per licensed driver

To calculate the collision involvement rates per licensed driver, the STATS 19 file for 2005 was used to derive the numbers of collision-involved car drivers (excluding taxi drivers). Separate collision involvement rates were calucated for male and female drivers. Drivers' sex was not reported in 1034 cases of all collisions in 2005, and these were excluded from the analysis. The numbers of collision-involved drivers according to STATS 19 in 2005 are shown in Table 2-6.

Table 2-6: Frequencies and percentages of collision involved car drivers according to STATS 19 in 2005.

	All drivers		**Males**		**Females**	
	Frequency	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
17-20	28956	12.03	19679	12.95	9277	10.45
21-29	54683	22.71	33872	22.29	20811	23.45
30-39	56929	23.65	34311	22.58	22618	25.48
40-49	45129	18.75	27194	17.89	17935	20.21
50-59	28777	11.95	18261	12.02	10516	11.85
60-69	14973	6.22	10473	6.89	4500	5.07
70+	11294	4.69	8189	5.39	3105	3.50
Total	240741	100.00	151979	100	88762	100

To calculate collision involvement rates per 100 licensed driver the frequencies of collision involved car drivers were divided by the number of licensed drivers in the respective age group (derived from Table 2-5) and multiplied with 100 (with 100,000 for fatal collisions).

The results are illustrated in **Error! Reference source not found.** to Figure 2-5. **Error! Reference source not found.** Collision involvement rates per licensed driver, including involvement rates for all severity collisions, showed a sharp decline from the youngest drivers (17-20 year olds) to the second youngest age group (21-29 year olds) and declined further, but less steeply with increasing driver age. For fatal collisions, 60-69 year old drivers were least frequently involved, and a slight increase of involvement rates was observed for drivers of 70 years and older, however, only to the level of middle aged drivers. For all severity collisions, male drivers had higher collision involvement rates than female drivers.

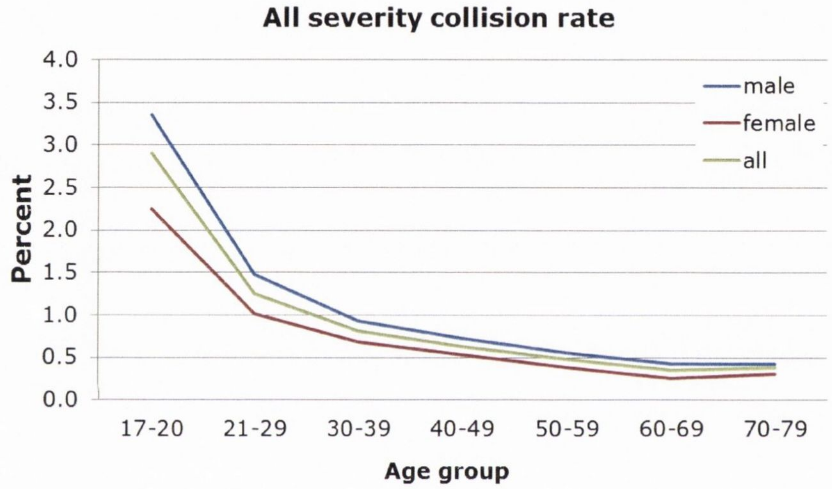


Figure 2-2: Collision involvement rates (all severities) per 100 licensed drivers in 2005.

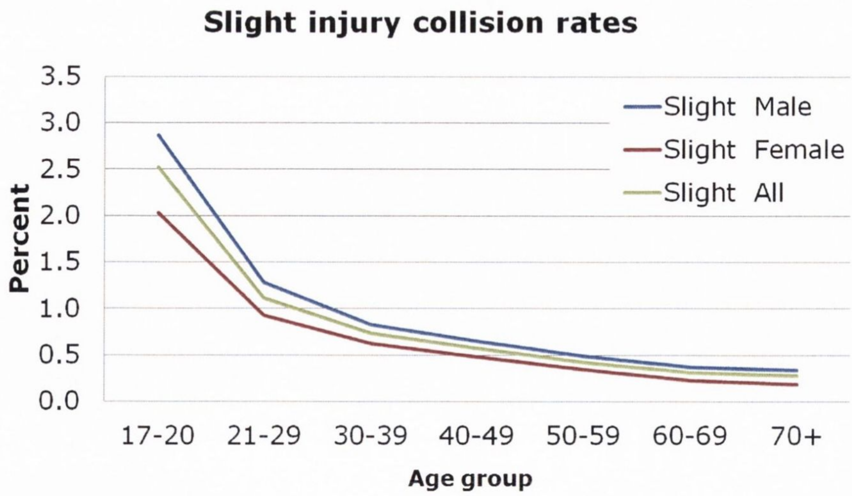


Figure 2-3: Collision involvement rates (slight) per 100 licensed drivers in 2005.

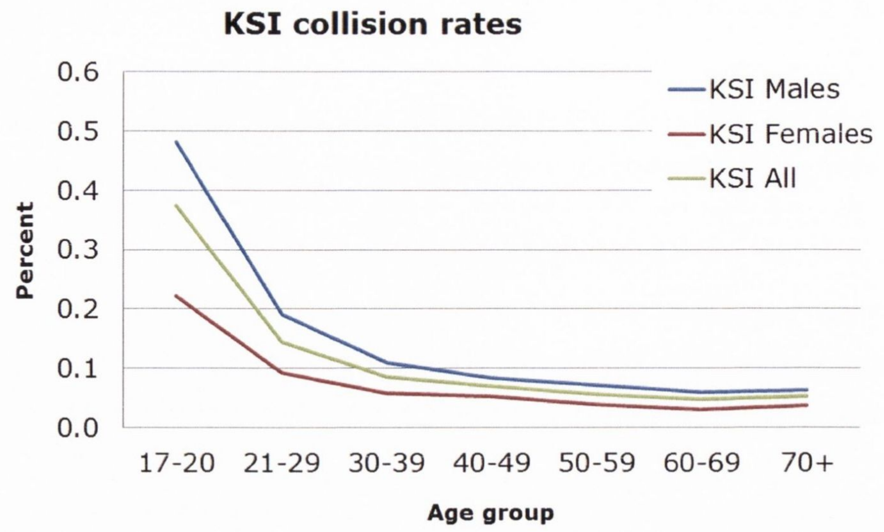


Figure 2-4: Collision involvement rates (killed and seriously injured (KSI)) per 100 licensed drivers in 2005.

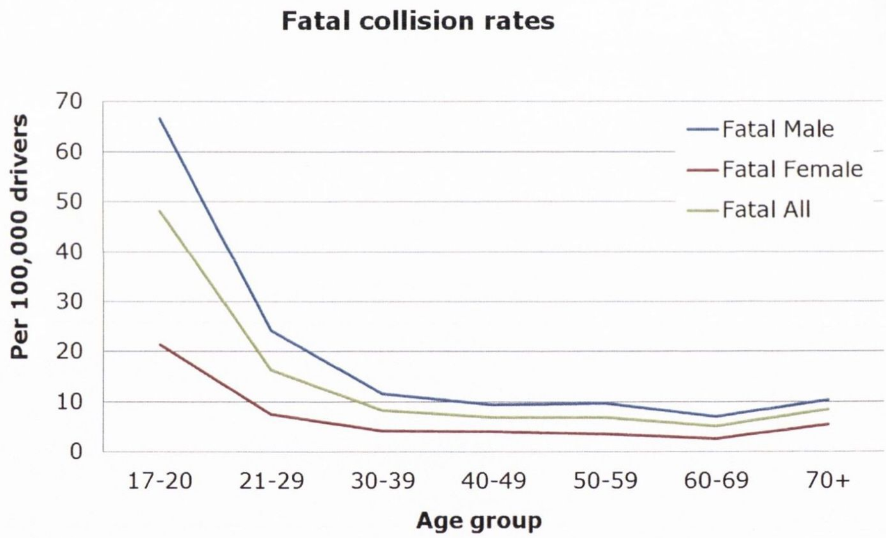


Figure 2-5: Collision involvement rates (fatal) per 100,000 licensed drivers in 2005.

Collision involvement rates per vehicle mile travelled

To derive an estimate of the approximate annual mileage for the different age groups, data for 2005 from the National Travel Survey were used (see Table 2-7). The survey lists the overall number of trips per year, percentage of trip travelled using different modes and the overall distance travelled per year (in miles). According to the National Travel Survey, the average trip length for car journeys in 2005 was 8.5 miles per trip (Department for Transport, 2005, Table 3.2, p. 14). This figure is, however, not differentiated by age or sex with the implication that age or sex specific changes in trip length cannot be accounted for in the current calculation of annual car mileage and may lead to inaccuracies of the estimates. To calculate the annual mileage driven by car, the number of trips carried out as a car driver was multiplied with the average trip length of 8.5 miles, resulting in an annual car mileage for the seven age groups for all drivers, male and female driver. Figure 2-6 shows the resulting estimated annual mileage per driver age group and sex.

Table 2-7: National Travel Survey Data 2005, including percentage of trips travelled by car, total number of trips (all modes) per year and total distance travelled per year (all modes), differentiated by age and sex.

	17-20	21-29	30-39	40-49	50-59	60-69	70+
All people							
% of trips as car driver	*24*	*43*	*56*	*62*	*58*	*49*	*38*
All modes (%)	*100*	*100*	*100*	*100*	*100*	*100*	*100*
All trips (number)	947	1,039	1,189	1,215	1,134	1,045	736
Miles travelled; all modes	6,406	7,863	9,143	9,755	8,986	7,117	4,020
Annual distance travelled by car	1950	3805	5670	6352	5594	4391	2406
Males							
% of trips as car driver	*27*	*47*	*61*	*67*	*68*	*64*	*57*
All modes (%)	*100*	*100*	*100*	*100*	*100*	*100*	*100*
All trips (number)	933	959	1,055	1,148	1,159	1,135	872
Miles travelled; all modes	6,633	8,403	10,530	11,420	10,480	8,311	4,916
Annual distance travelled by car	2160	3842	5449	6562	6661	6127	4200
Females							
% of trips as car driver	*21*	*40*	*53*	*57*	*48*	*34*	*21*
All modes (%)	*100*	*100*	*100*	*100*	*100*	*100*	*100*
All trips (number)	961	1,117	1,320	1,279	1,109	960	639
Distance travelled (miles); all modes	6,168	7,327	7,794	8,123	7,530	5,993	3,383
Annual distance travelled by car	1728	3768	5890	6143	4554	2755	1126

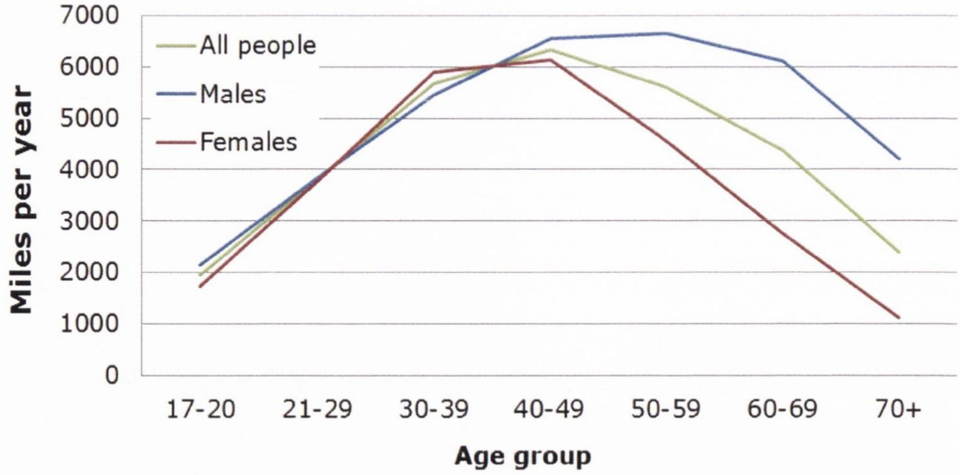


Figure 2-6: Estimated annual mileage across driver age group and sex in 2005.

For the comparison of collision involvement rates on the basis of miles driven, the estimated average annual mileage driven by car for the different age groups was multiplied with the number of licensed drivers in this age group to obtain an exposure measure for the age groups. Subsequently, the number of collision involved drivers for the seven age groups was divided by the exposure measure and multiplied with 1,000,000 (100,000,000 for fatal accidents) to obtain accident involvement rates per 1,000,000 miles travelled.

The results are shown in Figure 2-7 to Figure 2-10. The graphs indicate a U-shaped relationship for age and collision involvement rates with a prevalence of considerably higher collision rates in the youngest age group (17-20 year olds). Middle-aged drivers (40-69 year olds) had the lowest rates, and for the oldest drivers (70+ year olds) an increase of collision rates was visible.

Compared to collision involvement rates per licensed driver, where male drivers of all ages displayed higher rates than female drivers, male drivers had higher collision rates than females in all but the oldest two age groups where collision involvement rates were higher for females for all severities collisions. A similar picture emerged for slight injury crashes and KSI crashes showing very small differences between males and females between 40 and 69 years and females being more collision involved than males when aged 70 years or older. For fatal collisions male drivers' rates were higher, apart for those aged 70 years and older, where females again had higher rates. Sex differences were more pronounced for KSI collisions compared to slight injury collisions.

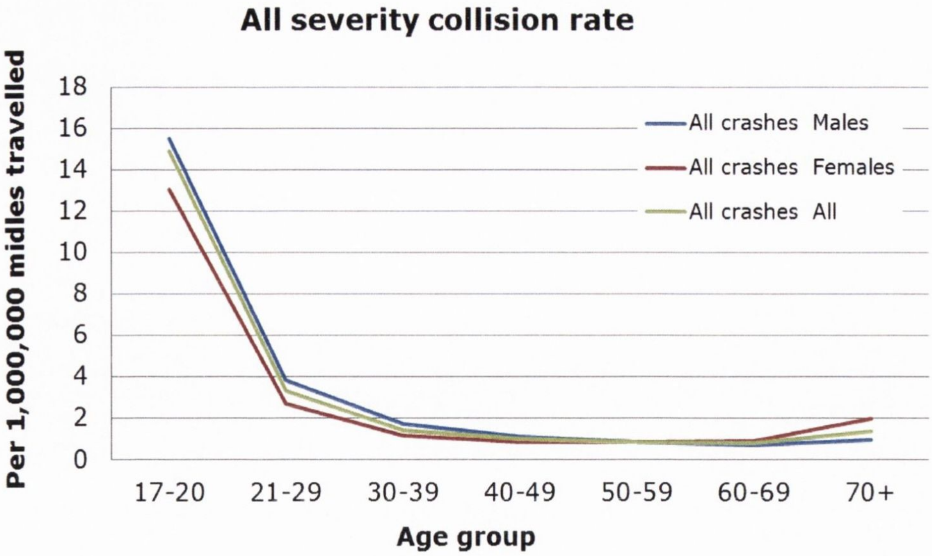


Figure 2-7: Collision involvement rates (all severities) per 1,000,000 miles travelled in 2005.

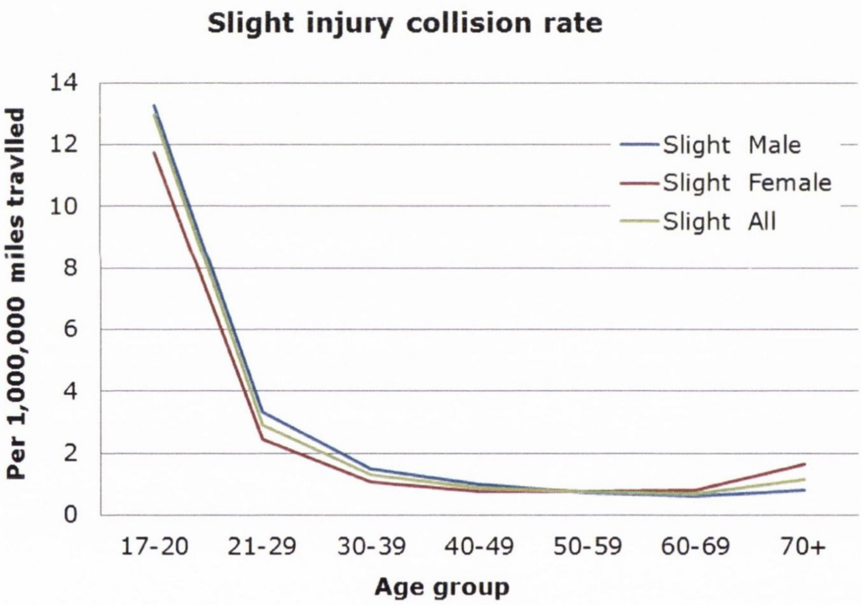


Figure 2-8: Collision involvement rates (slight injuries) per 1,000,000 miles travelled in 2005.

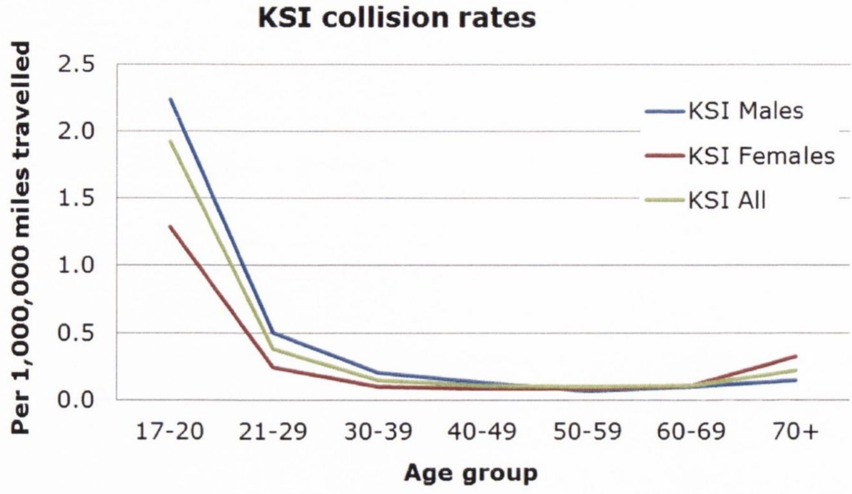


Figure 2-9: Collision involvement rates (KSI) per 1,000,000 miles travelled in 2005.

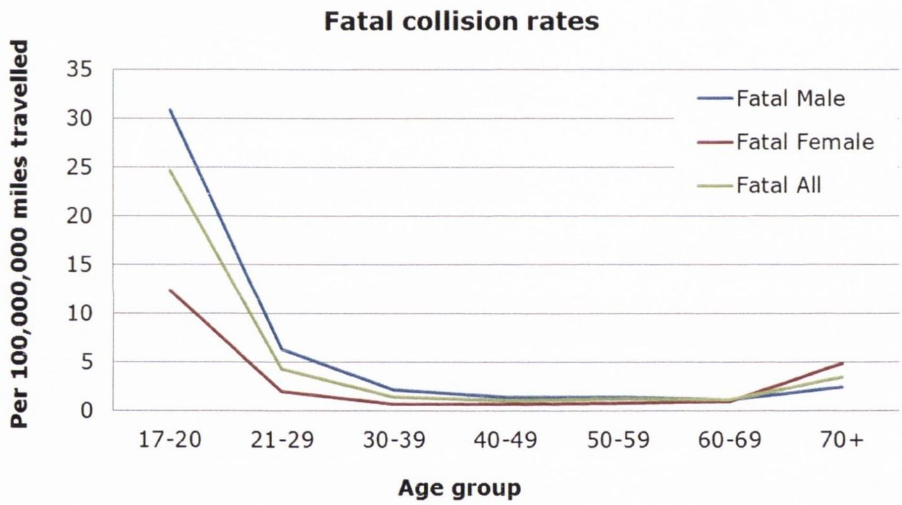


Figure 2-10: Collision involvement rates (fatal) per 100,000,000 miles travelled in 2005.

2.3.3 Description of collisions in the STATS 19 sample

On average, there were 2.2 (*SD*=0.9) vehicles and 1.5 (*SD*=1.0) casualties involved in each collision, with a maximum of 22 vehicles and 41 casualties in a single collision. The comparison of collisions in 2005 and 2006 indicated that the pattern of circumstances varied very little between the two years, with most of the time, the percentage allocation across the different categories in each year only differing by less than one percentage point (see Table 2-8 for an example of three variables describing collision circumstances).

Table 2-8: Percentage distribution of collision circumstances in 2005 and 2006.

	2005	2006
Road class	% distribution	% distribution
Motorway	5.41	5.44
A(M)	0.25	0.30
A	46.35	46.19
B	12.73	12.64
C	7.85	8.26
Unclassified	27.41	27.17
Total (n)	*241,775*	*230,676*
Light conditions		
Daylight: street lights present	50.12	50.36
Daylight: no street lighting	19.96	20.48
Daylight: street light unknown	2.99	2.17
Darkness: street lights present and lit	19.40	19.65
Darkness: street lights present but unlit	0.53	0.39
Darkness: no street lighting	6.34	6.31
Darkness: street lighting unknown	0.67	0.62
Total (n)	*241,775*	*230,676*
Road surface condition		
Dry	65.44	65.60
Wet/damp	32.18	32.94
Snow	0.57	0.25
Frost/ice	1.72	1.06
Flood (surface water over 3 cm deep)	0.10	0.15
Total (n)	*241,571**	*230,476**

* excluding missing cases

Because the differences between the two years were so small, only data for 2006 are presented in the following analyses.

The subsequent figures, Figure 2-11 to Figure 2-19, illustrate the characteristics of the recorded injury collisions differentiated by driver age. Four driver age groups were used, based on the age categorisation used by the National Travel Survey for collision involvement rates and the fact that collision involvement rates in the middle-aged groups were low (and thus collapsed into one): (a) young (17-30 years), (b) middle-aged (31-60 years), younger old (61-70 years) and older old (71 years and older);

findings were differentiated by sex for those variables where sex differences were apparent (month of collisions and time of collision) and combined for all other variables.

Collision numbers were higher in the autumn and winter months, whereby older drivers showed unexplained, markedly higher collision proportions in December compared to January. As volumes of traffic are higher during day-time hours and especially when people travel to or from work, the number of collisions at these times of day is consequently higher. "Hour of day" was also the variable where age differences and sex differences were most apparent. In comparison to younger driver groups, older drivers were over-represented in collisions between 10am and 3pm; that is at a time, where other driver groups are most likely to be at work. With regards to sex, collision involvement was particularly high for young and middle-aged females between 8-9am, most likely reflecting greater travel due in relation to childcare at this time of day.

Analysis of the weather conditions prevalent in 2006 injury collisions revealed that the majority of collisions occurred on dry roads. Confirming the findings from previous research on older driver collisions, older drivers, particularly the older old, were more frequently involved in collisions during daytime and in dry conditions than younger driver groups, which could point towards self-regulatory behaviour and the greater flexibility with regards to preferred travelling times. Older drivers also appeared to be more involved in collisions at T-junctions or staggered junctions and at cross-roads whereby the proportions for the older old were higher than those for the younger old.

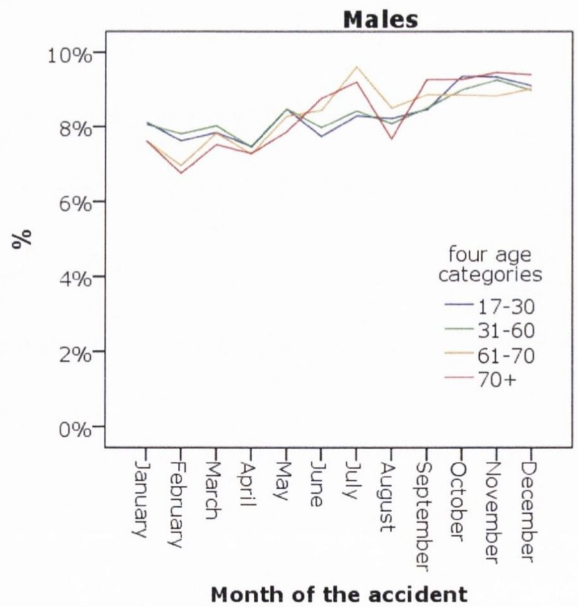


Figure 2-11: Distribution of collisions over the year (males).

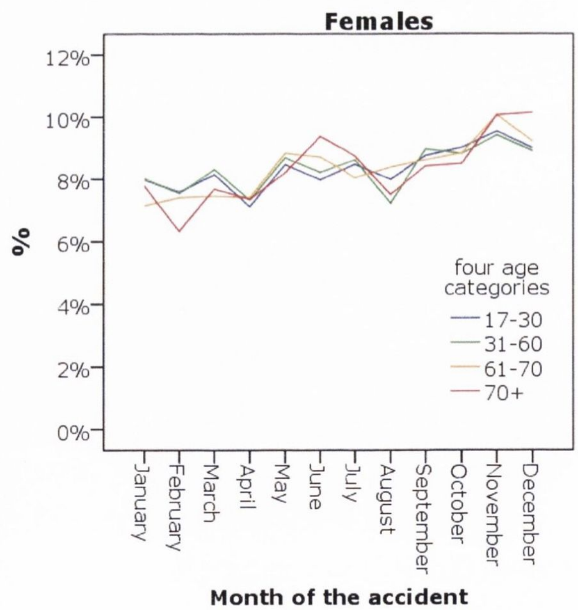
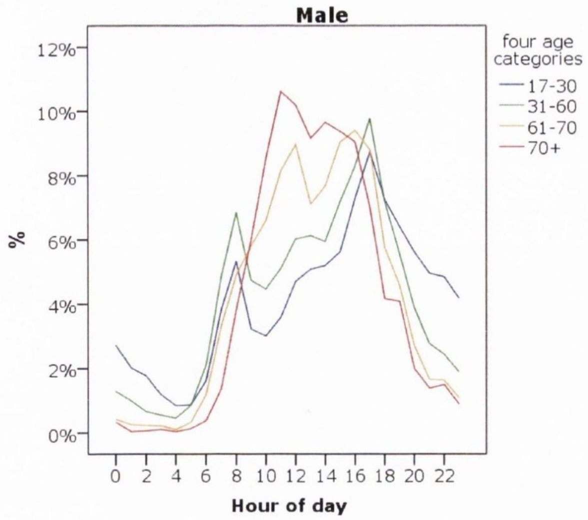


Figure 2-12: Distribution of collisions over the year (females).



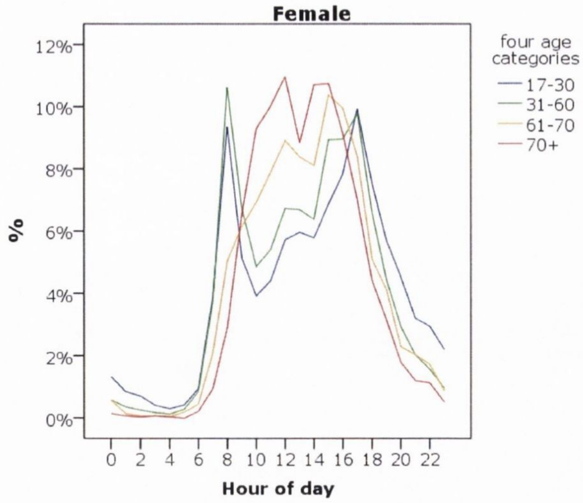


Figure 2-13: Hour of day when collisions happened (males).

Figure 2-14: Hour of day when collisions happened (females).

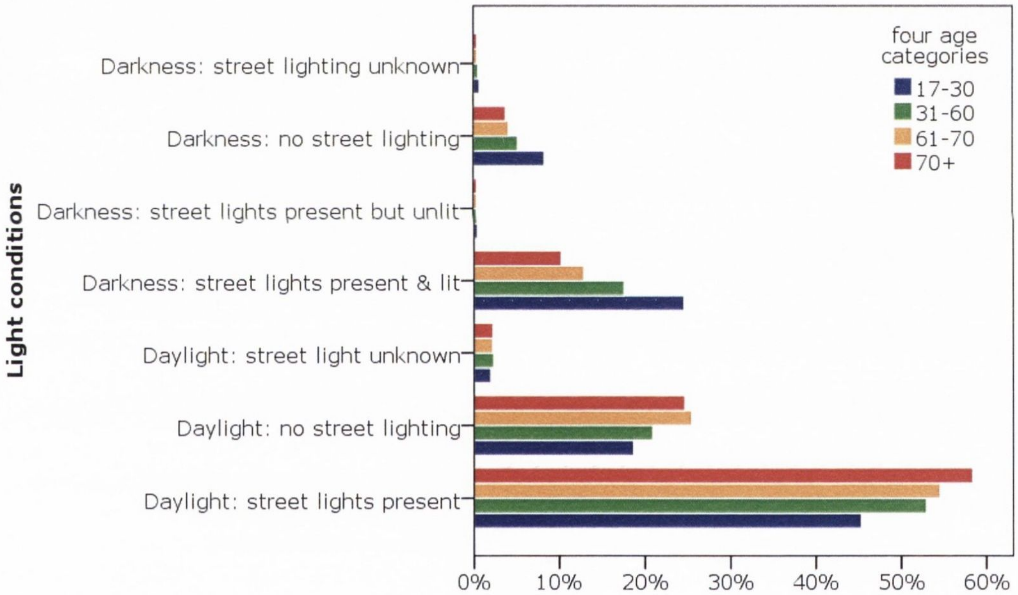


Figure 2-15: Light conditions (combined).

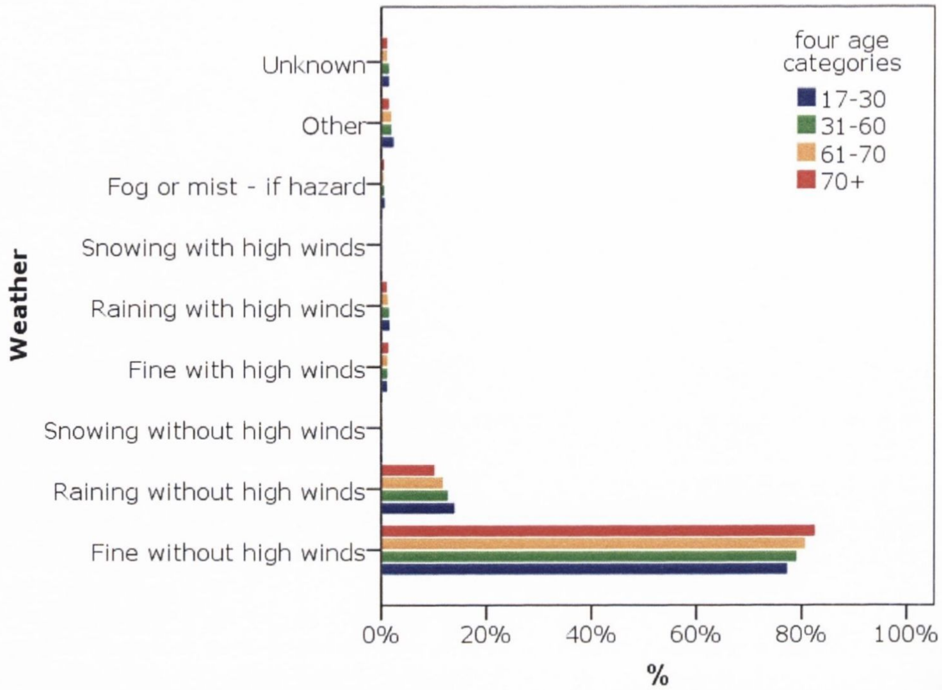


Figure 2-16: Weather (combined).

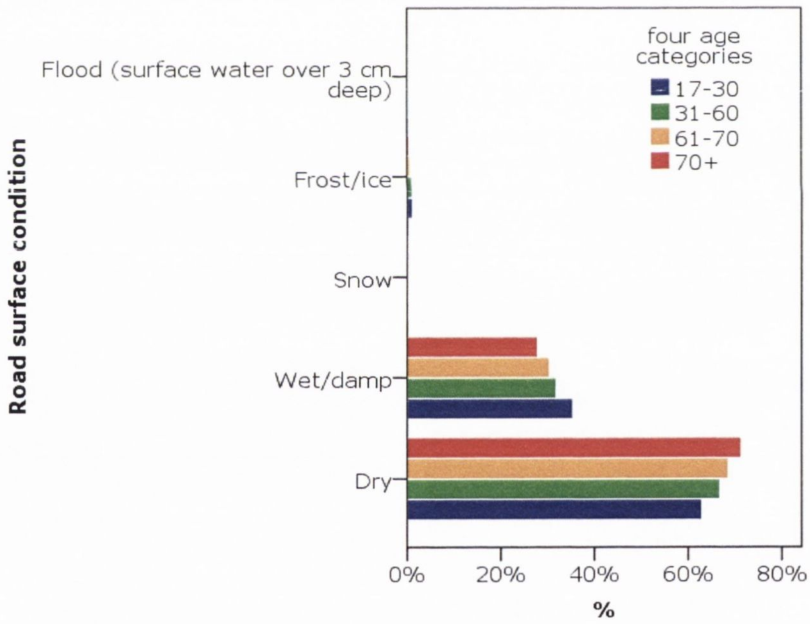


Figure 2-17: Road surface condition (combined).

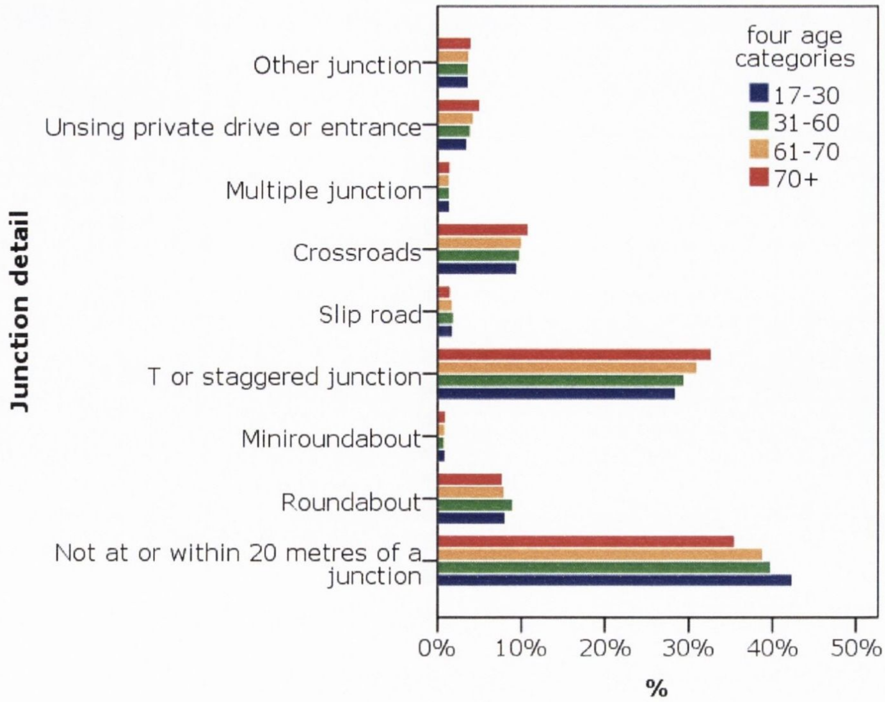


Figure 2-18: Junction detail (combined).

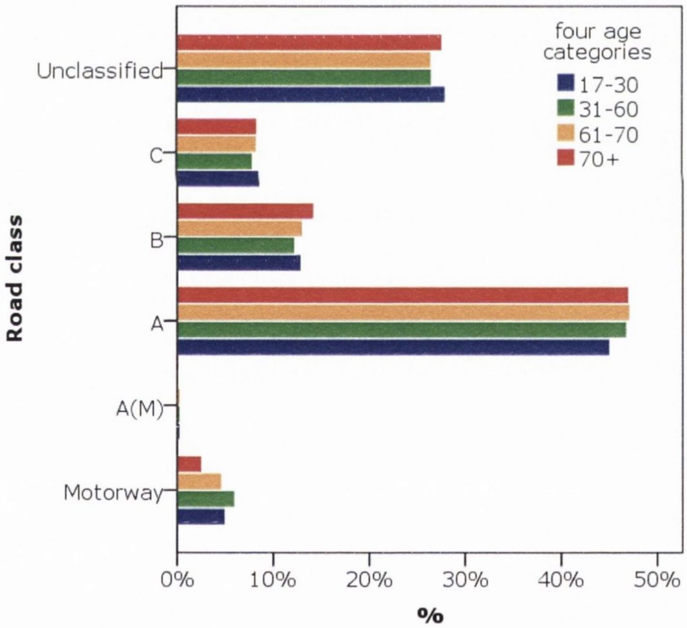


Figure 2-19: Road class where the collision happened (combined).

2.3.4 Characteristics of collision-involved drivers

111,656 car drivers were injured in the 230,676 injury collisions recorded in 2006. Table 2-9 provides a summary of findings on the driver characteristics involved in all injury collisions in 2006. As the column 'missing/not traced' indicates, for some of the drivers age but not sex had been recorded by the attending police officer.

Table 2-9: Frequencies and percentages on injured and uninjured car drivers as recorded in STATS 19 in 2006.

	Injured drivers						Non-injured drivers			
Totals	N= 111656						N= 119020			
Sex	♂		♀		Missing		♂		♀	Missing/ not traced
Frequencies	61636		50016		4		82392		35741	887
Valid Percent	55.2		44.8		0.0		69.2		30.0	0.7
Age means	37.5		37.3		39.0		39.4		38.6	34.1
Age std.	16.5		14.9		20.4		16.2		14.6	11.0
Age groups	♂		♀		Missing		♂		♀	Missing/ not traced
17-30 years (freq & %)	25968 (56.8)		19786 (43.2)		2					
31-60 years (freq & %)	29076 (52.5)		26305 (47.5)		2					
61-70 years (freq & %)	3519 (60.5)		2301 (39.5)		0					
71+ years (freq & %)	3073 (65.4)		1624 (34.6)		0					
Casualty class	Male		Female		Missing					
Slight (freq & %)	55485 (90.0)		47102 (94.2)		4					
Serious (freq & %)	5336 (8.7)		2688 (5.4)							
Fatal (freq & %)	815 (1.3)		226 (0.5)							
Casualty class by age	17-30		31-60		61-70		71+			
	♂	♀	♂	♀	♂	♀	♂	♀		
Slight (freq & %)	23105 (55.3)	18713 (44.7)	26621 (51.6)	24934 (48.4)	3132 (60.0)	2084 (40.0)	2627 (65.7)	1371 (34.3)		
Serious (freq & %)	2475 (71.6)	981 (28.4)	2168 (62.8)	1286 (37.2)	332 (63.2)	193 (36.8)	361 (61.3)	228 (38.7)		
Fatal (freq & %)	388 (80.8)	92 (19.2)	287 (77.1)	85 (22.8)	55 (69.6)	24 (30.4)	85 (77.3)	25 (22.7)		

2.3.5 Contributory factor analysis

The analysis of contributory factors investigated potential age effects regarding the frequency of certain contributory factors as well as regarding the patterns of contributory factors in car drivers involved in injury collisions for 2006 data.

Number of contributory factors associated with car drivers

According to Broughton, Keigan, Knowles & Smith (2010a) the number of factors recorded against a driver is important because it provides an indication of the attributed responsibility for the collision. Those drivers with a higher number of Contributory Factors recorded against them are more likely to be held to be responsible for the collision than those without. As illustrated in Figure 2-20, a high proportion of drivers do not have any contributory factors recorded against them (56.1% in the 2006 sample), whereby the middle-aged and younger old drivers have the highest proportion of not being assigned a contributory factor.

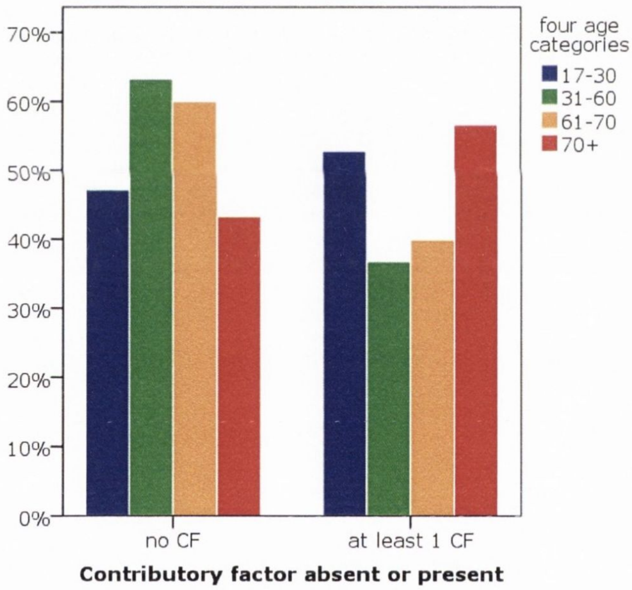


Figure 2-20: Proportion of drivers who have/ do not have contributory factors recorded against them, differentiated by age.

Percentage distributions shown in Figure 2-21 indicate that the proportion of older drivers who only have one or two contributory factors recorded against them is higher than the proportion of young, middle-aged and younger old drivers.

Plotting the mean number of contributory factors against age and sex as shown in Figure 2-22, indicated a U-shaped distribution for male drivers with the lowest number of contributory factors being recorded for the 61-70 year olds. For female drivers, the distribution was less consistent with the number of contributory factors falling from the youngest age group to the 41-50 year olds, and subsequently rising and falling between the 51 to the 81+ year olds. The comparison of contributory factors recorded against male and female drivers indicated that significantly more contributory factors were recorded against male drivers with the exception of 61-70 year old, where female drivers on average had slightly more contributory factors recorded against them.

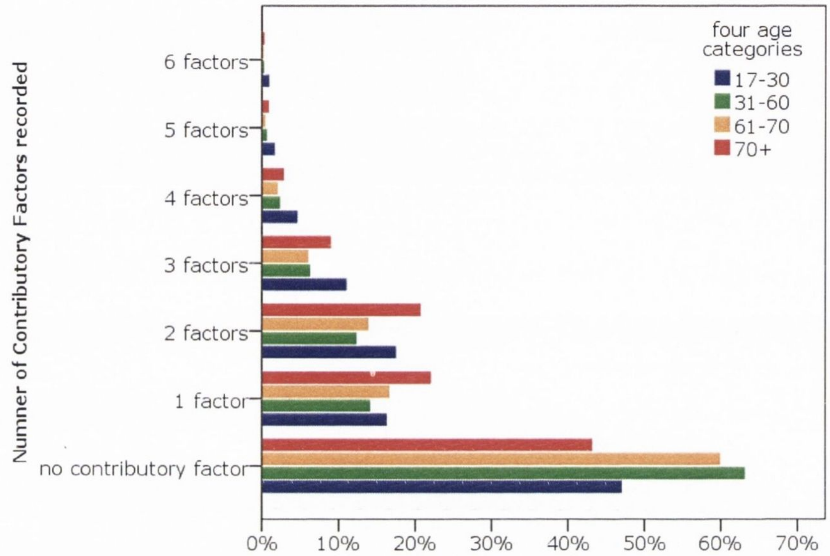


Figure 2-21: Percentage distribution of number of contributory factors >0 associated with three driver age groups.

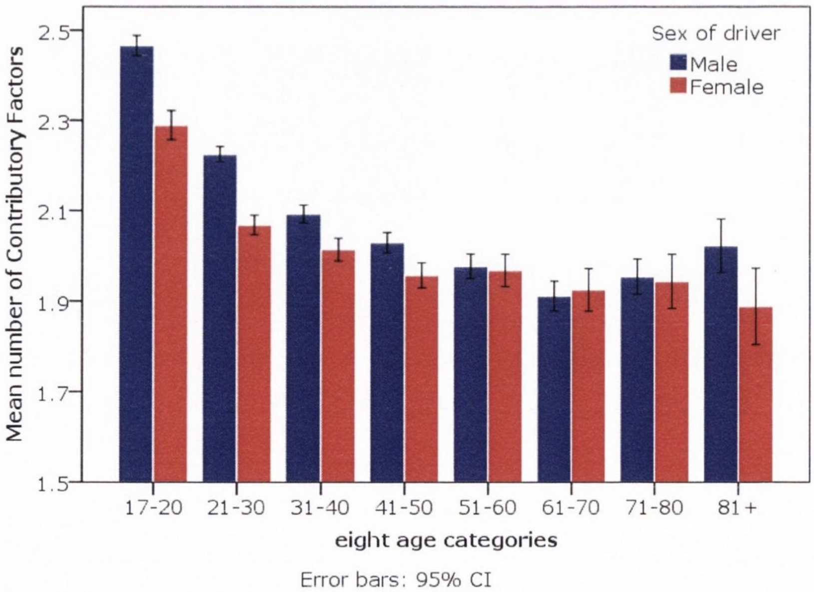


Figure 2-22: Average number of contributory factors (>0) associated with drivers, separated by driver age.

Risk perception as a function of age

The calculation of a ratio for drivers who have contributory factors recorded against them and those who do not (differentiated by age) results in the collision contribution curve shown in Figure 2-23. The figure suggests that with regard to the contribution of drivers to the crash they were involved in, very young and older old drivers are recorded to contribute to the collision more often than not. The ratios for drivers aged between 31 and 70 indicate that these drivers are less often assigned contributory factors.

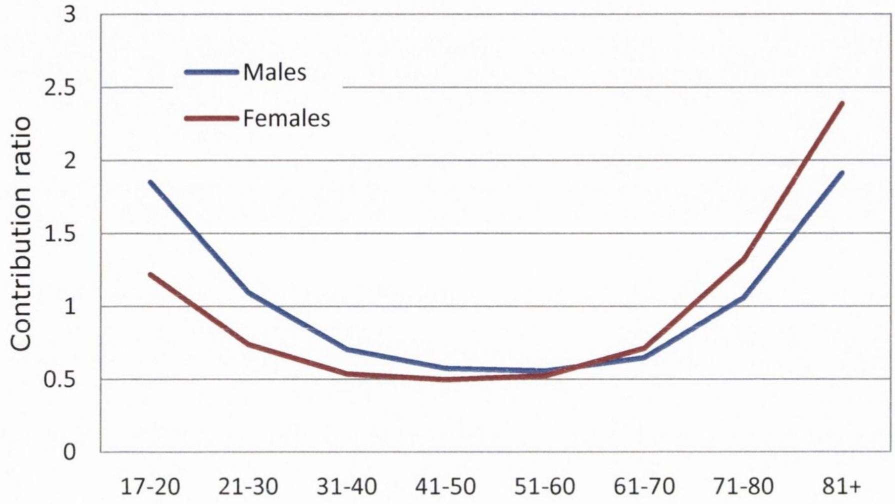


Figure 2-23: Collision contribution ratio for eight driver age groups.

Comparison of "very likely" and "possible" contributory factor patterns

As explained previously, police officers can indicate their certainty of the contribution of any factor in the collision by recording it as "possible" or "very likely". The following analyses therefore only included the data for drivers who had contributory factors recorded against them (43.9% (*n*=101,305) of the 2006 data). As a first step the frequencies of "possible" versus "very likely" factors were compared to identify systematic variations. Because contributory factors are not ranked according to their importance, the data for the six contributory factors were compiled and frequency distributions of "possible" and "very likely" factors were compared. Instances where a contributory factor had been recorded but the certainty judgement had been omitted or vice versa were treated as missing values and were excluded from analysis (n=6827 cases). The results are shown in Table 2-10. Comparisons of the frequencies revealed that in absolute terms, contributory factors were recorded as "very likely" more than twice as often than as "possible".

A criterion of |1%| was selected *(ad libitum)* to mark meaningful differences between the percentage distributions of "possible" and "very likely" contributory categories means that unless . Comparing percentage distributions of "very likely" and "possible" factors across 62 factors means that for the majority of factors, relative frequencies will be small (on average approx. 1.69%), even if some factors will be rated to occur more frequent than others. A 1% difference between the distributions of "very likely" and "possible" factors was considered small enough to capture meaningful differences between factors in the data. The differences between the distributions are displayed in the last column of Table 2-10 as the result of the subtraction of the percentage of "possible" and "very likely" factor percentage distributions. Negative values appear where the percentage of "possible" judgements on a contributory factor exceeded the percentage of "very likely" judgements.

The results indicate that the distribution of "very likely" or "possible" judgements were broadly similar. Differences exceeding the 1% criterion were only found for nine of the 62 factors. Factors referring to weather conditions such as "slippery road", to excessive speed such as "exceeding speed limit", "travelling too fast for conditions" and to factors referring to judgement errors such as "Failed to judge other person's path or speed" had greater proportions of possible judgements resulting in negative differences between very likely and possible percentage scores. Factors that imply a driver misjudgement such as "failed to look properly", "Disobeyed 'give way' or 'stop' sign or marking" and "poor turn or manoeuvre" and factors that are indicative of risky driving behaviour such as "loss of control" and "impaired by alcohol" were more frequently associated with "very likely" judgements.

Table 2-10: Frequencies & percentage distributions of "very likely" and "possible" judgements. Percentage differences exceeding |1%| between possible and very likely factors are marked in grey.

	Contributory Factor	Very likely	Possible	VL_%	P_%	VL%-P%
1	Poor or defective road surface	333	267	0.2	0.4	-0.2
2	Deposit on road	1019	504	0.7	0.8	-0.1
3	Slippery road (due to weather)	7250	3943	4.9	6.0	-1.1
4	Inadequate or masked signs or road markings	328	227	0.2	0.3	-0.1
5	Defective traffic signs	142	75	0.1	0.1	0.0
6	Traffic calming	74	65	0.0	0.1	0.0
7	Temporary road lay-out	145	157	0.1	0.2	-0.1
8	Road lay-out (e.g. bend, hill or narrow carriageway	1582	1302	1.1	2.0	-0.9

	Table continued	Very likely	Possible	VL_%	P_%	VL%-P%
9	Animal or object in carriageway	1000	383	0.7	0.6	0.1
10	Tyres illegal, defective or underinflated	439	376	0.3	0.6	-0.3
11	Defective lights or indicators	28	42	0.0	0.1	0.0
12	Defective brakes	133	367	0.1	0.6	-0.5
13	Defective steering or suspension	63	181	0.0	0.3	-0.2
14	Defective or missing mirrors	4	4	0.0	0.0	0.0
15	Overloaded or poorly loaded vehicle or trailer	42	46	0.0	0.1	0.0
16	Disobeyed automatic traffic signal	1381	546	0.9	0.8	0.1
17	Disobeyed "give way" or "stop" sign or marking	3592	720	2.4	1.1	1.3
18	Disobeyed double white lines	199	27	0.1	0.0	0.1
19	Disobeyed pedestrian crossing facility	315	100	0.2	0.2	0.1
20	Illegal turn or direction of traffic	649	83	0.4	0.1	0.3
21	Exceeding speed limit	2923	2139	2.0	3.2	-1.3
22	Travelling too fast for conditions	7329	4066	4.9	6.2	-1.2
23	Following too close	4690	2536	3.1	3.8	-0.7
24	Vehicle travelling along pavement	106	30	0.1	0.0	0.0
25	Cyclist entering road from pavement	55	19	0.0	0.0	0.0
26	Junction overshoot	1720	787	1.2	1.2	0.0
27	Junction restart (moving off at junction)	1656	546	1.1	0.8	0.3
28	Poor turn or manoeuvre	11118	3385	7.4	5.1	2.3
29	Failed to signal or misleading signal	737	648	0.5	1.0	-0.5

	Table cont.	Very likely	Possible	VL_%	P_%	VL%-P%
30	Failed to look properly	29383	9111	19.7	13.8	5.9
31	Failed to judge other person's path or speed	13581	6943	9.1	10.5	-1.4
32	Passing too close to cyclist, horse rider or pedestrian	699	326	0.5	0.5	0.0
33	Sudden braking	3959	2000	2.7	3.0	-0.4
34	Swerved	2836	1047	1.9	1.6	0.3
35	Loss of control	12942	3069	8.7	4.6	4.0
36	Impaired by alcohol	5183	962	3.5	1.5	2.0
37	Impaired by drugs (illicit or medicinal)	243	251	0.2	0.4	-0.2
38	Fatigue	797	737	0.5	1.1	-0.6
39	Uncorrected, defective eye-sight	78	120	0.1	0.2	-0.1
40	Illness or disability, mental or physical	1009	560	0.7	0.8	-0.2
41	Not displaying lights at night or in poor visibility	53	38	0.0	0.1	0.0
42	Cyclist wearing dark clothing at night	24	15	0.0	0.0	0.0
43	Driver using mobile phone	135	174	0.1	0.3	-0.2
44	Distraction in vehicle	1312	1194	0.9	1.8	-0.9
45	Distraction outside vehicle	845	778	0.6	1.2	-0.6
46	Aggressive driving	2505	1039	1.7	1.6	0.1
47	Careless, reckless, or in a hurry	12662	5271	8.5	8.0	0.5
48	Nervous, uncertain or panic	813	954	0.5	1.4	-0.9
49	Driving too slow for conditions, or slow vehicle	27	33	0.0	0.0	0.0
50	Learner or inexperienced driver/rider	3429	1931	2.3	2.9	-0.6
51	Inexperience of driving left	284	200	0.2	0.3	-0.1
52	Unfamiliar with vehicle model	352	423	0.2	0.6	-0.4
53	Stationary or parked vehicle	2310	1192	1.5	1.8	-0.3
54	Vegetation	237	174	0.2	0.3	-0.1

	Table cont.	Very likely	Possible	VL_%	P_%	VL%-P%
55	Road layout (e.g. bend, winding road, hill crest)	900	849	0.6	1.3	-0.7
56	Buildings, road signs, street furniture	138	116	0.1	0.2	-0.1
57	Dazzling headlights	159	247	0.1	0.4	-0.3
58	Dazzling sun	1586	1039	1.1	1.6	-0.5
59	Rain, sleet, snow or fog	1189	1073	0.8	1.6	-0.8
60	Spray from other vehicles	95	163	0.1	0.2	-0.2
61	Visor or windscreen dirty or scratched	94	38	0.1	0.1	0.0
62	Vehicle blind spot	378	456	0.3	0.7	-0.4
	Total	**149,289**	**66,094**	**100**	**100**	**0**

Age differences in the mean number of "possible" and "very likely" contributory factors were explored and are illustrated in Figure 2-24 and Figure 2-25 below. The findings again show the higher average number of "very likely" compared to "possible" factors. There is a clear tendency for police officers to record more "possible" and "very likely" contributory factors with young drivers than with middle aged and old drivers. Confidence intervals for the mean number of "possible" and "very likely" contributory factors were calculated to assess the heterogeneity of data for the different age groups. The data indicated very little variability of the data for the younger age groups. Whilst the average number of possible or very likely contributory factors was comparatively low for older driver groups (61 years and more), the variability increased considerably as indicated by the larger confidence intervals. The average number of recorded factors only increased slightly for the oldest drivers (71 years +), but was still lower than for middle aged or young drivers.

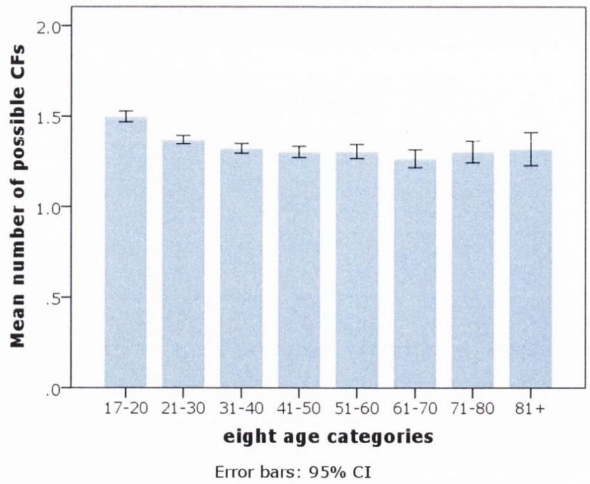


Figure 2-24: Average number of "possible" contributory factors associated with drivers, separated by age.

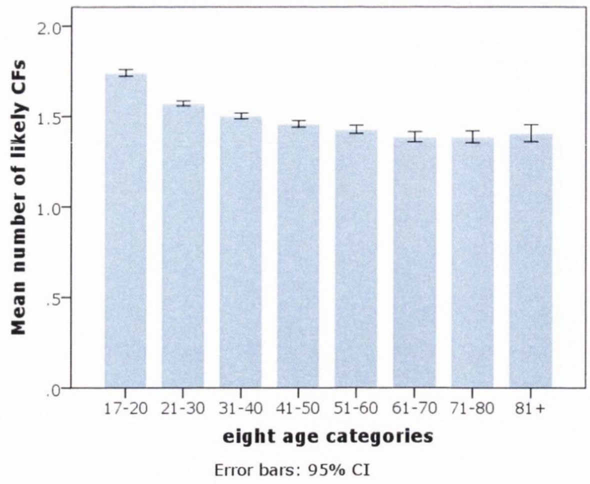


Figure 2-25: Average number of "very likely" contributory factors associated with drivers, separated by age.

Analysis of age differences on "very likely" contributory factors

To identify patterns of collision circumstances typical for older drivers, it was decided to only retain contributory factors that had been recorded as "very likely" by the police officer at the scene. "Possible" contributory factors were therefore excluded from further analysis to leave only "very likely" contributory factors in the data file of drivers who had contributory factors recorded against them. Five age groups were used in the analysis, similar to the ones used in the calculation of collision involvement rates in Section 2.3.2. Separate analyses were conducted for male and female to enable the comparison of differences in collision circumstances by sex. As before, percentage distributions across the 62 individual contributory factors, differentiated by age, were calculated.

Table 2-11 displays the top twenty contributory factors for the oldest driver group, the 71+ year old males and Table 2-12 the top twenty very likely contributory factors for 71+ year old females. These twenty factors accounted for between 73.6-89.3% of all "very likely" factors reported for men of all age groups and 74.9-90% for women of all age groups respectively. Comparison by age suggests that in younger driver collisions a greater range of contributory factors is assigned. The full list of the frequency distribution of the 62 individual contributory factors can be found in Appendix A, Table A-2 for female drivers and Table A-3 for male drivers.

For each of these top twenty contributory factors for the oldest age group, the ranking of the factor for each of the four other age groups was checked to identify how relatively important the factor was in the collision causation in each of the other driver age groups.

Risk perception as a function of age

For each of the twenty factors, relative ranks in each of the other four age groups are shown in brackets in Table 2-11 and Table 2-12.

The emerging pattern suggests that that there are some contributory factors that play a frequent role in older driver collisions but are also frequent in the collisions of other age groups, and that there are a number of contributory factors that seem to be specific to older drivers.

The most prominent factors that are common to all driver age groups and are also identical for male and female drivers include:

1. Failing to look properly;
2. Failing to judge another person's path of speed;
3. Poor turns or manoeuvres;
4. Disobeyed 'give way' or 'stop' sign;
5. Loss of control;
6. Careless, reckless or in a hurry.

For the first four of these factors, there are noticeable increases in the frequencies with age, indicating that these factors play an increasingly important role for older drivers. "Loss of control" and "careless, reckless or in a hurry", "slippery road (due to weather)", "swerving" and "sudden braking" decrease in frequency with age for both sexes.

Contributory factors that increase and appear to be specific to older drivers of both sexes, but do not rank as highly in the other age groups include "illness or disability, mental or physical", "uncorrected, defective eyesight", "junction overshoot", "dazzling sun", "nervous, uncertain or panic" and "passing too close to cyclist, horse rider or pedestrian". The findings indicate that compared to young and middle-aged drivers, older drivers appear to be more frequently associated with contributory factors that indicate a failure of a perceptually-based judgement. Sex differences in the oldest age group, indicated higher proportions for "poor turn or manoeuvre" and "loss of control" and "nervous, uncertain or panic" for female older drivers and higher proportions of "failure to judge another person's path or speed" and "careless, reckless or in a hurry" for older male drivers.

Whilst Table 2-11 and Table 2-12 used the oldest driver group (71+ year olds) to structure the ranking of contributory factors, youth specific factors were also identified and are included in the table under "Y". Contributory factors that were frequently recorded against young drivers and which tended to play a very small role in older drivers' collisions included "Learner or inexperienced driver/rider" and "impaired by alcohol" for "exceeding speed limit" and "aggressive driving" for both sexes.

Table 2-11: The percentage distributions of the twenty most frequent contributory factors for 71+ male drivers, differentiated by sex and age. The numbers in brackets indicate the rank of the Contributory Factor for the age category shown in the column.

	Male drivers					
		17-30	**31-50**	**51-60**	**61-70**	**71+**
1	Failed to look properly	12.4 (1)	19.0 (1)	22.0 (1)	23.6 (1)	24.3
2	Failed to judge other person's path or speed	6.6 (5)	8.9 (3)	10.8 (2)	11.7 (2)	12.8
3	Poor turn or manoeuvre	5.8 (6)	8.4 (4)	9.7 (4)	9.9 (3)	10.5
4	Careless, reckless, or in a hurry	11.1 (2)	11.1 (2)	10.4 (3)	9.3 (4)	7.3
5	Loss of control	10.2 (3)	6.6 (5)	4.7 (5)	5.1 (5)	5.3
6	Disobeyed "give way" or "stop" sign or marking	1.8 (15)	2.6 (10)	2.9 (9)	3.3 (7)	3.9
7	Illness or disability, mental/physical	0.1	0.3	0.8	1.2	3.3
8	Following too close	2.5 (13)	3.5 (9)	3.4 (8)	2.8 (8)	2.3
9	Junction overshoot	1.1	1.2	1.3	1.2	2.2
10	Dazzling sun	0.5	0.8	1.0	1.6 (13)	2.2
11	Travelling too fast for conditions	8.1 (4)	5.9 (6)	4.3 (6)	2.5 (9)	2.0
12	Nervous, uncertain or panic	0.5	0.3	0.4	0.7	1.8
13	Junction restart (moving off at junction)	0.6	1.0	1.5 (14)	1.7 (11)	1.8
14	Slippery road (due to weather)	5.1 (7)	3.9 (7)	3.8 (7)	3.5 (6)	1.7
15	Stationary or parked vehicle	1.0	1.6 (15)	2.1 (11)	1.9 (10)	1.6
16	Swerved	2.3 (14)	2.0 (14)	1.6 (13)	1.6 (14)	1.4
17	Road lay-out (e.g. bend, hill or narrow carriageway	1.2	1.1	1.1	1.3	1.2

	Table cont.	17-30	31-50	51-60	61-70	71+
18	Sudden braking	2.8 (12)	2.4 (11)	1.9 (12)	1.6 (12)	1.2
19	Uncorrected, defective eye-sight	0.0	0.0	0.1	0.1	1.2
20	Passing too close to cyclist, horse rider or pedestrian	0.3	0.5	0.6	0.9	1.1
	Sum of frequencies top 20 CFs	73.6	80.9	84.3	85.6	89.3
Y	Exceeding the speed limit	4.8 (8)	2.2 (12)	0.9	0.6	0.2
Y	Learner or inexperienced driver of rider	4.7 (9)	0.4	0.2	0.1	0.1
Y	Impaired by alcohol	4.0 (10)	3.7 (8)	2.2 (10)	1.0	0.4
Y	Aggressive driving	3.5 (11)	2.0 (13)	1.3 (15)	0.6	0.2

Table 2-12: The percentage distributions of the twenty most frequent contributory factors for 71+ female drivers, differentiated by sex and age. The arrows mark the direction of change in proportion with increasing age.

	Female drivers					
		17-30	31-50	51-60	61-70	71+
1	Failed to look properly	14.2 (1)	20.0 (1)	22.5 (1)	24.0 (1)	25.0
2	Poor turn or manoeuvre	7.8 (3)	11.0 (2)	11.6 (2)	12.4 (2)	13.5
3	Failed to judge other person's path or speed	6.6 (7)	7.8 (4)	8.6 (3)	8.4 (3)	9.3
4	Loss of control	7.9 (2)	5.7 (5)	5.0 (5)	4.8 (5)	5.6
5	Disobeyed "give way" or "stop" sign or marking	2.7 (12)	3.4 (10)	3.5 (8)	4.3 (6)	5.6
6	Careless, reckless, or in a hurry	7.5 (4)	7.9 (3)	7.3 (4)	6.0 (4)	5.1
7	Junction overshoot	1.3	1.1	1.4 (14)	1.3	2.5
8	Illness or disability, mental or physical	0.1	0.4	0.8	1.1	2.5

	Table cont.	17-30	31-50	51-60	61-70	71+
9	Nervous, uncertain or panic	0.8	0.6	1.0	1.3	2.4
10	Slippery road (due to weather)	6.9 (6)	4.9 (7)	4.8 (6)	4.2 (7)	2.4
11	Travelling too fast for conditions	7.5	5.6	4.1 (7)	3.0 (8)	2.3
12	Following too close	3.0 (11)	3.5 (9)	3.4 (9)	3.0 (9)	2.3
13	Dazzling sun	0.6	0.9	1.2	1.8 (13)	2.2
14	Junction restart (moving off at junction)	0.8 (6)	1.3 (15)	2.0	2.4 (10)	2.0
15	Stationary or parked vehicle	1.0	1.7 (13)	2.2 (11)	2.3 (11)	1.7
16	Road lay-out (e.g. bend, hill or narrow carriageway	1.5	1.2	1.4 (15)	1.4 (15)	1.5
17	Passing too close to cyclist, horse rider or pedestrian	0.2	0.5	0.4	0.6	1.0
18	Uncorrected, defective eye-sight	0.0	0.0	0.2	0.3	1.0
19	Sudden braking	2.5 (13)	2.2 (11)	1.9 (12)	1.9 (12)	1.0
20	Swerved	2.0 (15)	1.6 (14)	1.5 (13)	1.5 (14)	1.0
	Sum of frequencies top 20 CFs	74.9	81.4	84.7	85.9	90.0
Y	Travelling too fast for conditions	7.5 (5)	5.6 (6)	4.1	3.0	2.3
Y	Exceeding the speed limit	4.9 (8)	1.9 (12)	0.8	0.4	0.1
Y	Learner or inexperienced driver or rider	4.0 (9)	0.5	0.2	0.2	0.1
Y	Impaired by alcohol	3.9 (10)	3.7 (8)	2.3 (10)	1.1	0.3
Y	Aggressive driving	2.1 (14)	1.2	0.8	0.8	0.3

The emerging pattern suggests that that there are some contributory factors that play a frequent role in older driver collisions but are also frequent in the collisions of other age groups, and that there are a number of contributory factors that seem to be specific to older drivers.

The most prominent factors that are common to all driver age groups and are also identical for male and female drivers include:

1. Failing to look properly;
2. Failing to judge another person's path of speed;
3. Poor turns or manoeuvres;
4. Disobeyed 'give way' or 'stop' sign;
5. Loss of control;
6. Careless, reckless or in a hurry.

For the first four of these factors there are noticeable increases in the frequencies with age, indicating that these factors play an increasingly important role for older drivers. "Loss of control" and "careless, reckless or in a hurry", "slippery road (due to weather)", "swerving" and "sudden braking" decrease in frequency with age for both sexes.

Contributory factors that increase and appear to be specific to older drivers of both sexes, but don't rank as highly in the other age groups include "illness or disability, mental or physical", "junction overshoot", "dazzling sun", "nervous, uncertain or panic" and "passing too close to cyclist, horse rider or pedestrian". The findings indicate that compared to young and middle-aged drivers, older drivers are more likely to suffer from illness or disability and appear to be more frequently associated with contributory factors that indicate manoeuvring errors that may be mediated by increasing nervousness around driving and greater difficulties with perceptual judgements.

Whilst Table 2-11 and Table 2-12 used the oldest driver group (71+ year olds) to structure the ranking of contributory factors, youth specific factors were also identified and are included in the table under "Y". Contributory factors that were frequently recorded against young drivers of both sexes and which tended to play a very small role in older drivers' collisions included "Learner or inexperienced driver/rider", "impaired by alcohol", "exceeding speed limit" and "aggressive driving".

2.4 Summary and discussion

2.4.1 Reliability of the data and differences between years

The number of erroneous codes recorded decreased slightly between 2005 and 2006; at the same time, the absolute number of contributory factors recorded by the police increased. This most likely indicates that reporting of the police officers improved. The patterns of collisions and contributory factors identified for different age groups were almost identical between the years, demonstrating reliability in reporting behaviour.

To establish how well STATS 19 data compares against more reliable databases, a comparison with OTS data, gathered by trained collision investigators was carried out. The findings suggest that police officers recorded contributory factors somewhat less frequently than trained collision investigators. The overall pattern of recorded contributory factors appeared broadly similar. Differences in the contributory factors assigned by police officers and collision investigators occurred predominantly with regards to the contribution of the road environment which was more frequently recorded to play a role by police officers and with regards to "behaviour or inexperience" (more often recorded by collision investigators) and "driver error or reaction" (more often recorded by police officers). A possible explanation for the difference is the fact that contributory factors can be used in court and police officers may thus feel a strong need to be able to substantiate any claims of driver responsibility when assessing the contribution of a factor.

2.4.2 Collision rates of different driver age groups

The calculation of collision rates based on either the number of licensed drivers or on driven mileage revealed considerable differences in the shape of the distributions across driver age groups. Based on the number of licensed drivers, collision involvement rates for all severity collision declined steeply from the 17-21 age group to the 21-29 age group and further declined down to the oldest age groups (70+). For fatality rates a slight increase was observed for the oldest age group (70+), however, only to the level of middle-aged drivers. Collision rates based on person miles travelled, however, followed a more U-shaped distribution with very steep declines from the youngest age groups and visible increases for the oldest driver group (approximately to the level of 21-29 year olds). Whilst male drivers had higher collision involvement rates based on the number of licensed drivers, older female drivers had higher accident involvement rates based on miles travelled with the exception of the two or three youngest age groups. Similar findings are reported e.g. by McGwin and Brown (1999) who speculate that the higher collision rates for females may be associated with a greater proportion of driving in higher risk environments.

The shape of accident rate distributions found is consistent with earlier analyses such as the work carried out by McGwin and Brown (1999). Compared to the authors' US sample, however, overall collision rates in the British population were considerably lower (maximum of 3.35% of licensed drivers in the British sample compared to up to 16% in the US sample). The comparison of fatality collision rates also found lower values in the

British sample (up to 66.7 per 100,000 drivers compared to 110 per 100,000 in the American sample) with a more pronounced decline of collision rates from the youngest to the second youngest driver group. Age-related increases in collision involvement rates found for the British sample were less pronounced than those in the US study. Given the considerable differences between the years (1996 versus 2005 data), the differences between the licensing systems in the US and Britain and the difference in the age-categorisation in both studies as well as true differences between the collision involvement rates in the respective populations, such differences in accident involvement rates are to be expected.

Age-related increases in injury collision rates must also be considered in the light of increased frailty of older drivers. Older drivers suffer comparatively more from the adverse effects of road collision than younger drivers (the so-called frailty bias), which at least partly accounts for their increased collision involvement rates, particularly in KSI collisions (Li, Braver & Chen, 2003).

It can be argued that a considerable proportion of older drivers who still hold a valid driving licence chose not to make use of it or modify their driving in such a way that exposure to particularly demanding driving situations is avoided. Following this argument, collision involvement rates based on person miles travelled should be more informative when trying to quantify the challenges faced by older drivers in traffic as it is more likely to capture the older person who actively participates in traffic as a current driver. The results from the current collision of accident involvement rates suggests that increases in collision involvement rates occur with the beginning of the 7th life decade. Similar findings have been presented by Clarke, Ward, Bartle and Truman (2010). The investigation of collision involvement beyond the age of 70 should therefore be particularly fruitful; however, whilst STATS 19 allows such data exploration, the National Travel Survey does not provide age differentiations beyond that point and thus limited the current analysis.

2.4.3 Number of contributory factors associated with different age groups

Distinct age patterns were found for the number of contributory factors recorded against different driver groups. Similar to the middle-aged driver group, the younger old group was less likely to have any contributory factors recorded against them. The older old group was more similar to the young driver group and thus more likely to have at least one contributory factor recorded against them. On average and compared to young driver groups, older drivers had fewer contributory factors recorded against them. This was true for "very likely" and "possible" contributory factors. However, compared to young and middle-aged drivers, the number of contributory factors recorded against older drivers showed considerably more variability.

2.4.4 Analysis of individual contributory factor patterns

Contributory factor groups include a variety of 62 individual contributory factors, which were included in the analysis to identify age differences. Initially, the differentiation between "very likely" and "possible" contributory factors indicated that "very likely" factors are significantly more often allocated than "possible" contributory factors. This probably reflects the fact that police officers only tend to record contributory factors they think are likely to have contributed to the collision.

Subsequent analysis indicated different patterns in the frequency distributions of "possible" and "very likely" judgements for the 62 separate contributory factors. Factors that imply an influence of the road and weather environment or of excessive speed were more frequently associated with "possible" judgements. Factors that imply a loss of vehicle control by the driver, of poor driving manoeuvre quality, driving without due care or attention were more frequently associated with "very likely" judgements. This difference could be a reflection of police officers' recording behaviour. As contributory factors are disclosable in court, any factors that allocate blame to the driver are more likely to need to be substantiated by the police officer.

Subsequent analysis of age patterns on contributory factors focused on "very likely" contributory factors only and comprised the comparison of the frequency distributions for the twenty contributory factors most frequently recorded against the oldest driver group (71+ year olds).

"Very likely" contributory factors that were of particular relevance to older drivers, but which also showed comparatively high frequencies for middle aged and younger drivers included:

- Failing to look properly;
- Failing to judge another person's path or speed;
- Poor turns or manoeuvres;
- Disobeyed 'give way' or 'stop' sign;
- Loss of control;
- Careless, reckless or in a hurry.

This suggests that some of the difficulties experienced by older drivers are not qualitatively different from those other age groups encounter, but may vary quantitatively.

Contributory factors that were more frequent for older drivers, but tended to have very low prevalences in the younger driver groups, included:

- Illness or disability, mental or physical;
- Junction overshoot;
- Dazzling sun;
- Nervous, uncertain or panic;
- Passing too close to cyclist, horse rider or pedestrian.

The findings suggest that older drivers may specifically suffer more frequently than the other age groups from health-related problems and misjudgements. Again this finding compares well with the established literature on older drivers and their collision involvement (e.g. Clarke, Ward, Bartle & Truman, 2010).

Emerging patterns indicated that some contributory factors played a significant role for young drivers, but were considerably less prevalent for middle-aged or older drivers. These included:

- Learner or inexperienced driver;
- Impaired by alcohol;
- Aggressive driving;
- Exceeding the speed limit.

These findings are consistent with the international literature on collision involvement of young drivers which suggest that young novice drivers are over-represented in single-vehicle collisions at night where excessive speed, loss of control and intoxication are combined with a lack of driving experience (e.g. OECD, 2006).

3 Theories of risk and driving: A review of the literature

The previous chapter presented the findings of the analysis of police recorded British injury collision data (STATS 19) and identified age-related differences in terms of collision rates and the patterns in contributory factors that accompany the collision of different driver age groups. The analysis found increased collision rates for older drivers when rates were based on person miles travelled and higher collision rates for older females compared to older males. Contributory factors that were recorded particularly frequently against older drivers, but which also occurred in young and middle-aged driver groups, included those that pointed to failures in manoeuvring, failures in judgement as well as failures in attending properly to the traffic situation. The finding suggests that some of the errors older drivers make are not qualitatively different from those committed by younger age groups, but may be more prominent. Furthermore, a number of contributory factors were found to be almost exclusive to older drivers. These comprised factors that pointed towards failures of the visual system and general health problems and driving in a state of heightened tension or anxiety.

If collisions are interpreted as unsuccessful driving events, the exploration of their contributory factors can inform us about the circumstances which most likely accompany or cause breakdowns in driving performance. However, they do not deliver a comprehensive model of driving behaviour, of drivers' perception of risk and related decision making. Understanding drivers and their decision making has considerable potential for the development of assistance systems and technologies that can aid older drivers through difficult situations (Carsten, 2007). Equally, training interventions and adjustments of the road infrastructure may help improve drivers' perception of risk and their decision making in traffic.

The progression of this dissertation is therefore in the direction of exploring different theoretical conceptualisations of driver behaviour and how they may account for age related differences between younger, middle aged and older drivers which were reflected in the observed patterns of collision circumstances. Several psychological models of driver behaviour have been proposed, and this chapter will analyse the communalities and differences between the assertions put forward within them. This is followed by a review of experimental findings relating to the models reviewed and a review of the empirical evidence on age-related changes in the perception of risk and driver capability. An empirical study testing Fuller's Task Capability Model is described in Chapter 4.

3.1 Early research into collision involvement

According to Ranney (1994) much of the research activity prior to the 1960's and 70's focused on differentials models of collision involvement rather than on comprehensive model of driver behaviour. The attempt of this early research was to identify stable traits, biological characteristics and upper performance limits of the driver which could reliably identify those drivers with an above-average risk of being involved in collisions. The concept of 'accident proneness' was extensively investigated during 1920-1940 with the conclusion that there were significant associations between stable driver attributes such as personality, perception and cognitive skills and collision involvement, but that these were so small as to be of no practical or theoretical value (Haight, 1986). Haight (1986) suggested that whilst proneness as an internal condition may exist, drivers could successfully compensate for this condition in the way they performed the driving task. In addition to the limited success with identifying collision-prone drivers, research studies in the sixties suggested that driving was not merely determined by the upper performance limits of the driver, but that motivation modulated driver behaviour and influenced drivers' perceptual processes and decision making. Findings from two Scandinavian studies which investigated the effectiveness road signs (Johannson & Ruman, 1966; Johansson & Backlund, 1972) provided empirical support for this contention. Both required drivers to recall traffic signs along the route driven. The results indicated that drivers remembered those signs better that they regarded as important.

Furthermore, the notion of driving as a 'self-paced' task emerged through research published by Taylor (1964). In an on-road study he investigated the Skin Conductance Response rate (SCR) of drivers in different road environments as a measure of the subjective risk (tension or anxiety level) experienced by the drivers that in turn influenced the driving task in a closed-loop feedback process (Trimpop, 1996). Taylor found that the distribution of Skin Conductance Responses per unit distance travelled was similar to the distribution of collisions per unit total distance of vehicle travel (i.e. the collision rate). He interpreted the finding that the average skin conductance response rate of drivers per unit distance travelled did not significantly vary across different environments as an indication that drivers were sensitive to changes in risk and adaptively varied their performance in response to such perceived risks. Taylor suggested that *"drivers adopt a level of anxiety that they wish to experience when driving, and then drive as to maintain it..."* (p. 449). He argued that drivers produced the level of risk they wished to take by going faster or slower and implied a basic motivation of making progress.

The new understanding of drivers as purposeful creators of the driving task in a dynamically changing environment led to the emergence of motivational models of driver behaviour in contrast to the previous skill-based models. Motivational models according to Carsten (2007) focus on how drivers manage risk or task difficulty. The potential conflict between the desire to make progress and to maintain safety led to the introduction of 'risk' as a central variable and to the question of how it influenced driver behaviour. A number of models were proposed which are described and critically discussed in the following.

3.2 The Theory of Risk Homeostasis

Wilde's initial conceptualisation of his model as a risk compensation theory derived from studies (e.g. Peltzman, 1976) which suggested that drivers partly compensate safety benefits achieved through improvements in road layouts and vehicle safety features (e.g. seat-belts or dual braking systems) by adopting riskier driving styles. Changes in behaviour resulting from a road safety intervention that are contrary to the intended aim of the intervention or situations where safety gains in one road user groups are offset by safety losses in another have been described as behaviour adaptation (Lewis-Evans & Charlton, 2006) or 'pervert compensation' (Haight, 1986) and have been subject to considerable research efforts.

In its early version as risk compensation Wilde's model assumed that driving was based on a self-regulatory process in which behaviour adaptation was triggered by a perceived discrepancy between observed (subjective risk) and desired levels of risk and the aim to eliminate this discrepancy. Safety measures that did not address the desired level of risk were posited to be ineffective in the long-term, as drivers accounted for the anticipated safety benefits of the measures in their comparison of perceived and desired risk and subsequently choose riskier styles. Wilde extended the model later into the theory of risk homeostasis (Wilde, 1982; 1988; 1989) suggesting that drivers (unconsciously) aimed to maintain a subjectively optimal level of risk, the so-called target level of risk, which acted as the reference value in a closed-loop system and thus as the main determinant of driving behaviour. Borrowing elements from utility theory, which assumes that people's choices are made on the basis of utility maximisation (i.e. the best choice is the one that provides the highest utility to the decision maker), target level of risk was assumed to be the maximum mobility utility value resulting from the individual driver's calculation of benefits (subjective expected utilities) and dis-benefits of different behaviour alternatives. With long-term, short-term and momentary influences, the target level of risk was assumed to vary between and within drivers. The assumption of a target level of risk implied that drivers accepted a greater than zero collision risk (at least at a societal level, if not at a personal level) and regarded it as the price to pay in order to satisfy mobility needs. Assuming collision rate homeostasis, Wilde posited that traffic collision rates (measured as collisions per time unit of exposure) might oscillate due to drivers' compensation reactions to introduced safety measures in the short-term, but that they would return to their initial value in the long-term.

The main component of the model is the comparator (see red circle in Figure 3-1) within which the perceived level of risk is compared to the target level of risk. Based on Taylor's (1964) findings of the Electro-Dermal Activity (EDA) tracking objective risk in the road environment and his suggestions of EDA as the physiological correlate of arousal or anxiety, Wilde suggested that drivers continuously (and unconsciously) monitor this arousal to derive an estimate of the perceived level of risk in a given situation which is in turn compared to the target level of risk. Discrepancies between perceived level of risk and target risk were posited to be associated with too much or too little arousal (unpleasant for the driver), leading the driver to take adjustment actions aimed at reducing the discrepancy and the associated arousal.

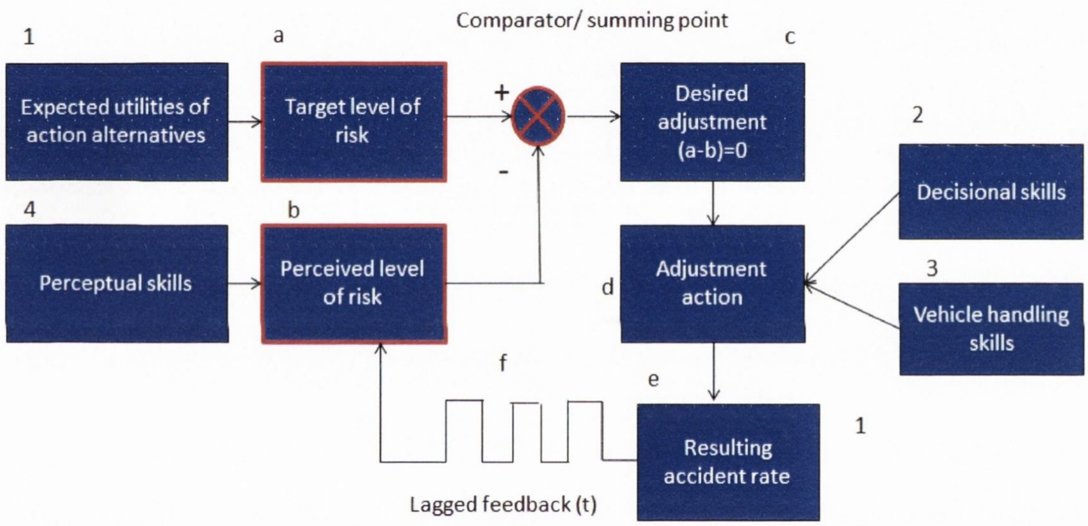


Figure 3-1: Main model components of the Risk Homeostasis Theory (Adapted from Wilde (1982), p. 212).

At the aggregate level, the theory proposed that the adjustment actions taken by the driver population when trying to reduce discrepancies in perceived and target risk are associated with a certain objective risk and produce the population's collision rates. This objective risk feeds back into the perceived level of risk with an assumed time delay. Thus linking subjective and objective risk together, Wilde assumed that drivers pick up on objective risk through day-to-day experiences of driving (e.g. near misses) rather than distil prevailing collision rates from (possibly inaccurate) government statistics. He also proposed that the media reporting on collision occurrences impacted perceived risk levels. He conceded that individual driver's perceptions would likely over- or underestimate risk, but argued that at the aggregate level, the mean risk perceptions and required adjustment actions are accurate, resulting in the homeostasis of risk. Driver skills play a role in the accurate perception of risk, in making correct decisions about necessary adjustment actions and implementing these adjustment actions well.

An overview of the full model is shown in Figure 3-2. The path of ascending numbers from box 1 to number 14 describes the process of information sampling from the dynamic road environment and anticipations about its future state that feed into the comparison of perceived risk and target risk, leading to decision making and the implementation of adjustment actions which ultimately determine the future state of driving conditions the driver will continue to sample information from. All components of the driver decision-making process are influenced by a number of factors (boxes 15 and 16) which Wilde categorised as "cognitive states" (ability to be safe) and "motivational states" (willingness to be safe). Both are characterised by long-term, trip-related and short-term variations between and within individuals (box 17).

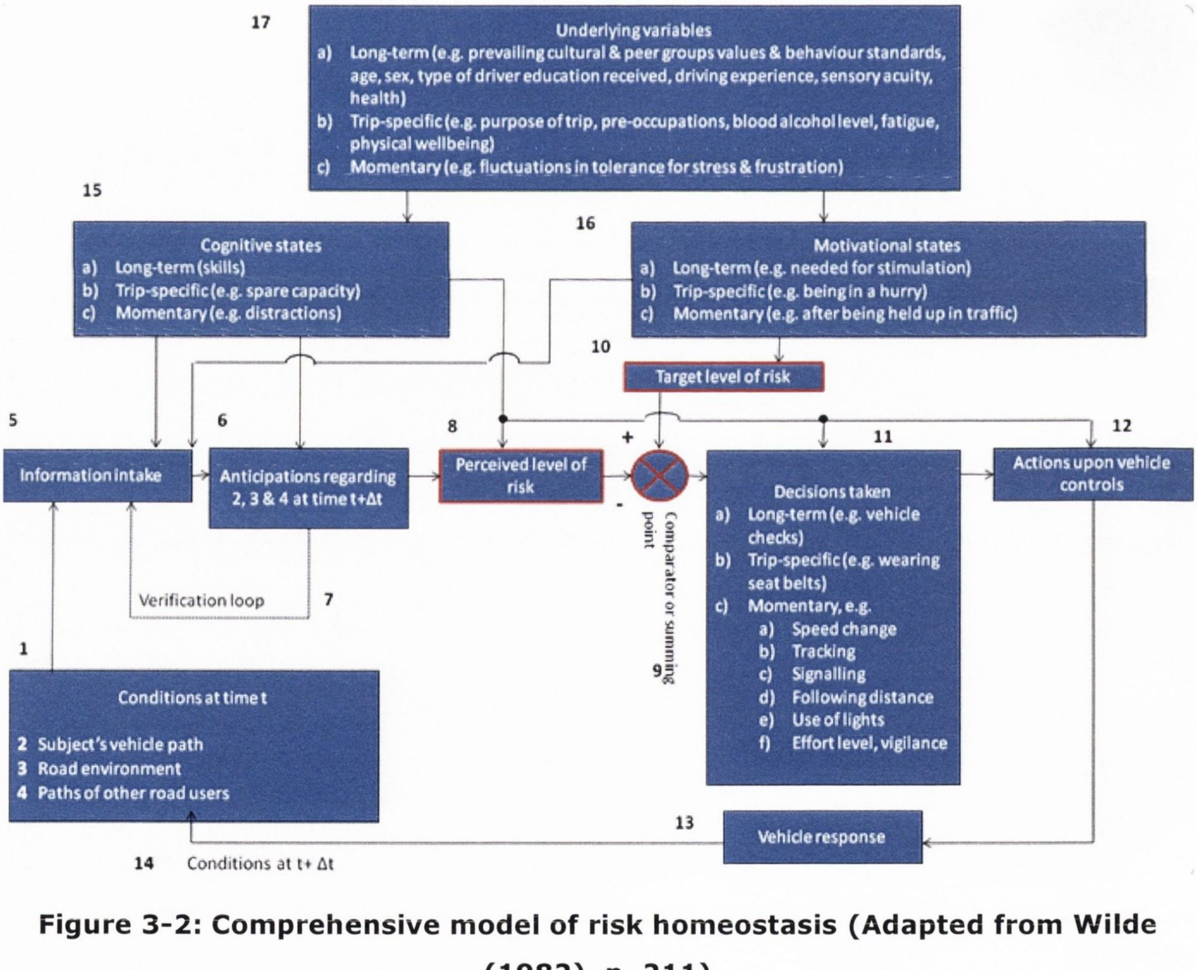


Figure 3-2: Comprehensive model of risk homeostasis (Adapted from Wilde (1982), p. 211)

Wilde deserves acclaim for being the first proponent of a comprehensive motivational model, based on the notion that driver capabilities, including perceptual, decisional and vehicle handling skills, affect risk. The introduction of a target level of risk suggests a dynamic concept of risk that arises from contradicting motivations (being safe versus making progress). However, as the following quote from Haight (1986) illustrates, the risk homeostasis theory has also been subject to fierce (and on-going) debate and extensive criticism:

"There is some question as to whether the theory is meaningless (since incapable of testing [sic]*) or simply false. Evans' (1986) conclusion that "there is no convincing evidence supporting it and much evidence refuting it" is if anything generous."* (p. 364).

Only the main points of criticism are summarised in the following. Wilde argues that only those road safety measures that change the target level of risk could successfully reduce collision rates in the long term; empirical findings, however, do not support this notion as measures such as speed limits have been found to lead to effective reductions in driven speed. Whilst a range of field and laboratory studies have found evidence for a mechanism of behaviour adaptation in response to the implementation of some safety measures, risk homeostasis with its associated hypothesis of constant collision rates per unit of time exposure has been refuted (Haight, 1986; McKenna, 1988; Trimpop, 1996; Rottengatter, 2002). McKenna (1988) points out that road safety trends over the last decades have shown steady decreases in national collision rates despite a growing number of vehicles on the road and increased traffic volumes which contradicts Wilde's posited stable target level of collision involvement over time. McKenna (1990) also notes that Wilde has been selective in his application of methodological criteria to studies that could act as evidence against the Risk Homeostasis Theory. Adams (1988) suggests that Wilde's theory is plausible, but not testable, because none of the variables specified by the theory can be measured accurately or at all. He argues that collisions are useless indicators of risk or safety and that measuring target levels of risk or perceived levels of risk is impossible.

The theory has furthermore been criticised for not providing sufficient detail about the mechanism of comparing perceived risk against target risk. Whilst Wilde posited this process to be unconscious and automatised in most instances, he argued that it is also open to conscious deliberation and can be reported on by the individual. His assumption that perceived risk informs feelings of risk which manifest themselves changes of electro-dermal activity, would suggest that drivers need to be sensitive to such changes. Fuller (2005b) argues that apart from extreme cases, drivers are not conscious of Skin Conductance Reponses. McKenna (1988) follows a similar line of argument stating that the psycho-physiological relationship between the collision rate and its psychological representation would have to be very sensitive to changes in very low probability events and resistant to many factors that affect every other dimension. He suggests that studies in the risk perception domain indicate that people do not have the required sensitivity to low probability events and that the theory's reliance on risk as the driving force of decision making assumes a capability humans generally do not have.

McKenna (1988) furthermore questions the necessity of the risk concept in explaining experimental findings cited in support of the risk homeostasis, namely Taylor's (1964) findings of high positive correlations between skin conductance response and collision rates in different road environments and high negative correlations between travelling speed and collision rate. While Wilde interprets electro-dermal activity as measure of subjective risk that varied directly with the objective risk, McKenna suggests that mental workload could account for the findings equally well and would make the concept of subjective risk in this context superfluous. Rottengather (2002) similarly argues that the risk concept is not required in the model. He suggests that the application of subjective expected utilities to road user behaviour, that is expected utilities with subjective probabilities attached to the event, would produce the same outcomes. Whilst it is good scientific practice to use the most parsimonious explanation to account for research findings, research recently published by Kinnear and Stradling (2011) on electro-dermal response in relation to hazardous driving scenes presented on video to inexperienced versus experienced drivers suggests that skin responses reflect not merely workload, but an emotional fear response.

Trimpop (1996) comments that the target level of risk in Wilde's theory is conceptualised as a uni-dimensional variable with overreliance on its negative aspects or dis-utilities. He supports the conceptualisation of risk as a multi-dimensional variable that accommodates positive risk motivations such as thrill seeking and supports the notion of greater temporal fluctuation. Whilst Wilde incorporates these considerations in the schema of his model, he does not specify the mechanism by which such risk motivations may influence the determination of the target level of risk.

The theory has been criticised for its lack of testable hypotheses (Trimpop, 1996; Hoyes & Glendon, 1993; Adams, 1988; Rumar, 1988). Haight (1986) states that the theory is unfalsifiable because it does not specify quantifiable measures of compensation such as changes in speed or following distances. Hoyes and Glendon (1993) argue in a similar vein and suggest that the theory does not specify cognitive or behavioural pathways along which it may operate. They furthermore point out that the assumption of compensation behaviours that fluctuate over time and across activities hamper empirical investigation of the theory, both, in the laboratory and the field. Hoyes and Glendon (1993) also suggest that Wilde's assumption that the media's reporting of collisions influences drivers' perceptions of risk is problematic. Finally, the combination of individual and aggregated level of analysis in the model has been raised as a concern. Trimpop (1996) for example questions how far individual driver motivation and behaviour could be transferred to a societal level. Of all motivational models, the theory is the only one that makes predictions about collision rates on a societal level.

3.3 The Zero Risk Model

In contrast to Wilde's Risk Homeostasis Theory, Näätänen and Summala (1974; 1976) posit that driving is typically characterised by the absence of perceived (or subjective) risk and therefore refer to their theory as the Zero-Risk Theory of driving. Summala and Näätänen (1988) emphasise the role of motivational influences on driver behaviour and of adaption processes, which are attributed to exposure-related changes in driver perception and cognition. In their model, behaviour is assumed to be governed by the influence of inhibitory motives (subjective risk) and excitatory motives. Excitatory motives, also described as 'extra motives' (Näätänen & Summala, 1976) are additional to the desire to make progress and are posited to be influenced by personality, the driver's state and journey-related motives. Extra motives include time gains, thrill seeking, self-assertion or expressing one's identity, competing or testing one's own and others' limits. Subjective risk in the model is defined as a feeling of uncertainty or anxiety and does not imply estimates of collision risk.

In contrast to Wilde's assumption that drivers assess the subjective expected utilities of different behavioural alternatives, the Zero-Risk Model can be described as a 'satisficing model' in decision theoretical terms[8], in which a simple comparison between excitatory and inhibitory motives impacts driving decisions. Summala and Näätänen (1988, p. 91) suggest that "*whenever a fear response, felt or anticipated, emerges under conditions of fast dynamic situations, decision making is realised as a uni-dimensional comparison of the strength of two motives, excitatory and inhibitory, rather than as a 'rational' comparison of positive and negative utilities and associated probabilities of each alternative.*"

The inhibitory determinant of driving behaviour is incorporated as a subjective risk monitor (see Figure 3-3) which is only activated when a critical threshold of subjective risk is exceeded (e.g. in the event of a near miss) or anticipated to be exceeded. In the subjective risk monitor different degrees of risk or fear are generated when the monitor is activated, depending on the amount and nature of the risk experienced in the present or for the expected traffic situation, in which learned safety margins are violated. The authors propose EDA as a possible, yet unspecific indicator of subjective risk and suggest that avoidance learning is a central mechanism of the inhibitory function. When

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[8] In contrast to optimal decision making, where all alternatives are compared and the best solution is detected, satisficing describes a decision making strategy, whereby available alternatives are only searched, until an acceptable solution is found.

subjective risk exceeds the critical threshold and the risk monitor is activated, it can affect on-going behaviour or future decision making with the aim of reducing subjective risk. Future decision making is influenced by avoidance learning: drivers learn to recognise the cues that precede the experience of fear and take avoidance action. Continuing to drive under activation of the risk monitor is possible; however, in this case the excitatory motivation has to be very strong.

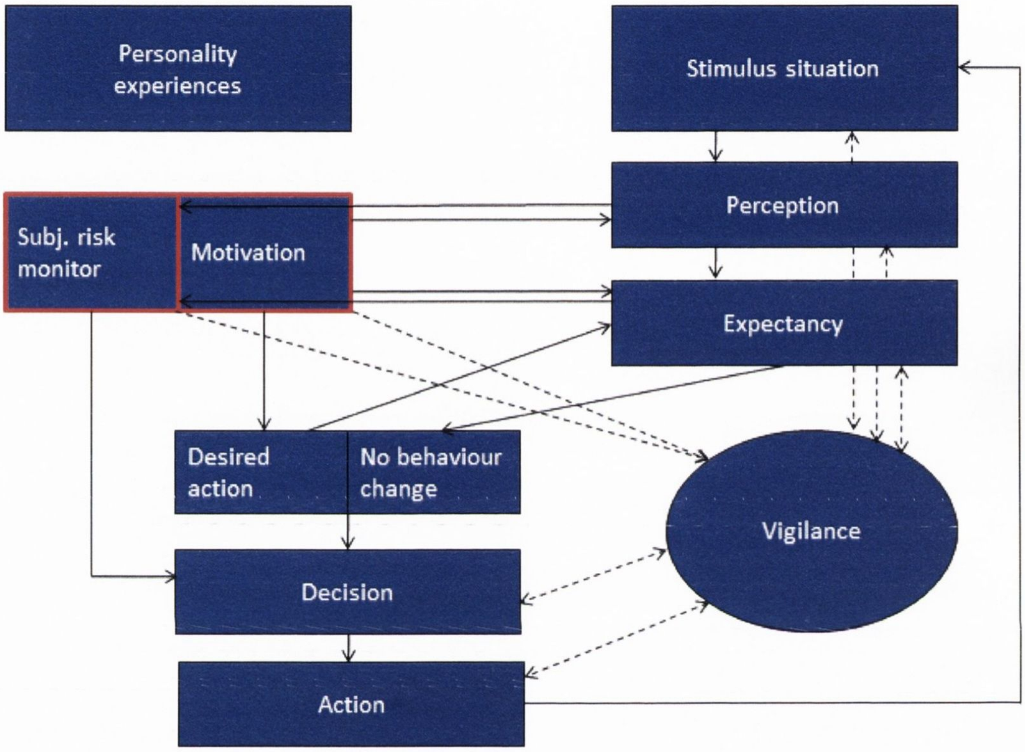

Figure 3-3: The Zero-Risk Model (Adapted from Näätänen & Summala (1976), p. 187).

Figure 3-3 illustrates the central components of the Zero-Risk Model, starting with a stimulus situation and ending with a driver response. Perception is described as an active, selective process, which is controlled by drivers' motives and their experience (Summala & Näätänen, 1988). Perception triggers expectancies which are described as vivid, perception-like predictions based on learning effects and which comprise the anticipation of the continuation of perceived events and the subjective certainty of the occurrence of the expected sequence of events (this somewhat resembles the "anticipation" component of Wilde's Risk Homeostasis Model). Realistic expectancies according to Näätänen and Summala (1974) are the pre-requisite for successful driving, and expectancies are modified through (perceptual) learning experiences, which gradually lead the driver to develop internal models of the traffic environment. However, the authors suggest that the internal models of experienced drivers underestimate the stochastic nature of traffic and its associated risk, which according to the authors explains drivers' inability to take into account small stochastic risks within the traffic system. Expectancies lead to decisions as to what kind of behaviour change (if any) is needed. Decisions are characterised as autonomic, relatively primitive and non-cognitive. Personality and experience feature in the model, but haven't been linked by the authors to any particular component of the driver decision-making cycle.

The authors propose that attention to and perception of traffic situations is modified by motivation and experience and is a selective, active and unconscious process. Vigilance is proposed as a central mechanism which is influenced by internal states of the driver or external states of the stimulus situation (traffic environment). The arrows between vigilance and decision/ action component of the model indicate that driver decisions and actions can lead to increases in vigilance and effort in response to perceived requirements of the driving task. Referring to the concept of automatisation, Summala and Näätänen (1988) posit that with increasing driving experience, the flow from perception to expectation to decision and action is automatised which leads to an automatic and unconscious control of the car most of the time. Initial feelings of uncertainty diminish as confidence in the control skills increases (Summala, 1998).

Näätänen and Summala (1974) explain drivers' reluctance to adhere to safe driving standards (e.g. wearing seat belts) by the fact that the subjective risk is nil most of the time. Learning is of central importance in the model as drivers with repeated confrontations adapt to situations which initially evoke a fear response. Most of the time drivers proceed on the basis of habitualised patterns and learned safety margins with no concern for risk (Summala, 1998).

The theory proposes that measures to improve road safety (e.g. driver training or simplification of the traffic environment) are often less successful than anticipated because they do not take sufficient heed of the fact that drivers are motivated agents who create the difficulty of the driving task themselves. Näätänen and Summala (1974) argue that in the absence of subjective risk (a state that characterises most of our driving), safety benefits achieved through the simplification of the driving task will be absorbed in a compensatory fashion through the adoption of riskier driving styles that satisfy extra motives of the driver (such as time gains). According to the theory, subjective and objective risk are only weakly correlated; with increasing experience (or exposure) drivers behaviourally adapt to risk in traffic through a process of extinction resulting from the fact that riskier driving is rarely associated with negative consequences (Summala, 1988). This leads to raises of the critical threshold in the subjective risk monitor and in the objective likelihood of a collision (because, for example, of the adoption of higher driving speeds to satisfy extra motives) in the continued absence of subjective risk.

The initial description of the Zero-Risk Model (Näätänen & Summala, 1974) does not clearly specify the process of how driving decisions are made when the risk monitor is not activated. Further detail on the assumed process is provided in later publications on the model (Summala, 1988; 1996). Given that drivers rarely experience risk, safety margins as simple heuristics are proposed as the critical measure to be controlled. Summala (1988; 1996) defines safety margins as the spatial or temporal distance of the agent from the hazard, derived from the concept of 'critical space'. They include longitudinal time or space distances in car-following or lateral separation from road markings or other road users. The two proposed safety margin heuristics used by drivers in controlling traffic risk are Time-to-collision and Time-to-line-crossing. Summala (1996) suggests that the control mechanisms for safety margins are basic human skills that are acquired by learning and eventually become a habitual process (largely automised) that does not require conscious processing. The maintenance of safety margins can be threatened when extra motives push drivers towards higher speeds, because of an insensitivity to low probability events or because of the growing desensitisation to potential threats.

Implications from the theory are that road safety measures should NOT focus on lowering the fear threshold, because driving typically takes place when subjective risk is subliminal. Instead, measures should aim to reduce the variability of driver performance, increase the predictability of hazards, e.g. by clearer signage. Summala (1996; 2000) suggests that limits in human perception systems (e.g. peripheral and foveal vision at night) may result in inappropriate feelings of control, adaptation to risk and distorted decision making on the road. He takes a sceptic stance towards the possible contribution of driver education to traffic safety and proposes that novice drivers' habitual behavioural patterns should be modified from the very beginning of their driving careers with a focus on training hazard perception skills such that they become automatic, since the growth of self-confidence with increasing driving experience tends to eliminate conscious attention to safe driving practices. Considering the powerful influence of motivation as well as drivers' biases in the perception of risk, Summala (1996; 2000) supports the introduction of restrictive measures to encourage safe driving practices.

In addition to the general criticism of motivational theories for their lack of measurable variables and testable hypotheses (Ranney, 1994; Hoyes & Glendon, 1993; Adams, 1988), criticisms of the Zero-Risk models have been put forward by Fuller (1984) who questioned the face validity of the assumption that the preponderance of extra motives raises the critical risk threshold and the objective risk of a collision whilst the subjective experience of risk remains low. The dissociation between subjective and objective risk has also been called into question by Brown (1980). Rothengatter (2002) suggested that the activation of the risk monitor should logically result in sudden changes of driving behaviour, something that is rarely observed.

In response to the argument that feelings of risk could not be an important determinant of driver behaviour if they were zero most of the time, Summala and Näätänen (1988) argued that based on avoidance learner drivers would anticipate or make appropriate adjustments to upcoming hazards. The later explication (Summala, 1988) of safety margins as the continuous control variable filled this gap by specifying the process that governs driving behaviour. Responding to this new formulisation, Fuller (2005b) suggested that whilst this model was attractively embedded in the behavioural learning paradigm, it could not account for how drivers would learn to recognise and safely respond to the large variety of different traffic scenarios, selecting appropriate safety margins. Maintaining the thrust of his earlier criticism Fuller (2009) argued that risk feelings must continuously play a part to enable the driver to maintain safety margins, even if they only have the characteristic of 'whispers' of affect (Slovic, Finucane, Peters & MacGregor, 2003). He claimed that without continuously taking account of the emotions triggered by elements in the road and traffic environment and discrepancies between current and goal states, the driver has no basis for decision-making.

The model can be criticised for the lack of clarity regarding the process of behavioural adaptation to risk and the role of internal models of the traffic environment. Behavioural adaptation is an assumed mechanism whereby a sense of uncertainty and fear disappears with increasing driving experience and adoption of riskier driving styles, and, in particular, increased driving speeds. Following the logic of the model, the so called 'risky shift' should continue, until the critical risk threshold is reached, thus activating the fear monitor with its inhibitory effect on driving behaviour. For experienced drivers with a long history of extinction of subjective risk responses, the critical risk threshold should continue to rise and subjective risk should become more strongly associated with objective risk because of the performance of riskier manoeuvres. This would suggest that experienced drivers should drive faster than inexperienced (with no obvious ceiling to speed increments) and should with increasing driving experience be involved in more collision than inexperienced drivers because of the closer association between subjective and objective risk for this population. Whilst research studies may not have specifically tested this assumption, there seems to be sufficient evidence that more experienced drivers are not statistically more collision involved or do not drive faster than less experienced drivers. Summala and Näätänen may argue that this may be due to experienced drivers' more accurate internal model of the traffic environment; however, the integration process of expectancy and risk adaptation in producing actual driver behaviour is not sufficiently specified to provide definitive answers.

3.4 The Threat Avoidance Model

Similar to the Zero-risk model, Fuller's threat avoidance model is based on the assumption that drivers are generally not motivated to take risks, but want to make progress through the traffic environment and need to take continuous avoidance actions to do so safely. In contrast to the assumption that drivers monitor risk, as proposed by both, Summala and Näätänen (1974; 1976) and Wilde (1982), Fuller suggests that drivers monitor the probability of the occurrence of a potentially aversive stimulus. Risk in the model is conceptualised as a feeling of risk that occurs in response to experienced or anticipated catastrophic events such as the loss of control or a collision.

The threat avoidance model emphasises the importance of conditioning processes and learning in the acquisition of driving skills. Fuller (1984) argues that catastrophic events in traffic such as collisions or loss of control (aversive stimuli) occur only rarely because drivers quickly learn to avoid them. The aversive nature of the stimuli according to Fuller arises from the interaction of driver action and stimulus characteristics.

Stimuli that precede and point to the occurrence of subsequent aversive stimuli serve as so-called 'discriminatory stimuli'. Discriminant stimuli are conditioned through learning processes and can comprise internal (driver state) or external (traffic environment) stimuli. However, as Fuller points out, discriminatory stimuli and aversive stimuli are not necessarily contingent.

According to the model (see Figure 3-4), drivers can neutralise potentially aversive stimuli (box "a" in the model) if they initiate an anticipatory avoidance reaction (box "c" in the model). Aversive stimuli are associated with high negative arousal (i.e. tension, anxiety, stress, risk) which facilitates the process of avoidance conditioning. Anticipatory avoidance reactions are not always displayed, because the lack of contingency between discriminative and aversive stimuli or because the delayed avoidance reaction is intrinsically rewarding (e.g. by increasing arousal or as a means to demonstrate competence). Fuller (1984) proposes that intra- and inter-individual differences in preferences for anticipatory and delayed avoidance responses exist, based on evidence from a range of animal conditioning studies.

If a driver does not react to a discriminative stimulus (box "e" in the model), an aversive stimulus may subsequently not appear, resulting in a neutral situation (box "d"). If an aversive stimulus occurs (box "b"), the driver must take a delayed avoidance action (box "f") to avoid a collision. Fuller suggests that the likelihood of a collision (box "g") increases with the time an avoidance reaction is delayed.

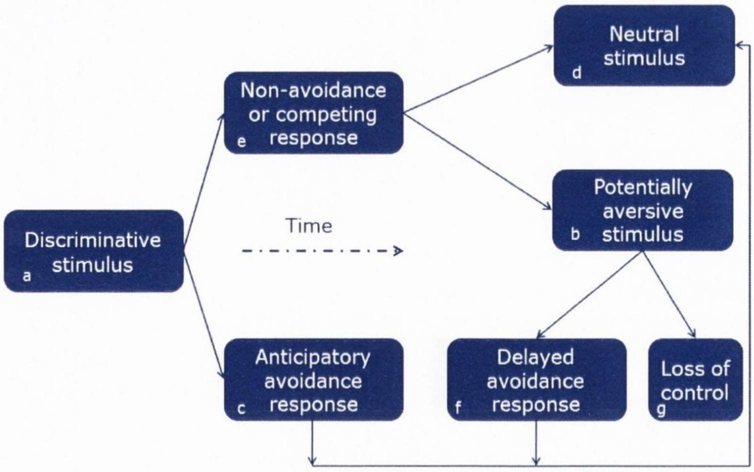

Figure 3-4: Basic Threat-Avoidance Model (Adapted from Fuller (1984), p. 1142).

Drivers' reactions to discriminatory stimuli (circle "w" in Figure 3-5) are proposed to depend on the strength of the association between discriminatory and aversive stimulus and on the consequences of anticipatory and delayed avoidance reaction (shown as circle "y" in Figure 3-5): if the probability of an aversive stimulus (shown as ellipse "v") is low, the likelihood of anticipatory avoidance reactions decreases, as they are assumed to be associated with a cost (e.g. losing time). If the driver does not receive feedback indicating that the anticipatory avoidance reaction was necessary, extinction of the reaction is facilitated. Fuller posits that learning histories determine the values of the parameters for each individual driver. However, whilst trial-and-error is an important posited mechanism, Fuller (1988) states that learning is also possible through guidance or rule-learning.

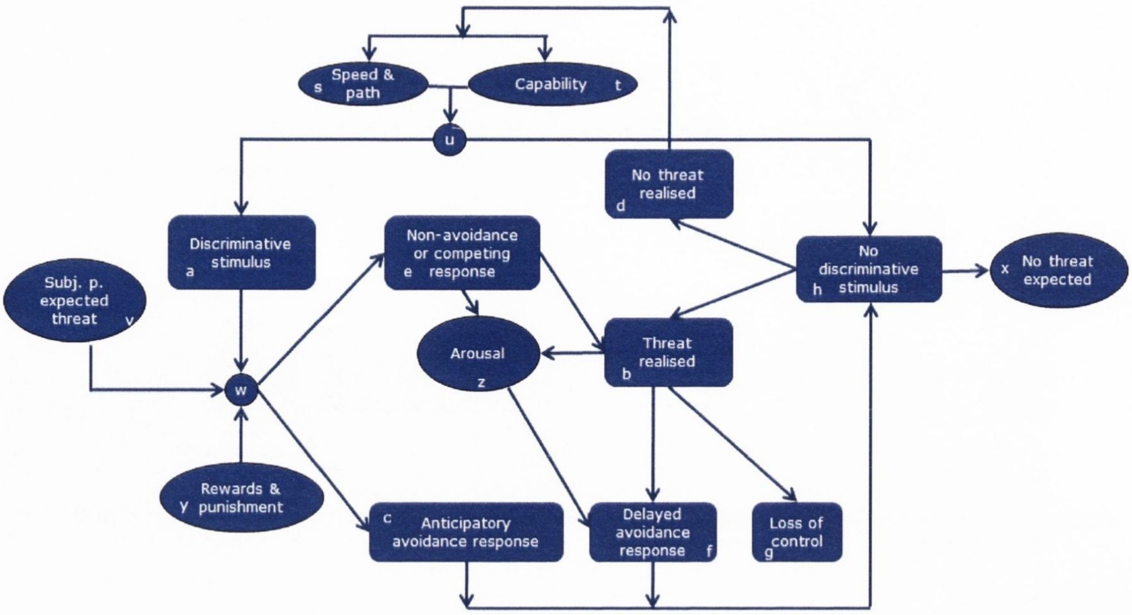

Figure 3-5: Comprehensive Threat-Avoidance Model (Adapted from Fuller, 1984, p. 1148).

According to Fuller (1988; 1991), the process of learning to drive comprises the recognition of discriminatory stimuli and their contingencies with subsequent aversive stimuli. The posited learning mechanism is punishment. Feelings of risk (arousal, shown as ellipse "z" in Figure 3-5) can emerge as a result from ineffective avoidance reactions or from approaching an aversive stimulus.

Fuller (1991) emphasises that the natural contingencies in traffic are insufficient to establish and maintain safe driving, either, because the contingencies are too difficult to learn or because the antecedents of hazards are too unreliable. He also asserts that behaviours that are incompatible with safety can be too strongly rewarded. Based on the model, Fuller (1984) lists the following implications for road safety measures:

- The avoidance of arousal levels that are too low/ too high;
- The removal of aversive stimuli from the traffic environment;
- The training of anticipatory avoidance reactions, independent of actual contingencies with aversive stimuli;
- Training focused on increasing the effectiveness of avoidance reactions;
- Avoidance of influences that reduce the driver's sensitivity to arousal.

The observation of shifts towards the adoption of riskier driving behaviour (Fuller, 1991) is proposed to result from the lack of contingency between discriminatory stimuli and potentially aversive stimuli and from the extinction of anticipatory avoidance responses through lack of reinforcement. He suggests that novice drivers may be particularly prone to erroneous assessment of contingencies (not knowing what follows) whereas experienced drivers are increasingly prone to conditioning errors (having learned that punishment does not happen).

Whilst the formulation of driving as threat avoidance and its associated principles of avoidance conditioning is grounded in well-established mechanisms of learning theory, the model's suffers from the same criticism that Fuller himself raises (Fuller, 2005b) in response to the Zero Risk Theory. The theory asserts that driving is governed by the maintenance of learned safety margins, and Fuller suggests that a learning model cannot account for how appropriate response behaviours are emitted in reaction to a large variety of different traffic scenarios. Whilst Risk Homeostasis Theory and Zero Risk Theory describe the driver as a purposeful agent who creates the driving task himself, the Threat Avoidance model adopts a more passive view of the driver, describing him as a creature of the contingencies of the environment he faces. Fuller (1988) suggests that human subjective probabilities are likely to be a function of reinforcement schedule effects as well as of frequency of exposure to particular contingencies and other variables. Whilst his model is less static compared to Subjective Expected Utility Models of behaviour and accounts for the fact that goal-directed action undergoes continued evolution and regards action not as choice, but construction (Fuller, 1988), predictions of driver behaviour based on the model are not possible, unless the full learning history of an individual is known. This clearly limits the predictive value of the model.

3.5 The Task-Capability Interface Model

Fuller's (2000; 2009) subsequent theory development is still based on the assumption that a driver's motivation for a collision is zero and that statistical risk plays no role in the determination of driver behaviour. In contrast to the threat avoidance model, however, he asserts in the task-capability interface model and its associated hypothesis of task difficulty allostasis (originally referred to as task difficulty homeostasis) that drivers do not monitor the occurrence of potential threats, but the difficulty of the driving task which acts as the main determinant of driving behaviour and arises out of the dynamic interplay of two main variables, task demand and driver capability. Task demand is defined as the objective complexity of the driving task which Fuller (2000) interprets as a control task in a dynamic environment. It arises from the integration (see Figure 3-6) of the road environment, the behaviour of other road users, vehicle characteristics, vehicle trajectory and driver communication. Driving speed is postulated to be the main determinant of task demand, with higher speeds leaving less time for perceptual and decision making processes, thus making the task more difficult. Fuller suggests that the choice of driving speed is influenced by motivational states of the driver, which are assumed to vary intra- and inter-individually.

The driver brings his capability to the task; the upper limit of capability is determined by biological characteristics of the driver (the so-called constitutional features, see Figure 3-6), which for example comprise information processing capacity and speed, reaction time, physical reach, motor coordination, flexibility and strength (Fuller, 2005b). Following on are knowledge (rules of the road, procedural knowledge, which defines what to do under what circumstances) and a representation of the dynamics of the road and traffic scenarios which enable a prediction of how these scenarios will develop (thus resembling the expectancy concept proposed by Näätänen and Summala, 1974; 1976) and skills (basic vehicle control, handling skills in challenging circumstances, arising out of training and experience). Capability is assumed to be modified by human factor influences (including age, attitudes, motivation, effort, fatigue, drowsiness, time-of-day, drugs, distraction, emotion and stress) which determine the momentary capability of the driver and by experience: based on their superior mental representations of the road environment, more experienced drivers can use top-down and feed-forward control decisions which become manifest in a more anticipatory driving style, including greater safety margins, quicker neutralisation of threats and a greater potential to recover from error (Fuller, 2009).

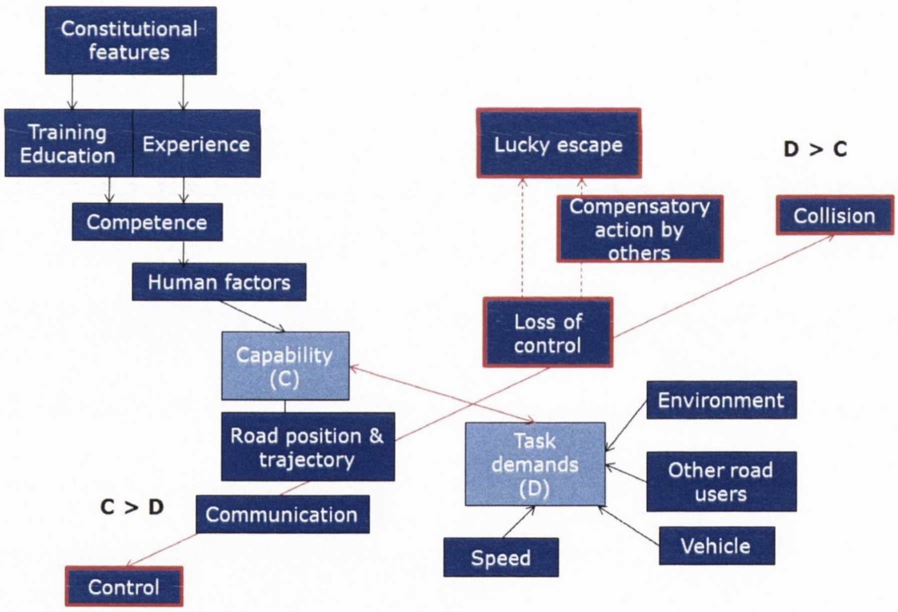

Figure 3-6: The Task-Capability Interface model (Adapted from Fuller (2005), p. 465).

Together, task demand and driver capability determine the difficulty of the driving task, whereby task demand and capability are not assumed to be independent. Rather, task demand as an external stimulus in itself is assumed to impact driver capability by modifying a driver's level activation/arousal and with that the level of a driver's capability. For example, drowsy drivers may increase their speed to increase task demand.

Collisions happen when task demand exceeds driver capability, as illustrated in Figure 3-6 as D>C. Drivers can tackle the avoidance of collisions by altering either of these two components - increasing capability (e.g. increasing vigilance, reducing the quality of the driving performance or dropping additional tasks) or reducing task demands (e.g. reducing speed). Fuller (2005b) suggests that the model allows the integration of driving task taxonomies such as the GDE matrix (Hattaka, Keskinen, Gergersen, Glad & Hernetkosi, 1999) and differentiates between long- and short term processes of decision making. For example, drivers can manipulate task difficulty momentarily (by reducing the driving speed) or long-term (referring to the GDE matrix's planning or strategic level) by:

- Purchasing a car with good safety features;
- Choosing an easy driving route;
- Allowing more time for the journey;
- Avoid driving in high traffic densities;
- Avoid driving in bad weather;
- Increase their effort;
- Increase their driving competence.

With increasing task difficulty, feelings of risk increase which, based on Taylor (1964) findings, are physiologically represented as arousal and manifest themselves in changes of electro-dermal activity (Fuller, 2005b). Drivers are assumed to target an optimal range of arousal or feeling of risk which determines driving behaviour; whilst the lower boundary of the range is determined by the avoidance of boredom and the need to make satisfactory progress, the upper threshold is influenced by the driver's:

- Journey goals (e.g. determined by available time for journey, presence of passengers etc.);
- Perceived capability (function of estimates of competence and sensitivity to the effects of human factor variables);
- Effort motivation.

In a later publication Fuller (2009) adds that long-term influences such as personality (e.g. extroversion versus introversion) and momentary influences such as driver state (e.g. feelings of anger, competitiveness, social influences etc.) contribute to the optimal task difficulty range. It is this recognition of the variation of internal driver states in addition to external changes in demand that leads Fuller to replace the original 'homeostasis' concept (Fuller, 2000; 2005b) with that of 'allostasis' (Fuller, 2009) which describes the adaptation to a more dynamic target condition and which is defined as *'maintaining certain levels of biological conditions that vary according to an individual's needs and circumstances'* (Kalat, 2008, cited by Fuller, 2009).

Driver decision making is based on the continuous comparison of the perceived task difficulty against the preferred range of task difficulty. Fuller (2009) suggests that the mechanism in the comparator comprises a meta-cognitive process which is sensitive to the degree of deviation from sub-goals of the driving task (such as maintenance of directional control, sampling and processing of required information and enabling of required responses). Deviations from sub-goals could, according to Fuller (2009), trigger a fear or anxiety response because of the potentially punishing consequences. However, the question if the degree of fear felt is systematically related to such measures as time-to-line crossing or time-to-collision or is triggered in an all or nothing manner (i.e. driven by possibility rather than probability) is yet to be investigated by research. Discrepancies arising from this comparison lead to adjustment actions, which create the future driving situation and task difficulty (as illustrated in Figure 3-7).

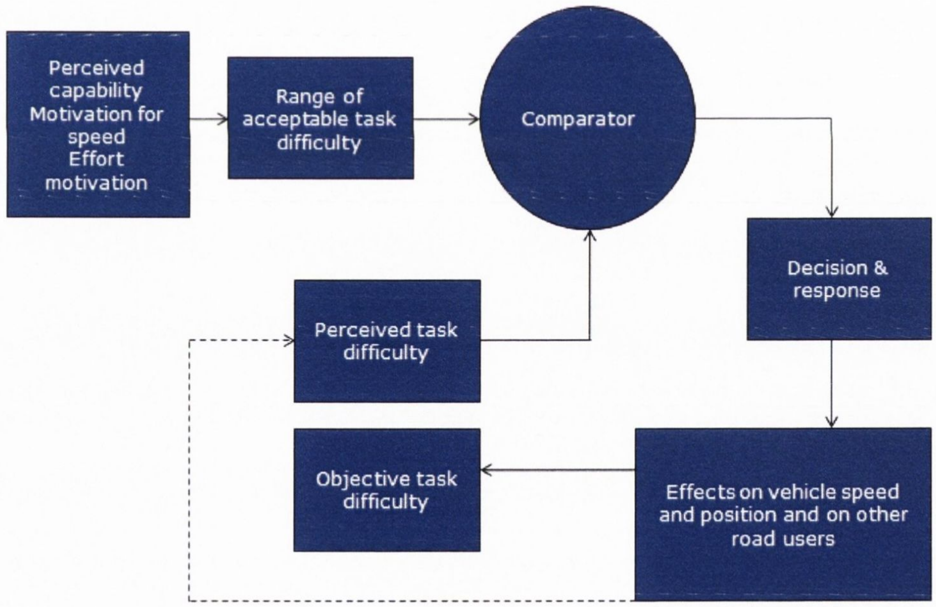

Figure 3-7: The process of driver decision making in the Task-Capability Interface model (Adapted from Fuller (2005), p. 467).

Fuller (2005b) argues that task difficulty is not a new concept but has been previously known as mental workload (e.g. Kahnemann, 1973 or Brookhuis & de Ward, 2001) in definitions that described workload as the proportion of capacity an operator needs to spend on task performance. According to Fuller (2009) task difficulty directly corresponds to mental workload and may be operationalised in time-to-collision and time-to-line crossing measures. He also proposes that task difficulty provides an operational definition of "hazards" and suggests that these arise out of the dynamic interplay between the driver's immediate capability and the features of the task demand. Feelings of risk are assumed to increase the more the driver approaches his upper capability limit. However, Fuller (2005b) proposes that risky shifts in driving behaviour may occur, if negative consequences of driving close to the upper capability limit fail to manifest themselves (an extinction process described in the threat avoidance model). Again, a potential influence of personality traits is assumed (e.g. sensation seeking) in drivers who purposefully explore the upper limit of task difficulty.

Road safety measures according to the model, should improve the management of the interface of driver capability and task demand, and in particular address:

- The overestimation of capability;
- The underestimation of task demand;
- The greater acceptance of risk and higher driving speeds to satisfy goals;
- The lack of understanding of the limiting impact of driver impairment on driver capability.

In his later work, Fuller (2005a; 2009) focuses on the role of emotions (and in particular, the feelings associated with the impending loss of control) as determinants of task difficulty. He refers to research carried out by Damasio (2003) who emphasises the adaptive value of emotions and their ability to attract attention to stimuli, which can subsequently guide and enhance decision making. In Damasio's Somatic Marker Hypothesis, emotional signals mark options and outcomes with a positive or negative signal that narrows the decision space and increases the probability that action will conform to past experience. Somatic markers are posited to become linked to stimuli and patterns of stimuli through a learning process which is controlled by an internal, innate preference system and external circumstances (stimuli, action alternative and consequences). Applying the concept to the driving context, Fuller (2005a; 2009) describes emotions as experiences concomitant with reward and punishment which help to select the driving goals and motivate the approach to them. Fuller posits that driving goals are feelings-motivated and involve both positive, approach-motivating feelings associated with the achievement of the mobility goal and negative, avoidance-motivating feelings associated with collision or road run-off. Fuller suggests that somatic markers are not only external stimuli, but can also arise from the perceived discrepancy between goal states and current states and that they provide fast heuristics for decision making that are particularly pertinent to decision making requirements in a dynamic road environment. He describes a model developed by Wickens, Toplak and Wiesenthal

(2008) which (based on Damasio's Somatic Marker Model) assumes two processes: one that is fast and frugal and activates gut feelings that fit the immediate situation, much like reflex behaviour. Included are processes of implicit and instrumental learning, over-learned associations and behavioural regulation by emotions. The other system involves slower, more controlled and effortful processes which necessitate the consideration of alternatives. This includes processes related to cognitive abilities and executive functions. Fuller (2009) suggests that further research is needed to understand the roles of these processes for driver decision-making in real time with simultaneous monitoring of affective and cognitive activity.

3.6 Summary

Several motivational driver behaviour models were reviewed, including Wilde's Theory of Risk Homoeostasis (1982; 1988; 1989), Näätänen and Summala's Zero Risk Theory (1974, 1976), Fuller's Threat Avoidance Model (1984) and Fuller's Task Capability Interface Model with its associated Risk Allostasis Theory (2000; 2005; 2009). The comparison of the models shows similarities in that all models assume a process of comparison where actual driving is compared to a target, and which initiates a process of behaviour adaptation if a discrepancy between the two values is observed. All models propose that feelings of risk are associated with intolerable discrepancies. However, models vary with regard to the variables that are assumed to determine driving behaviour and the process by which these variables trigger feelings of risk. Whilst Wilde assumed that perceived risk of a collision modified driving behaviour, Fuller (1984) initially suggested that drivers monitored the occurrence of potentially aversive threats; in his later model of Risk Allostasis he expanded that feelings of risk associated with increases in task difficulty are monitored by the driver. Such feelings can, according to Fuller, be unconscious, and learned avoidance responses ensure that people most of the time drive in such a way that feelings of risk do not manifest consciously. Näätänen and Summala contradicted the tenet of a continuous monitoring process and suggested that only if critical safety margins were violated, feelings of risk became salient and triggered driver actions. In their model learned safety margins ensure that drivers usually drive in such a way that the risk monitor is not activated.

The reviewed models in this chapter provide very little detail on the effect age has on the posited central parameters. The influence of demographic factors, including age, is more or less implicit all models that were reviewed. In Wilde's Risk Homeostasis Theory, for example, age is explicitly mentioned as a long-term, "underlying factor". Whilst the Zero Risk Model and Threat Avoidance Model do not explicitly refer to age, they emphasise the impact of learning histories of the individual, and therefore, also hint at the importance of age. However, only the Task-Capability-Interface Model spells out, how age as a variable influences the posited relations, i.e. through its influence on driver capability. The Model therefore provides the most useful theoretical framework for the subsequent exploration of age effects on the perception of risk. However, even the Risk Allostasis Theory does not make it clear how the age-related deteriorations in cognitive, perceptual and motor components on the one hand and increasing driving experience on the other hand may interact with each other in their impact on feelings of risk, perceptions of task difficulty and perceptions of subjective risk.

Whilst Wilde's Theory of Risk Homeostasis has been heavily criticised, The Zero Risk Theory and the Task Capability Interface Model have attracted the most empirical research in recent years. Empirical findings that can shed light on the posited variables and associations are summarised below.

3.7 Empirical studies

Fuller (2009) describes the proposition that drivers continuously make real-time decisions to maintain the perceived difficulty of the driving task within certain boundaries, mainly by adjusting their speed, as the control concept at the heart of the Task Difficulty Allostasis. A review of the scientific evidence in relation to the Task Capability Interface Model for speed choice in particular has been carried out by Fuller et al. (2008). Speed reductions, however, are also compatible with the Zero-Risk Model, if the Risk Monitor was activated via inhibitory motives or violation of safety margins.

Research studies in the simulator have indeed demonstrated that drivers react to increases in workload by reducing driving speed, e.g. when given additional tasks such as making mobile phone calls (e.g. Haigney, Taylor & Westerman, 2000; Burns, Parkes, Burton, Smith & Burch, 2002) or texting (e.g. Reed & Robbins, 2008). Haigney, Taylor and Westerman (2000) found increased mean heart rates during periods of making hand-held or hands-free mobile phone calls in a driving simulator and interpreted these as an indication of higher cognitive load which drivers aimed to compensate for by adopting slower speeds during the period of the call. Reed and Robbins (2008) equally found reductions in driving speeds which they interpreted as compensatory behaviour to mitigate collision risk. Performance on measures of lateral position and maintenance of following distances were also affected in the study.

Lewis-Evans and Charlton (2006) conducted a simulator study where participants drove on three different road types, each of which included sections where the road was narrowed or widened (all other things being equal). After completion of the drives, participants were required to order pictures of the road scenes they had driven through (in an order that made sense to them) to ascertain whether participants were able to explicitly or implicitly order the road images by risk, road width or some other feature.

In a subsequent questionnaire, participants were asked to state appropriate speeds for the different road images, the perceived difficulty of the drives, the perceived likelihood of a collision, driving confidence, road preference and road width associated with the road images. The results showed that participants drove significantly more slowly and further away from the road edge on the narrower road. An asymmetry was found in that speed decreased for the narrow road but did not increase for wide roads above the speeds driven on control roads, which the authors interpreted as evidence for Summala's Zero-Risk Theory. Differences were found in subjective risk ratings for the three road environments which correlated with participants' driving speeds. The authors proposed that risk *"appeared to be a subjective reaction that arose from their* [participants'] *implicit experience of the road environments rather than an explicit factor motivating conscious decisions about appropriate speeds"* (p. 615). Participants' reported strategies for ordering the static pictures of the roads did not suggest an explicit awareness of the differences in either risk or road width. This led the authors to conclude that explicit considerations of objective risk did not impact behavioural adaptation, but that the phenomenon was associated with implicit, pre-conscious processes.

Fuller's original experimental work

A number of research studies have empirically tested specific predictions of Fuller's Task Difficulty Allostasis Model and the relationship between task difficulty and subjective risk. Fuller, McHugh and Pender (2008) investigated the association between task difficulty and subjective risk with 30 normally practised drivers (student population). Specific hypotheses were that:

1. Task difficulty ratings would closely correlate with speed;
2. Probability of loss of control ratings (i.e. subjective ratings of objective risk) would not be correlated with speed at low speeds but would correlated with speed once some speed threshold was reached;
3. Ratings of feelings of risk would significantly correlate with ratings of collision probability.

Participants watched video footage of short driving sequences filmed in daylight conditions at 30 mph from the driver's perspective. The driving speeds were digitally altered and showed at 5 mph increments for each road environment, resulting in the following number of clips:

- Residential road: 20-60 mph (9 clips);
- Country road: 30-80 mph (11 clips);
- Dual carriageway: 50-100 (11 clips).

The clips were presented in ascending order of speed, and after watching each clip (without knowing the actual speed) participants were asked to rate each sequence on 10-point Likert scales on:

- Task difficulty ("How difficult would you find it to drive this section of the road at this speed?");
- Feelings of risk ("How much risk you would experience driving this section of the road at this speed?");
- Statistical probability of a losing control for each sequence ("Imagine you had to drive this section of the road at this speed every day for the next month (i.e. 30 times). How many times do you think you would have an accident or lose control of the vehicle?").

In line with hypothesis 1, linear regressions found task difficulty ratings to be closely related to speed, with speed accounting for on average 98% of the variance in task difficulty ratings across all three road types.

As predicted by hypothesis 2 the estimated probability of losing control only increased after a critical speed threshold (see Figure 3-8) was reached for more than 80% of participants (residential road: 85%; country road: 93%, dual carriageway: 81%); those participants for whom thresholds were not observed either rated the probability of loss of control as zero or as greater than zero from the first clip onwards.

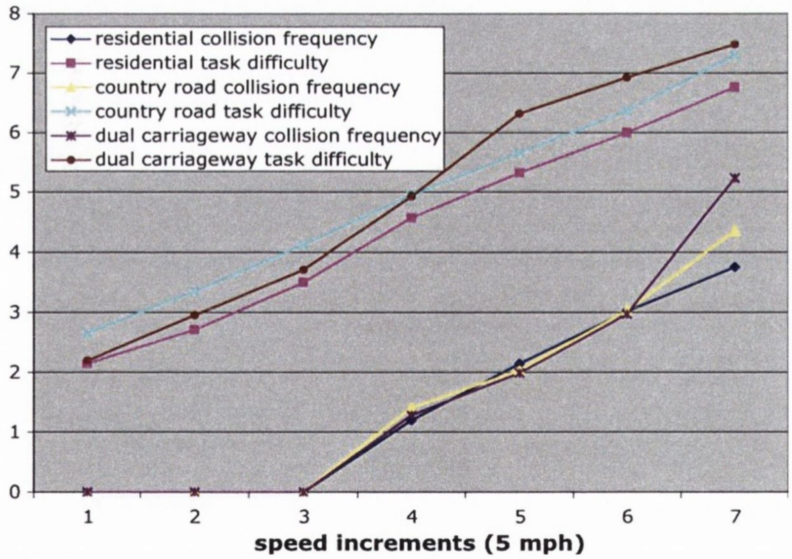

Figure 3-8: Task difficulty ratings and collision frequency estimates for 30 trials per road type (Fuller, Hugh & Pender, 2008, p.17)

Contrary to expectation (hypothesis 3), feelings of risk did not correlate with likelihood estimates of loss of control, but instead correlated with speed the same way task difficulty did, with linear regressions showing that speed accounted for on average 98%

of the variance in ratings of experienced risk across all three road types. The overall relationship (Pearson correlation) between task difficulty and ratings of experienced risk was $r=0.81$, $p<0.001$.

A replication study with forty current drivers (including a wider age range of 18-55 years) used the same stimulus material, 7-point Likert scales and introduced an additional question to account for the possible effect of the presence of other road users on subjective risk estimates ("Imagine this section of the road with other road users present. If you were to drive on this road at this speed every day for a month (i.e. 30 times), how many time to you think you would crash?"). After the completion of the ratings, participants were shown one road type again (randomly chosen) and asked to specify their preferred driving speed for this environment. To assess the reliability of the findings, 15 participants were asked to rate the clips for one randomly selected road environment again. Re-test reliabilities for each type of rating and each road type were highly significant and suggested the effects identified were robust. The replication study corroborated the earlier findings, identifying similarly high correlations. Speed accounted for 97% of the variance of task difficulty. Subjective risk (collision likelihood) again remained zero, independent from task difficulty or feelings of risk, until a critical speed threshold had been reached. This pattern was observed in 78% of participant trial blocks. The strong overall relationship between ratings of task difficulty and ratings of experienced risk again found its expression in a high Pearson correlation across all road types of $r=0.98$, $p<0.001$. Subjective ratings of the likelihood of a crash/loss of control in the absence or presence of other road users were compared using Wilcoxon signed rank tests without establishing significant differences between the ratings for any of the road environments. The review of the preferred speed data showed that for 38 out of the 40 participants the preferred speed was below the speed for which subjective risk exceeded zero for the first time.

The findings that preferred driving speed in the majority of cases remained under those where subjective risk started to exceed zero led Fuller et al. (2008) to conclude that drivers preferred driving in the absence of subjective risk. Both studies supported the existence of a critical threshold for subjective risk. Based on the findings the authors concluded that feelings of risk are not the same as the perceived probability of losing control/having a crash. Feeling of risk, with its close association with task difficulty, was interpreted to be the continuously monitored parameter that allowed the driver to maintain a preferred difficulty level and that would motivate the driver to take action when task demand approached capability. The findings of high correlations between task difficulty and feelings of risk are in contradiction to the assumptions of the Zero-Risk

Theory, which would suggest that feelings of risk are only experienced after a critical threshold has been exceeded and the subjective risk monitor has been activated.

Kinnear, Stradling and McVey (2008) replicated Fuller's study with a larger participant sample (n=152, age range 20-62 years) and increased its generalizability by using new stimulus material and including driving experience as an independent variable. Participants included learner drivers, inexperienced (<3 years driving experience) and experienced (>3 years driving experience) drivers with equal representation of males and females. It is also noteworthy that the inexperienced driver group in his sample was younger than the learner driver group (m=20.8 years versus m=21.3 years) and that learner drivers in the sample were characterised by an unusually long learning to drive process (m=16.9 months, SD=15.7 months) compared to the national average of 14.1 months according to Wells, Tong, Sexton, Grayson and Jones (2008).

The authors created a new set of video clips recorded from the driver's perspective and digitally altered resulting in nine clips (approx. duration 25 seconds) per road environment. No other road users, obstacles or obvious hazards were present in any of the clips. Based on research on motorcyclists (Broughton, 2008), an additional road environment condition was included, to allow a differentiation between straight and bendy country roads. This research also led Kinnear et al. (2008) to include an additional question on the enjoyment of the drive together with an additional hypothesis predicting a negative correlation between enjoyment and task difficulty once a critical speed threshold had been exceeded.

The research hypotheses were therefore:

1. Task difficulty and feelings of risk ratings will be associated with speed and each other;
2. The probability of loss of control ratings (subjective risk) will increase with speed only after some threshold is exceeded;
3. There will be a difference in response by experience level to either task difficulty, feelings of risk or the probability of loss of control;
4. At higher speeds, enjoyment will be negatively related to task difficulty whereby as task difficulty increases, enjoyment will decrease.

The questions measuring task difficulty, feeling of risk and objective collision risk were slightly altered and included:

- Task difficulty; 7 point Likert scale (*"How difficult would you find it to drive this section of the road at this speed?"*)

- Feelings of risk; 7 point Likert scale (*"How risky would it feel to drive this section of road at this speed?"*)
- Driver hedonism: 7 point Likert scale (*"How enjoyable would it feel driving this section of road at this speed?"*)
- Subjective risk: the question of estimating the risk of collision was replaced with an estimate of the probability of losing control (possible answer range 0-100): *"Imagine if 100 drivers like you, of the same age and experience, were to drive this section of road at this speed and in these conditions. How many do you think would lose control of the vehicle?"*

All video clips were presented to participants in Power Point in ascending speeds for each road type, following research that suggested that order effects of the video clips (slow speeds to fast speeds) were negligible (Lynne, 2006, cited in Kinnear, Stradling & McVey, 2008). Potential order effects for road types and rating questions were controlled for by counterbalancing them, with half of the participants watching the videos and answering the rating questions in reverse order.

At the end of the procedure, participants completed a questionnaire that gathered demographic and driving-related information and required them to specify their maximum driving speed rather than the preferred driving speed as used by Fuller, McHugh and Pender (2008). Whilst Kinnear, Stradling and McVey (2008) state that the aim of this change was to explore driver's maximum acceptance of task demand, and thus, the upper boundary of the target level of task difficulty, the inclusion of both questions would have enabled comparisons between both variables.

The findings presented a mixed picture regarding the research hypotheses. Spearman' Rho correlations found task difficulty and feelings of risk to be strongly correlated to driving speed in line with the predictions of hypothesis 1 (Residential: r_s=0.95, p<0.001; Straight Country: r_s=0.61, p<0.001; Bendy Country: r_s=0.71, p=0.031; Dual Carriageway: r_s =0.89, p=0.001). Correlations between task difficulty and feeling of risk for each speed and road environment suggested that the relationship between the two measures became stronger with increasing speeds. Kinnear, Stradling and McVey (2008) interpreted this as the result of the reduced safety margin associated with the speed related increases in demand and (more or less) stable driver capability.

In contrast to Fuller, McHugh and Pender's (2008) findings, the statistical risk estimate did not start to increase after reaching a speed threshold, but increased gradually from the lowest speed condition onwards. However, for a large number of participants, thresholds could also not be established because subjective risk was constant (always zero or always greater than zero for all speed conditions). Correlations between participants' thresholds, where thresholds existed, and the reported maximum driving speed failed to reach significance, indicating a (puzzling) lack of association between the two variables and leading to the rejection of the second research hypothesis. Lewis-Evans and Rothengatter (2009) suggested that the absence of subjective risk thresholds might be due to the fact that Kinnear, Stradling and McVey (2008) asked participants to judge another driver's likelihood of a collision rather than the driver's own likelihood. Kinnear in his doctoral thesis (2009) suggests that the finding may be due to the change in the rating scale (1-100 instead of 1-30).

In relation to the third hypothesis no significant differences for drivers of different experience levels were found for perceived task difficulty or perceived feeling of risk. Experience-related differences did, however, became manifest in subjective risk ratings (drivers' estimates of the objective likelihood of a collision). Collision probabilities were rated significantly lower by experienced drivers than by learner or inexperienced drivers, particularly at higher speeds. The authors interpreted this difference as an indication that inexperienced drivers relied on effortful, conscious processing (cost-benefit analyses), whilst experienced drivers relied on the feeling of risk for this purpose. Kinnear et al. (2008) argued that the lower subjective risk estimates of experienced drivers arose from the longer learning histories of experienced drivers and their associated better (and automated) insight relationship between task difficulty and subjective risk ('risk as feeling'), compared to the slow and effortful processing of the association by inexperienced drivers ('risk as analysis'). Whilst therefore task difficulty and feeling of risk ratings would be comparable between the two groups, more experienced drivers should estimate subjective risk lower than less experienced drivers.

Correlations between task difficulty and enjoyment ratings confirmed the fourth hypothesis in that higher speeds were negatively correlated with feelings of enjoyment once a threshold had been reached; the threshold speeds after which these negative correlations became significant, differed between the four road types.

Further experimental research which involved measures of actual driver behaviour was conducted by Lewis-Evans and Rothengatter (2009). The authors criticised Fuller's assumption that feelings of risk are monitored continuously, however only reach consciousness if a critical threshold is exceeded. In line with the Zero Risk Model they argued that feelings are by definition the conscious and subjective experience of an emotion, that drivers usually do not experience feelings of risk in their daily driving and only become aware of them when critical safety margins are violated. The authors posited that the process of continuous monitoring of a variable, be it feeling of risk or statistical risk of a collision, is implausible and criticised Fuller's (2009) (speculative) inclusion of Damasio's Somatic Marker Theory for its lack of clear integration with the contention of the Risk Allostasis Theory that drivers select a range of task difficulty and aim to operate within it. The authors argued that the Somatic Marker Theory implied that certain learned stimuli trigger, when encountered, an emotion that leads to feelings of risk and subsequent driver action, and as such fits better with a learnt threshold avoidance relationship as proposed in the Zero Risk Model or Threat Avoidance Model.

In their replication study, improvements to previous experimental research included the randomisation of speed conditions within the road environment to avoid order effects, the inclusion of two wordings for the question on the probability of a collision (including both, Fuller's and Kinnear's version) and the use of a driving simulator to obtain measures of actual driving behaviour, including a free drive condition where drivers should chose their preferred speed. To explore the effect of previous experience, the authors included a rating on how typical each speed was for the participant.

Research hypotheses were as follows:

1. Feelings of risk will be absent in low speed conditions and will only start to linearly increase with speed once a certain threshold is exceeded.
2. Feelings of effort (as a measure of mental workload) and comfort will be significantly related to task difficulty and feelings of risk.
3. Feelings of risk, task difficulty and effort when driving at the participants' preferred speed will be the same or lower than those associated with lower speeds; they will only start to increase for speeds above the drivers' preferred speed.

Forty-seven students participated in the simulator study with equal representation of males and females. Participants held their driving licences for approx. 2.5 years on average, indicating comparatively little driving experience. Road environments used in the study included a section of dual carriageway and a residential road environment, both without other road users present. The driving simulator used in the study was a STSoftware driving simulator with a 180 degree field of view in a car mock up with controls and occluded speedometer.

After a familiarisation drive in the simulator, participants completed an observation task and a driving task. In both tasks participants experienced nine speed conditions (in 10 kph increments) per road environment which were presented in randomised order. In the observation task, participants watched and subsequently rated drive replays. In the driving task, speed was set by cruise control, but participants steered the vehicle and subsequently rated the drive. In the observation condition, after the completion of the ratings per road environment, participants were asked to state their preferred and maximum driving speed at which they could still retain control over the vehicle for the environment. In the driving condition participants were asked after completion of all fixed speed drives to carry out one drive where they should select the speed they preferred to drive at in the road environment (using the same rating questions). Driving speed in the free drive was collected at 10 Hz.

Speed ranges for the dual carriageway were 80-160 kph and 20-100 kph for the residential road environment. The order of presentation of the road environments and tasks was counterbalanced between male and female participants. A questionnaire gathered demographic and driving-related information. Seven point Likert scales were used to collect participants' ratings of each speed condition with regards to:

- Task difficulty;
- Feeling of risk;
- Experienced comfort;
- Experienced effort.

Whilst task difficulty and comfort used a bipolar scale (feelings of comfort in reverse order to match the direction of feelings of difficulty, effort and risk), feelings of risk and effort were rated on uni-polar scales where a score of 1 equalled the absence of the variable being assessed (i.e. no risk, no effort). Additionally, participants were asked to identify after each speed condition, if they would never, seldom, sometimes, nearly always or typically always drive at the speed experienced on the road type shown.

To measure subjective risk, participants had to answer two questions, replicating both, Fuller et al.'s (2008) and Kinnear et al.'s (2008) operationalisation of subjective risk. The first asked for the likelihood of a loss of control if they drove the road shown at the speed shown every day for two month (i.e. 60 times); the second asked for the likelihood of the loss of control if a driver like the participant drove the road shown at the speed shown every day for two month (i.e. 60 times).

Rating data collected were used to create an average and a relational dataset. The average dataset included the mean ratings on all dependent variables for the observation task and the driving task (with exception of the free drive ratings). To create the relational data set, the average driving speed from the free drive condition was calculated for each participant (preferred speed). Subsequently the ratings from the fixed speed driving task that corresponded with the three fixed speeds lower and three fixed speeds higher than the average free drive speed were selected and arranged around the ratings associated with the free drive speed, e.g. resulting in the following order: Ratings for 30, 40, 50, 54 (mean free drive speed), 60, 70, 80 kph.

Both datasets were analysed using MANOVA, correlation and regression analysis. For the relative data set MANOVA showed a significant main effect for speed but not for road type. For the average dataset, MANOVA indicated significant three-way interactions between road type, task type and speed. Subsequent analysis for each subjective variable by road type and task showed significant main effects of road type only on ratings of comfort, ratings of loss of control for the drivers themselves and ratings of typical speed. In all these cases, residential roads were associated with higher ratings than the dual carriageway, indicating greater perceived effort and risk in the residential environment. Main effects of task type were found for task difficulty, feelings of risk, effort, comfort, loss of control for self and others, but not for habit. Significant differences were always in the direction of higher ratings for the observation task compared to the driving task. This is an interesting finding as it would suggest that even though participants have "more to do" in the driving condition, the (at least partial) engagement in the driving task (and, possibly, a greater feeling of control) leads to lower estimates of risk, difficulty and effort. In comparing reported preferred and maximum speeds and actually driven preferred speeds, the authors furthermore found inconsistencies between reported speeds and driven speeds. Whilst for almost all participants the reported preferred speed was lower than the reported maximum speed, the reported preferred speed did not necessarily match the driven preferred speed on both, residential roads and the dual carriageway: 43%/53% drove at a speed lower than both their reported preferred and maximum speed, 38%/23% drove at a speed higher than the reported preferred speed but lower than the maximum speed, and 13%/19% drove at a speed faster than both reported speeds. The remaining 6% had missing data. Again, this would suggest that ratings without actual engagement of the participant in the task lead to outcomes that do not necessarily reflect actual behaviour as well as ratings obtained for tasks that require the participant to act.

In line with previous research (e.g. Finn & Bragg, 1986; Harre & Sibley, 2007) that showed positive self-enhancement biases in drivers' estimates of their own driving skills, caution and collision involvement, subjective risk ratings for other drivers' likelihood of losing control were always higher than for the drivers' own.

In agreement with the first research hypothesis and in contrast to previous experimental findings, Lewis-Evans and Rothengatter (2009) observed that ratings of task difficulty, feeling of risk and subjective risk (of own or other's loss of control) did not linearly increase, but remained absent in slow speed conditions and only started to rise once a certain speed threshold had been exceeded (see Figure 3-9). Regression analysis confirmed the absence of a significant association between risk, difficulty and speed for the first three speed conditions in both task conditions and for both driving environments with the exception of subjective risk for self and other in the observation task on the dual carriageway. However, from the fourth speed condition onwards correlations between all dependent measures and speed became significant, with higher correlations between task difficulty and feeling of risk and speed, and lower correlations between subjective risk and speed in the driving task compared to the observation task. Differences between the four measures were more pronounced for the residential road environment than for the dual carriageway. Compared to the previous studies, the identified correlations between task difficulty and speed were smaller, ranging between r^2=0.21 (dual carriageway, observation task) and r^2=0.48 (residential road driving task).

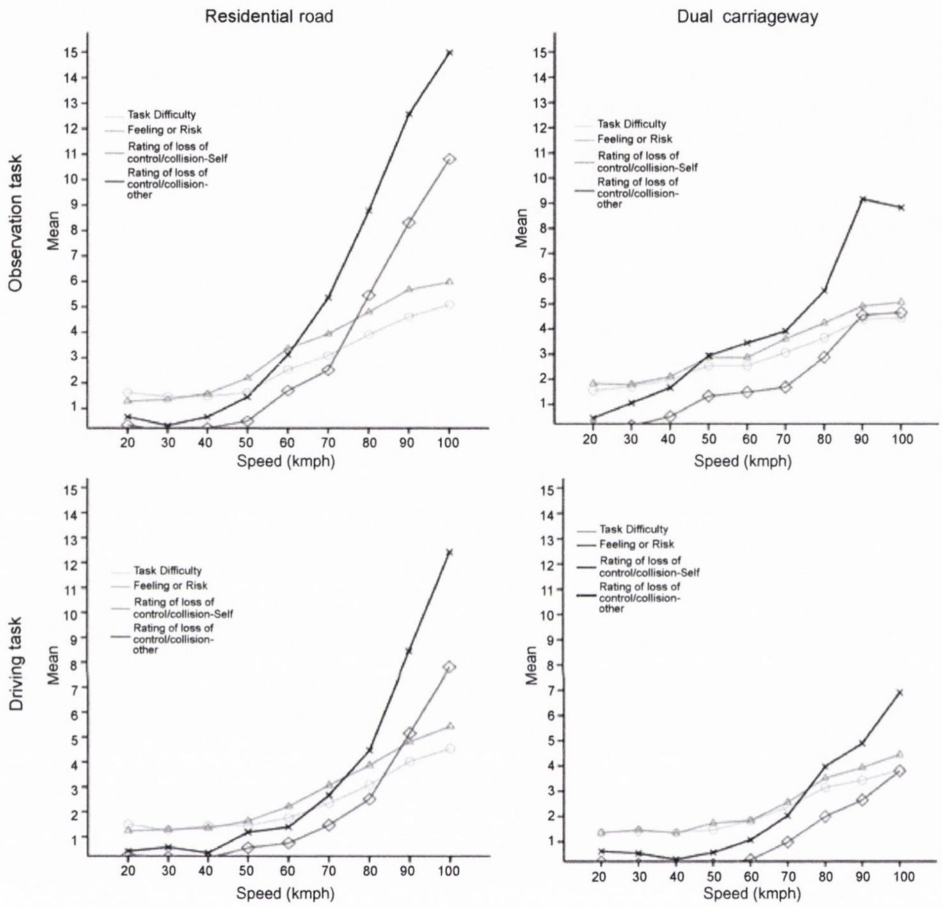

Figure 3-9: Average ratings of task difficulty, feeling of risk and loss of control in relation to increasing speed across both road and task types (Lewis-Evans & Rothengatter (2010), p. 1058).

In relation to the second research hypothesis, the authors found that ratings of effort, comfort and indications of typical speed on residential roads showed a U-shaped relationship with speed for both, the observation and the driving task; however, the U-shape was less marked for the driving task, where the downward trend for effort was not statistically significant. On the dual carriageway, the left side (at slow speeds) of U-shape for effort and comfort ratings was far less pronounced; from the fifth speed condition onwards, ratings for effort and comfort increased almost linearly with speed in both task conditions. Typical speed on the dual carriageway, however, followed a U-shape. Regression analysis found significant associations between all dependent variables for the upper half of the speed conditions in both tasks and in both road environments, ranging between r^2=0.15 in the driving task on the dual carriageway and r^2=0.44 in the observation task on the residential road. The strength of the association between dependent variables and speed was always greater on residential roads than for the dual carriageway. For the lower half of the speed conditions, correlations were significant only for the typicality of the drive in both, observation and driving task on the dual carriageway. On residential roads, correlations were significant for all dependent variables with the exception of effort in the driving task. However, the size of r^2 was much smaller, ranging between r^2=0.05 and r^2=0.32.

For the average rating data Pearson's correlations between task difficulty, feeling of risk and effort were high (r=0.81-0.91, p<.01) across both road types and tasks, confirming Fuller's posited relationship between task difficulty and feeling of risk. These variables were moderately to strongly correlated with comfort and loss of control (r=0.44-0.77, p<.01) and weakly to moderately correlated with subjective measures of risk (r=0.29-0.59, p<.01). Similar findings, although slightly lower, were found for the relative data set. The identified associations supported Lewis-Evans and Rothengatter's (2009) second research hypothesis.

To explore the third research hypothesis, the relative data set was used (see Figure 3-10) with zero on the x-axis marking the preferred speed in the free drive condition. The ratings of task difficulty, risk, effort and comfort stayed low until the preferred speed was reached and began to increase markedly after that point. However, probability estimates for others' loss of control increased before the preferred speed on both, residential roads and dual carriageway, whereas the estimates for the probability of one's own collision only increased after the preferred speed.

Regression analysis showed that above the preferred speed all dependent variables were significantly correlated with speed with r^2 ranging between r^2=0.04 for comfort on the dual carriageway and r^2=0.28 for the typicality of the speed on the residential road. In line with the previous study findings, the strength of all associations was greater on residential roads than on the dual carriageway. For speeds below the preferred speed, only feeling of risk in the residential road environment (r^2=0.07, p<0.01), typicality of the drive in both environments (residential road r^2= 0.19, p<0.001; dual carriageway r^2=0.07, p<.01) and comfort on the dual carriageway (r^2= 0.04, p<.05) were significantly associated with speed. Typicality of the drive followed a clear V-shape, with the lowest (most typical) rating being given for the preferred speed. The majority of the evidence supported the third research hypothesis.

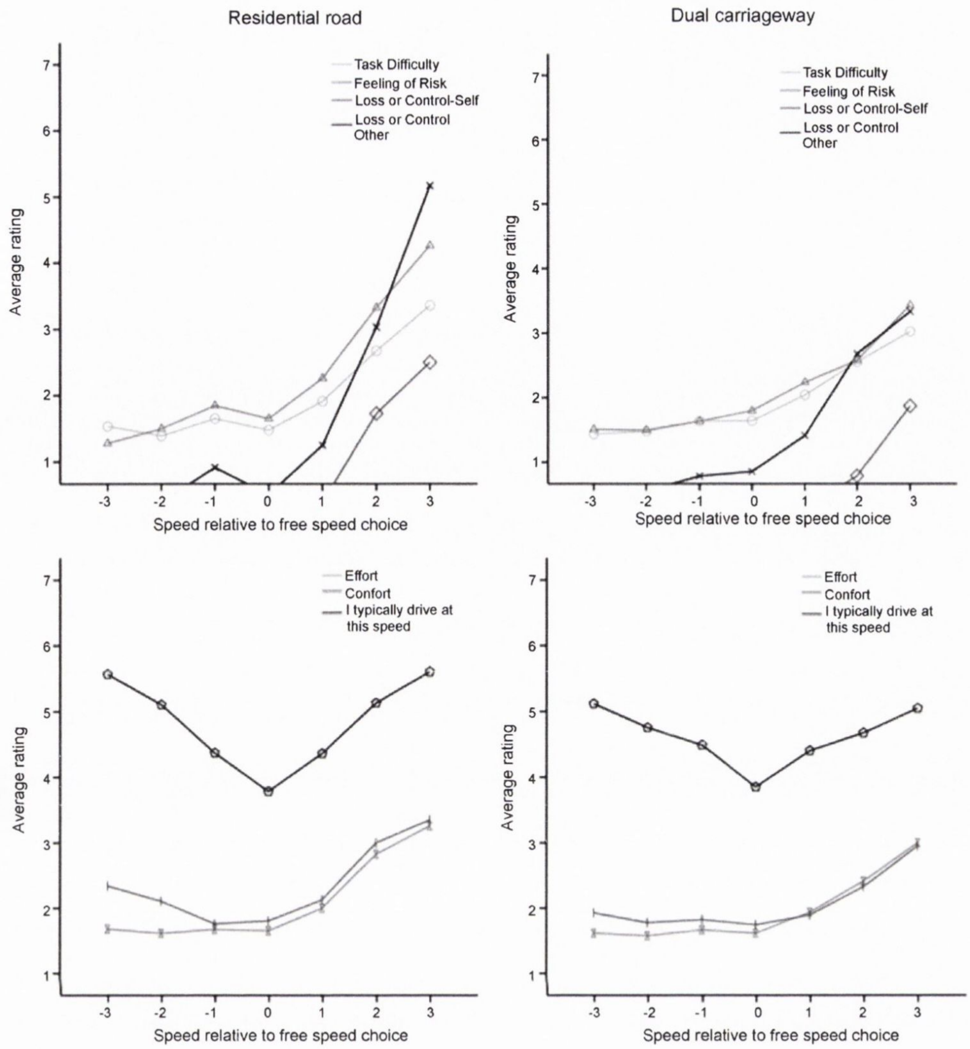

Figure 3-10: Relative ratings of task difficulty, risk, loss of control, effort, comfort and "I typically drive at this speed" across both road types. On the x-axis, a relative speed of 0 corresponds to the average rating participants gave for the free speed condition; the negative numbers refer to the three fixed speeds lower than, the three positive numbers to the three fixe speeds higher than the average free speed (Lewis-Evans & Rothengatter (2010), p. 1059).

Based on the findings the authors concluded that contrary to Fuller's prediction of a linear increase of feelings of risk with speed, a threshold model, whereby feelings of risk and task difficulty only start to increase when a certain speed threshold has been exceeded, fitted the data better. Based on the comparatively lower regression coefficients for task difficulty and feeling of risk and speed they also suggested that the increase in feelings of risk and task difficulty, once the threshold was exceeded, was less steep than previously posited. The authors argued that feeling of risk ratings for low speeds were very low (between ratings of 1 and 2), suggesting that drivers typically drove in the absence of a feeling of risk, and that feelings of risk ratings only started to increase after the preferred speed had been passed (with the exception of residential roads where feelings of risk were significant correlations prior to the preferred speed were found). The authors questioned how participants can aim for and select a certain feeling of risk range, if their ratings at the preferred speed do not significantly differ from the ratings they give for lower speeds. This is the central question on the determining variable of driving behaviour, and it is noteworthy that neither of the variables additionally investigated by Lewis-Evans and Rothengatter (2009), including effort or comfort, can act as the determining variable, as they follow a similar threshold model, possibly with the exception of comfort on the residential road, which follows a more U-shaped distribution. Thus, the authors did not put forward an alternative variable that could act as the key variable which dictates driver behaviour. On the basis of the study's results, the variable that would best underpin the selection of the preferred speed, is the typicality of the speed, which for both environments presents a V-shape and where preferred speed is rated as most typical. The pronounced dip for this variable is, however, a somewhat artificial result, as one would expect that a driver, when instructed to drive at his preferred speed, would also rate this as his most typical speed.

Given that none of the variables apart from the typicality of the drive can explain why drivers pick their preferred speed, above which all dependent variables start to increase, it remains unclear what the determinant of driver behaviour should be according to Lewis-Evans and Rothengatter (2009). The authors suggest that in line with the workload literature, optimal levels of effort are characterised by the absence of (or very low) measurable effort and suggest that their findings may in this respect support Summala's Safety Margin Model (2005). They subsequently draw attention to the fact that speeds above the preferred speed condition were associated with marked increases in all dependent variables. This is interpreted as support for the assumption that the perception of these increases may act as warnings to the driver, causing them to reduce their speed (as posited by the Zero-Risk Model).

The authors conclude that their findings support a threshold model for perceived task difficulty, feeling of risk, subjective risk, effort and comfort and suggest that experience of risk acts as a warning to drivers and only becomes salient, once certain conditions have been met. They suggest that the data are in line with the assumptions of the Zero-Risk Model, the Threat Avoidance Model and the Safety Margin Model.

This contention raises several questions. The assumption that above-threshold feelings trigger a warning to the driver would require drivers to exceed the threshold in the first place. This would mean that within the free speed condition, drivers would need to initially accelerate to the point where feelings of task difficulty, risk and effort approached the threshold and become salient; they would subsequently have to drop slightly below that speed and maintain the achieved preferred speed for the rest of the drive. However, if warning feelings in the free drive condition were at least briefly activated, we would expect this to become manifest in the ratings associated with the preferred speed condition. The absence of increases in ratings for the preferred speed condition suggests that this is not the case. This would imply that drivers need to be able to anticipate the onset of such feelings for speeds above their preferred speed based on some previous internal learning mechanism. If the assumption of such an anticipation mechanism is accepted, some trigger variable is still necessary to kick-off the process. In a simulated road environment, where the only safety margins to be maintained (e.g. driving lane width or approach of a curve in the road) are comparatively generous and no other road users are present, the violations of safety margins as proposed by the Zero Risk Theory seems unlikely.

Unfortunately, Lewis-Evans and Rothengatter (2009) also say nothing about the process of calculating the average speed of the preferred drive or indeed fixed speed conditions. For instance, it is unclear whether the process of acceleration to preferred or fixed target speed is or is not included in the speed calculation. If it is, an assumption would have to be made that acceleration periods for both conditions needed to be the same to allow the comparisons of the speeds. For example, if cruise control accelerated more quickly to the target speed in the fixed speed condition than the driver in the free drive condition, this would lead to an underestimation of the average preferred speed in relation to the fixed speed and would result in a shift of the data of the relational data set which may impact the findings.

3.8 Where does that leave us theoretically and methodologically?

Whilst the Task-Capability Interface Model and the Zero Risk Model have been subject to a number of recent empirical studies, the evidence remains somewhat inconclusive. The main areas of agreement as well as the main areas of continuing debate are summarised in the following.

The significant association between task difficulty and speed as posited by the Risk Allostasis Theory has been confirmed in three research studies, even though the strength of the association is subject to considerable variation and only emerged in Lewis-Evans and Rothengatter's (2009) study, once a critical speed threshold had been reached. Whilst Fuller et al. (2008) found speed to explain approx. 98% of task difficulty in all three road environments tested, Kinnear et al. (2008) found a weaker relationship, particularly for country roads. Lewis-Evans and Rothengatter (2009) only found significant associations between task difficulty and speed for the upper half of the speed condition with task difficulty explaining between 21% (dual carriageway, observation task) and 48% (residential road, driving task) of the variance in speed.

Risk perception as a function of age

The available evidence supports the notion that feeling of risk tracks ratings of task difficulty rather than subjective risk. Whilst Fuller et al. (2008) and Lewis-Evans and Rothengatter (2009) found highly significant correlation coefficients of approximately r=0.8, Kinnear et al. (2008) reported slightly weaker correlations between task difficulty and feelings of risk at lower speeds and similarly high correlations at higher speeds; a finding which the authors attributed to the narrowing of participants' safety margins at higher speeds. All three studies agree that feelings of risk track task difficulty more closely than subjective risk. Whilst the association *per se* is supported, there is still controversy whether feeling of risk increases linearly with speed and task difficulty (as posited by the Risk Allostasis Model) or only after a certain threshold has been reached (as proposed by the Zero-Risk Theory). Lewis-Evans and Rothengatter's (2009) results point towards the existence of a threshold model whilst linear increases in feelings of risk were observed in Fuller's and Kinnear's studies. This means that the debate of whether feelings of risk are continuously monitored, even if this happens unconsciously, or whether they only get activated, and are subsequently consciously monitored, when task difficulty has reached a certain threshold and safety margins are reduced, continues.

Estimates of the likelihood of a collision or subjective risk follow a threshold model in Fuller et al. (2008) and Lewis-Evans and Rothengatter (2009), whereas Kinnear et al. (2008) observed linear increases from the slowest speed condition onwards. Because of their inclusion of one's own and others' risk of loss of control, Lewis-Evans and Rothengatter (2009) were able to directly compare how the two ratings differed. They reported that estimates for other driver's risk of collision were reliably greater, a finding that fits well with the literature on positive self-bias (see Section 3.9.2 for a full discussion). The findings reported by Lewis-Evans and Rothengatter (2009) also suggest that subjective risk starts to exceed zero not at the preferred speed but one or two speed conditions later; this was also reported by Fuller et al. (2008), however on the basis of a verbally reported preferred speed rather than a driven one. This would suggest that the probability of losing control does not impact preferred driving behaviour and that drivers prefer driving in the absence of risk. This finding is compatible with the theoretical positions of Threat Avoidance, Zero Risk and Risk Allostasis, but not Wilde's Risk Homeostasis Theory.

Differences in findings emerging for the different road environments have not been discussed in previous work. Residential road environments brought out the strongest patterns between the dependent variables, whereas dual carriageways were associated with less clear-cut results. Whilst it is intuitive that dual carriageways with their broader driving lanes, lower curvature and central reservation should be associated with lower task demand, a systematic investigation of the applicability of Fuller' conceptualisation, i.e. how the elements of the road environment might impact the driver's perception of task demand and any changes on the dependent variables associated with greater task demand is outstanding.

Variables additional to those used in Fuller's original research were introduced by Kinnear et al. (2008) and Lewis-Evans and Rothengatter (2009), including enjoyment, effort and comfort. Whilst the distribution of the enjoyment ratings for slow and medium speeds varied, significant negative correlations emerged between enjoyment and speed and enjoyment and task difficulty for the upper third of the speed conditions, suggesting that enjoyment decreased as task difficulty increased. For effort and comfort, Lewis-Evans and Rothengatter (2009) found U-shaped distributions in the observation task, but less clear-cut right halves of both distributions in the driving task. For both variables, significant increases were observed once the preferred speed was exceeded. With regard to the search of a variable that can be continuously monitored to inform driving decisions, both, enjoyment and comfort suffer from similar problems as feeling of risk. Their theoretical integration into the model, whilst attempted, particularly by Lewis-Evans and Rothengatter (2009), remains unclear.

With Lewis-Evans and Rothengatter's (2009) use of driving simulation, the direct comparison of ratings derived from the mere observation of a drive and those derived from a driving part task (steering at fixed driving speeds) are possible. The findings suggest higher ratings on all dependent variables under all conditions in the observation task compared to the driving task. It seems plausible that any engagement in the driving task should improve the accuracy of the ratings. Whilst it may not always be possible to employ a simulator for a research study, the fact that the profiles of the ratings distributions are similar, reassures us that apart from accepting an artificial inflation of the ratings, the pattern of the findings remains similar.

All motivational models of driver behaviour, including Wilde's, Summala's and Fuller's posit the strong influence of driver motivation on driver decision making, yet experimental research on the impact of motivational variables in the driving context has been comparatively sparse. A driving simulator study by Jackson and Blackman (1994) tested aspects of Wilde's Risk Homeostasis Theory by measuring the impact of motivational (collision cost) and non-motivational factors (speed limit, speeding fine) on participants' target risk. Hoyes, Dorn, Desmond and Taylor (1996) found evidence in a driving simulator study that the concept of utility was not necessary in the process of behavioural adaptation to changes in intrinsic risk. Näätänen and Summala (1974; 1976) report findings from a dart-throwing experiment that aimed to test the inhibitory effect of subjective risk on subsequent behaviour. In the study participants had to throw darts to achieve a daily score over a period of 2.5 weeks. Different areas of the dart board were associated with different scores with one penalty area which, when hit, required the participant to repeat the approximately one hour trial. The experiment therefore allowed participants to either make safe progress or to achieve the required score quicker by adopting a riskier throwing style. According to the authors, participants started with throwing low to medium scores, but gradually started to take greater risks until a hit in the penalty areas and associated punishment and reported subjective risk led them to return to less risky throwing strategies. However, this corrective effect was found not to last very long. Whilst the authors compared the findings to similar adaptation processes in driving, this process has not been tested in the driving context.

Some evidence on inter-individual differences in driver motivation comes from questionnaire based driver typologies, as for example in Musselwhite's (2006) study, that clustered survey respondents into four distinct groups, including calculated risk takers, unintentional risk takers, continuous risk takers and reactive risk takers, based on their motivations and attitudes to risk. Whilst it can be argued that the investigation of the influence of effort motivation and other motivational factors may not lend itself easily to laboratory-based experimentation, no attempts have been made to date to explore the feasibility of including driver motivation as a variable. Whilst Kinnear et al. (2008) and Lewis-Evans and Rothengatter (2009) asked for maximum speed before losing control, the way the question was phrased was not apt to provide a "motivational scenario" but rather a skill-based assessment of the driver of his car control. Overall, it is surprising that the motivation component of motivational models has been subject to comparatively little experimental research.

Most importantly in relation to the interest of this thesis, none of the models or the empirical work relating to them has explored age-effects. Whilst demographic factors, including age, are mentioned in all models that were reviewed, only the Task-Capability-Interface Model spells out, how age as a variable influences the posited relations, i.e. through its influence on driver capability. The Model therefore provides the most useful theoretical framework for the subsequent exploration of age effects on the perception of risk. However, the Risk Allostasis Theory does not make it clear how the age-related deteriorations in cognitive, perceptual and motor components on the one hand and increasing driving experience on the other hand may interact with each other in their impact on feelings of risk, perceptions of task difficulty and perceptions of subjective risk. This makes the development of testable hypotheses about age and its impact on driver decision making-difficult.

Independent from theoretical models of driver behaviour, a considerable body of research has investigated how age impacts the perception of one's one capability as a driver and of risk associated with driving. The following section provides a brief overview of the literature with regard to age-related changes in driving capability and risk perception and relates them to the Risk Allostasis Model with the aim of formulating testable hypotheses for a subsequent empirical study.

3.9 Age-related changes in self-awareness and risk perception

As already outlined in Chapter 1.4, the driving patterns of older drivers differ from those displayed by younger age groups. Older people drive fewer miles, because of the end of the working career, changes in lifestyle and, possibly, because of the recognition of decreased driving performance (Ball et al., 1998; Lyman McGwin & Sims, 2001; Rimmo & Hakamies-Blomqvist, 2002; Rosenbloom, 2001). Compensatory adjustments of older drivers in response to changed cognitive, sensory and motor capacities are subsumed under the term self-regulation, a subject which has attracted considerable research interest over recent years because of the aging of societies in Western industrialised nations. Self-regulation thereby comprises the compensatory reduction of driving as well as the strategic avoidance of particular driving situations, which is assumed to take place in response to a loss of function (Charlton et al., 2006).

A number of studies have explored older drivers' self-regulation and the question, whether or to what extent older drivers are aware of age-related deteriorations and adjust their driving accordingly. Such studies have investigated older drivers' confidence and self-rated abilities in relation to a number of given driving situations that are assumed to present a particular challenge to the older driver. Justifications for the selection of such situations and for their appraisal as difficult are usually not provided. Some situations, especially driving at night or in the rain are discussed in the context of age-related visual impairments (e.g. Ball et al., 1998). Others, for which no specific explanations are articulated, map well onto collision patterns of older drivers. Situations described as difficult for the older driver typically include driving at night, in bad weather, dense traffic, merging, changing lanes, turning, motorway driving and negotiation of intersections. Because of the considerable similarity of the situations used in the different studies, they are not reported separately for each study in the following text. Studies of this kind either investigate differences in self-reported ratings of confidence, avoidance or driving ability between different driver age groups, drivers with different health status and other demographic characteristics, or they relate these ratings to the performance in on-road driving tests. For this review, only studies targeting healthy older drivers rather than particular clinical groups, such as older drivers suffering from dementia, were of interest.

A related body of research, mainly influenced by the observation of higher collision rates in young drivers, has focussed on the question how accurately drivers perceive risk and whether there are systematic biases that affect risk perception and, consequently, driving decisions. Here, the interest is to identify how different demographic groups (e.g. in terms of age, experience or sex) assess subjective risk (usually defined as the perceived probability of being involved in a collision) and own capability as a driver. Risk and capability estimates in these studies are typically provided for the self in relation to same-aged peers and to other (younger or older) age groups. Risk estimates either refer to the risk associated with specific driving situations or to the general collision risk of different population subgroups. Whilst some of these studies explicitly assert an interest in the older driver's perception of collision risk, most of them include age as one of several demographic variables.

Findings from both lines of research are briefly summarised in the following and are subsequently synthesised and related to Fuller's Theory of Risk Allostasis.

3.9.1 Awareness of age-related deterioration of driving abilities and compensatory changes in driving behaviour

The importance ascribed to studies that explore self-regulation in the older driver is based on the premise that older drivers' willingness to undergo interventions aimed at maintaining their safe mobility depends on their ability to recognise age-related deteriorations and to adjust accordingly their own ratings of and confidence in their driving ability (Marottoli & Richardson, 1998). Marottoli and Richardson (1998) differentiate between 'confidence' which they describe as a belief in one's ability and 'awareness' which constitutes one's ability to perceive one's own limitations. In terms of a behavioural outcome, both, lack of confidence and lack of awareness should ultimately lead drivers to adjust their driving patterns.

Using telephone interviews with 901 American drivers aged 65 years and older Lyman, McGwin and Sims (2001) identified significant associations between medical conditions, functional, cognitive and visual deteriorations and reduced and restricted driving. Rimmo and Hakamies-Blomqvist (2002) reported from a mail survey with a stratified sample of 939 Swedish drivers aged between 52 and 92 years that those drivers with self-reported impaired health were more likely to reduce their exposure and to avoid potentially difficulty driving situations.

Holland and Rabbitt (1992) examined how changes in subjectively perceived and objectively measured sensory efficiency affected older drivers' perceptions of their own driving safety, and whether the self-reported compensatory changes in driving were reflected in self-reported collision rates. The study included 54 current drivers in their 50's, 60's and 70's who completed a questionnaire on self-reported vision and hearing abilities, avoidance of potentially difficult driving situations and their collision rates over the previous three year period. Subsequently vision (visual acuity, visual angle) and hearing tests (pure tone audiometer) were carried out and results fed back to the participants. After two months, a second questionnaire measured whether drivers had made any changes to their driving on the basis of the feedback they had received. Analyses of variance identified significant age differences in vision and hearing tests that indicated deteriorated visual and aural performance for older drivers. However, self-ratings of visual and aural capacity did not differ significantly with age, the latter because drivers uniformly perceived their hearing to be fairly bad. The authors found that participants who reported having difficulties seeing in the dark or at dusk were more likely to say they avoided driving in the dark (r=0.43, p<.005). Older drivers who reported having difficulties seeing in bright light or glare were more likely to say that they avoided driving in the dark or at dusk (r=0.47, p<.001; r=0.51, p<.001). The authors found evidence for a link between compensatory behaviour and collision involvement in that those drivers who reported avoiding more of the six potentially difficult driving situations included in the questionnaire were significantly less likely to have been involved in a collision in the last three years (r=-0.26, p<.05). In response to the feedback received on the vision and hearing test, 36 of the 59 participants reported to have made changes to their driving patterns. Holland and Rabbitt (1992) concluded that drivers aged 60 and older displayed a lack of awareness with regards to the age-related changes in visual abilities. Given that the majority of drivers reported sensible changes to their driving patterns in response to the feedback received on sensory deteriorations, the authors suggested that self-initiated compensatory behaviour could contribute to a considerable degree to the safety of elderly drivers.

Ball et al. (1998) conducted a similar study with a larger sample of American drivers to explore the relationship between functional limitations, avoidance and collision risk. The study used a stratified sample of 257 participants, aged 55 years and older who had been involved in 0, 1-3 or 4 or more collisions over the past five years. Visual assessment comprised measures of contrast sensitivity, visual acuity, visual field sensitivity and eye health examination, whereas the cognitive assessment included a dedicated test for cognitive status in the elderly and the Useful Field Of View (UFOV) test with subtests for processing speed, divided attention and selective attention. Information on driving habits, including exposure and avoidance was gathered via questionnaire, and data on drivers' collision involvement over the previous five years was obtained from state records. Correlations between visual and cognitive deficits and driving avoidance indicated that drivers with visual and/or cognitive impairment or eye health problems more frequently avoided driving and generally drove less. Relationships between cognitive status and avoidance were weaker than those between visual function and avoidance. Subjects were grouped depending on whether or not they had vision impairment types and impaired versus non-impaired UFOV. Multiple analyses of variance to identify whether the patterns of reported avoidance differed significantly across groups indicated that all groups reported a similar level of avoidance for night-time driving. For all other situations different avoidance patterns emerged, indicating that drivers with greater impairment particularly avoided driving in rush hour, heavy traffic, driving in the rain and motorway driving. The authors concluded that older drivers avoid driving in situations where rapid or unexpected events occur in a visually cluttered environment, often under conditions of reduced visibility and suggested this to be a safety strategy typical of the older driver population in general. Correlations were calculated between avoidance items and history of collisions and showed significant correlations with driving in the rain ($r=0.20$, $p=0.002$), making left turns ($r=0.18$, $p=0.004$), and driving in rush hour ($r=0.15$, $p=0.018$), indicating that those who had a history of collisions avoided these situations significantly more. Corroborating Holland and Rabbitt's (1992) earlier results Ball et al. (1998) concluded that a firm link exists between visual and attentional impairments and avoidance of driving in potentially challenging situations. They interpreted the fact that drivers with cognitive impairments reported less avoidance of driving situations than those with visual impairments as evidence that cognitively impaired older drivers under-report driving problems, possibly because they fail to recognise the impairment and to adjust for it accordingly. Based on the current data, it was not possible for Ball et al. (1998) to ascertain if self-regulation effectively reduced collision risk.

Charlton et al. (2006) conducted telephone interviews with 265 Australian drivers aged 55 years and older to explore associations between health status and functional ability. Forty percent of participants reported that their driving speed was slower now than compared to five years ago, even though 80% of participants felt that the quality of their driving was the same as it had been then. Confidence levels for potentially difficult driving situations was generally very high with lowest confidence ratings being given to driving at night in the rain (44% very confident in this situation). Drivers aged 75 years and older were less likely than younger drivers to be very confident in the majority of driving situations, except at intersections with no traffic control, making right-hand turns at fully controlled traffic signals and when changing lanes. Approximately one quarter of the sample reported avoiding specific traffic situations; this most frequently included driving at night (25%), on wet nights (26%) because of vision problems and driving in busy traffic (22%) for reasons of personal preference and comfort. Only 10% of drivers reported avoiding intersections. Chi-Square tests found confidence and avoidance of difficult driving situations to be strongly associated, indicating that drivers tended to avoid situations in which they did not feel confident. Overall health and vision condition were significantly associated with the avoidance of driving at night and in the rain.

Logistic regressions with drivers who self-regulated (avoided difficult driving situations) versus those who did not as the criterion, identified sex (females more likely to self-regulate than males), age (drivers over 75 more likely to self-regulate than younger drivers), previous collision involvement (those with a recent collision were more likely to self-regulate), vision condition (those with impaired vision were more likely to self-regulate) and confidence (those with high confidence were less likely to self-regulate) as significant predictors. Drivers who were very confident in all eight driving situations included were four times less likely to be self-regulators.

In an interview study with 125 healthy American drivers aged 72 years and older participants, Marottoli and Richardson (1998) asked participants to provide confidence ratings on ten potentially difficult driving situations as well as information about their driving patterns, avoidance of driving situations, five year history of adverse driving events such as collisions and five point ratings of their own driving ability in comparison to same aged peers. A subset of 35 participants also underwent a 50 minute on-road driving test with an occupational therapist who scored the driving performance on a 35 item scale and provided an overall assessment of the drive based on the error score obtained by the participant. The analysis focussed on the relationship between confidence and self-rated ability, and their relationship with driving patterns, adverse driving events and performance in the on-road test. Using Pearson correlations and Chi square statistics, Marottoli and Richardson (1998) found that confidence and self-rated driving abilities were significantly associated with each other, however, showed no significant relationship with adverse driving events, sex, age or performance in the on-road test. The nine subjects who had failed the driving test rated their ability at least as good as that of their peers, even though seven of them also had a history of adverse driving events. The authors concluded that objective evidence of driving ability did not appear to impact drivers' confidence or self-ratings of ability. Based on the findings, they suggested that drivers that displayed a discrepancy between self-perception of ability and actual driving performance would benefit from measures increasing their awareness and supporting their adjustment of driving practices.

Baldock et al. (2006) assessed self-regulatory behaviour and driving performance in a study with 104 healthy current drivers aged between 60 and 92 years. Reported confidence and avoidance of difficult driving situations, as well as self-rated self-efficacy in avoiding difficult driving situations, was gathered. Ninety of the 104 survey respondents subsequently completed a 40-minute on-road test on a set test route in the presence of an occupational therapist and a driving instructor. Performance on the test was scored using high weightings for driving errors that required the driving instructor to intervene, medium weightings for hazardous errors and low weightings for habitual errors. The findings showed that the reported confidence and regulatory self-efficacy in the group was high, whereas the reported avoidance of driving situations was low. Parallel parking and driving at night in the rain were reported to be the most frequently avoided driving situations. Negative correlations of medium to high size were found between confidence ratings and avoidance scores. Fourteen of the ninety participants failed the on-road driving test. The correlations between overall test score and overall avoidance score were low and not significant; however, correlations between overall test score and avoidance of specific driving situations such as driving in the rain (r=.33, p<.01), driving at night (r=.34, p<0.1) and driving at night in the rain (r=.35, p<.01) were significant. Based on the finding that on-road driving ability was not significantly correlated with overall driving avoidance, Baldock et al. (2006) concluded that older drivers do not appropriately self-regulate their driving and suggest that this phenomenon is not exclusive to very old drivers or drivers suffering from medical conditions as suggested by previous research.

Whilst the strategy of self-regulation has thus far been regarded as a characteristic of aging drivers, there is a small number of studies that have investigated the onset of self-regulatory behaviour or how wide-spread self-regulatory behaviour is in drivers aged 18 years and older. Naumann, Dellinger and Kresnow (2011) conducted a nation-wide, cross-sectional telephone survey with 8126 current drivers in the US and used multivariate logistic regression to identify associations between specific restrictions and age groups. More than half of all drivers (53.5%) reported at least one driving self-restriction. The most commonly reported restriction across all respondents was avoidance of driving in bad weather (47.5%), followed by at night (27.9%) and on highways or high-speed roads (19%). In addition to assessing self-restrictions among older drivers, the study showed that self-regulatory behaviours were also quite prevalent among younger age groups. Twenty-five percent of drivers between the ages of 18-24 reported avoidance of driving at night, 50% reported avoidance of driving in bad weather, and nearly 20% reported avoiding driving on highways or high-speed roads. For older drivers, the proportion of drivers who reported avoidance of the three situations increased with age:

- from 46% for the 65-74 year olds to 56% for the 75+ year olds for driving at night
- from 52% for the 65-74 year olds to 59% for the 75+ year olds for driving in bad weather
- from 28% for the 65-74 year olds to 33% for the 75+ year olds for driving on highways or high speed roads.

The findings suggested U-shaped distributions of avoidance behaviour across the lifespan with increase for older drivers from age 55 onwards. Reasons for older drivers according to the authors included driving confidence, cognitive functioning, physical impairments, and vision problems, with visual decline being the most frequently reported physical problem responsible for reducing driving in the previous year (25% of respondents). Young drivers, according to Naumann et al. (2011), are more likely to be physically and cognitively healthier, and the reasons for observed driving restrictions in this group are likely to be life-style related (e.g. still living with parents).

Higher self-regulation scores in young and older drivers compared to middle-aged drivers were also found by Gwyther and Holland (2012) in a UK study with 395 current drivers. Based on their findings the authors suggested that self-regulatory behaviour was present across the driving lifespan and occurred not merely as a result aging, but was driven by driving anxiety and negative affective attitudes.

A French study by Moták, Gabaude, Bougeant and Huet (2014) explored the connection between perceived and objective functional decline and self-regulatory behaviour with a convenience sample of 26 young (26-35 years) and 91 older (65-85 years) drivers. The researchers gathered ratings of the perceived quality of physical and mental health (100mm visual analogue scale) as well as scores on the Mini Mental State Examination (MMSE) and the Digit Symbol Substitution Test (DSST) as measures of cognitive impairment and processing speed. Additionally, participants rated their avoidance of ten driving situations, and bivariate Pearson's correlations between self-declared avoidance and age, driving experience, cognitive function, mental health and physical health were calculated to identify differences between the age groups. An interaction between age and situation was predicted whereby some of the situations would attract greater avoidance ratings from older drivers.

A significant age effect emerged with older drivers reporting greater avoidance of all ten situations than the younger drivers; however, effect sizes were small. There were also more significant correlations between self-reported driving avoidance and both, health-related perceptions and objective indicators of cognitive function among older drivers, suggesting that self-regulation is a strategy that is typical of this group. Results also showed that for older drivers, but not for younger drivers, self-declared avoidance was correlated with age, driving experience, mental health, physical health, MMSE and DSST. Of the ten situations, driving at night, at night in the rain, long distances, in the rain, during rush hour and on highways were correlated more positively with age in the older driver group than in the young driver group: the older the drivers in the over 65 group, the more they reported avoiding these specific situations; in the under 35 group, older participants reported less avoidance. Contrary to expectation, no significant interaction for age and situation emerged, which the authors attributed to the considerable inter-individual variability in the participants' avoidance ratings.

Results of a regression analysis found age, driving experience, self-declared physical and mental health, MMSE and DSST scores together explained 17% of self-declared avoidance (adjusted $R^2 = .17$, $F(6,83) = 4.00$, $p<.001$), with age explaining 10% ($F(1,89) = 10.91$, $p = .001$) and self-declared mental health explaining 7% ($F(1,89) = 7.92$, $p<.01$).

Whist the authors suggested that age-related avoidance patterns may stem from differences in risk appraisal they also noted that eyesight problems may lead older drivers to avoid situations such as night-time driving or driving in the rain more than young drivers. However, they point out eye-sight related differences in self-regulation between young and older drivers have not been the subject of studies to date.

Summary

The review of studies exploring non-clinical age-related deteriorations and self-regulation indicates that older drivers indeed undertake compensatory adjustments of their driving behaviour and that there is good support for an association between health deteriorations, especially of the visual system, and related reductions of exposure generally, and avoidance of potentially difficult driving situations particularly. However, studies that have investigated self-regulatory behaviour indicate that self-regulation is not exclusive to older drivers, but is reported by sizeable proportions of young and middle-aged drivers as well. Naumann et al. (2011) suggest a U-shaped distribution of avoidance across the life span, with gradually accelerating increases from age 55 onwards. The authors conclude that *"Driving self-restrictions may be better understood as a spectrum across ages in which drivers' reasons for restriction change."* (p. 67) and suggest that whilst avoidance in older drivers is underpinned by an increasing experience of functional deteriorations, in particular in relation to vision, young drivers' avoidance may be more influenced by lifestyle factors. As Moták et al. (2014) point out, inter-individual differences in self-reported avoidance are considerable.

Significant correlations between confidence in and avoidance of potentially difficult driving situations suggest that drivers tend to avoid situations where their confidence is low. Confidence levels, however, possibly with the exception of Ball et al.'s (1998) study, were generally high in the samples under scrutiny, suggesting that in most driving situations older drivers do not display any lack of confidence in their driving abilities. It is noteworthy that all studies in this review consistently identified driving at night, in the rain or generally under conditions where age-related impairments of the visual system were particularly relevant, as situations that attracted the highest avoidance scores.

Complex traffic situations that should be particularly challenging for older drivers on the basis of their collision patterns such as turns at uncontrolled junctions, roundabouts etc. did not seem to attract equally high avoidance ratings. This begs the question whether older drivers accurately perceive driving situations that present a particular challenge to them. Holland (1993) suggests that whilst older drivers are generally aware of their elevated risk as road users, they may be unaware of the actual sources of the risk; in one of her studies, driving situations that driving instructors described as particularly problematic for older drivers were not perceived to be challenging by the older drivers themselves. Holland (1993) therefore proposed that the inaccuracy of risk perception in specific situations may be an important factor in elderly driving safety and may limit the potential benefit of compensatory adjustments.

The direct comparison between self-rated and objectively assessed visual and aural capacities in Holland and Rabbitt's (1992) study produced further evidence of a discrepancy between subjectively perceived and objective levels of functioning which the authors attributed to the gradual nature of the changes in sensory capacities as well as age-related changes in the drivers' reference systems (increasing social isolation of older people with age leads to a narrower reference group against which the person will compare). Ball et al. (1998), who had additionally included objective assessments of the cognitive status of older drivers, reported that drivers with cognitive impairment reported less avoidance than those with visual impairment. Marottoli and Richardson (1998) and Baldock et al. (2006) who concentrated on the link between confidence, avoidance and driving performance as measured by on-road driving tests and previous collision involvement found no significant links between perceptions of own ability and driving performance. The findings overall suggest that whilst older drivers do display self-regulating behaviour, they may lack sensitivity towards age-related deteriorations and towards driving situations where such deterioration may put them at particular risk of a collision. An interesting contribution in relation to this point was made by Siren and Kjær (2011) who conducted four focus groups with healthy, older drivers aged 64-84. Exploring the construct of "older drivers" and of "risk" in a content analysis of the focus group material, the authors found that when describing changes to their own driving, older drivers reported behaviours that one would typically interpret as self-regulation or compensation; however, participants themselves interpreted such modifications as reflections of good driving skills and consideration rather than the expression of experiencing problems in traffic due to deteriorated skills or abilities. Adoption of a defensive driving style, compensating for other road users' mistakes, choosing lower speeds were described as mechanisms to control risk in traffic which was perceived to be predominantly caused by external circumstances. Only when focus group participants construed older drivers as others, modifications were interpreted as compensation and a reflection of the deterioration of skills and problems in driving. Siren and Kjær's (2011) study may help to explain Charlton et al.'s (2006) findings that 40% of survey participants reported to have slowed down their driving speed within the last five years, even though 80% of participants felt that the quality of their driving was the same as it had been then. It would suggest that healthy older adults may maintain a certain biased view towards their capability as drivers, which supports the continuation of their driving careers and thus contributes to overall wellbeing. However, this lack of sensitivity may also prevent older drivers from taking appropriate compensatory action in specific situations where the risk of a collision is high. Holland and Rabbitt's (1992) study which found older drivers willing to make adjustments to their driving patterns in response to feedback on driving capability, suggests that providing information about specific situations in which age-related deteriorations may put older drivers at a higher risk of a collision and about specific compensation actions could make a useful contribution to maintaining the safe mobility of this driver group.

3.9.2 Systematic biases in risk perception and driving skills

A separate body of research has dealt with biases of drivers' perception of personal risk and driving skills and the question, how risk estimates may systematically differ as a result of age or driving experience. Risk in this literature is thereby described as *'the ratio between some measure of adverse consequences of events and some measures of exposure to conditions under which those consequences are possible'* (Brown & Groeger, 1988, p. 586). The authors state that the risk concept differs from that of mere probability since it emphasises the harmfulness of the consequences in question. 'Hazard' and 'danger' are described as different from risk as they are not a ratio, but characteristics of objects and events. This clarification of terms also explains why the substantial body of literature on hazard perception is not considered here. Rather than drivers' ability to identify and react to distinct stimuli in the road environment that may develop the potential to cause harm, the focus of the current work is how drivers of different age groups may differ in their judgements of the risk arising from the exposure to different driving situations.

Several authors have argued that subjective risk estimates rather than the 'objective risk', as monitored statistically by road traffic authorities, affect the decision making of individual road users (Brown & Groeger, 1988; Grayson, Maycock, Groeger, Hammond & Field, 2003), given that objective risk is a population based post-hoc measure, whereas subjective risk represents individuals' predictions of the likelihood of adverse future events (Siren & Kjær, 2011). Accordingly, the majority of studies in this research literature have explored drivers' perceived risk of being involved in a collision in a specific traffic situation, and usually in comparison to a reference group[9] (such as same age peers or the 'average' driver). Only a few studies have measured absolute bias by assessing the accuracy of drivers' estimates of population collision rates (and thus, participants' awareness of road safety trends). Risk estimate studies are also surrounded by some controversy as it has been argued generally that people do not have the required sensitivity to low probability events (e.g.; McKenna, 1988; Rothman, Klein & Weinstein, 1996), and more specifically that collision risk does not affect drivers' decisions as individual risk is too small to be of significance (Rumar, 1988; Groeger & Brown, 1989).

Studies in this domain have rarely linked ratings of risk and capability to measures of actual driver performance[10]. Differences also exist with regards to the nature of the estimates: whilst some studies have collected general subjective risk estimates, others gathered perceived risk estimates associated with specific driving situations. As the focus of this work is on drivers' perception of risk in specific traffic situations, the emphasis in the reporting and interpretation of the findings will be on situation-specific risk estimates rather than estimates of road safety trends.

By and large, systematic biases in road collision risk perception and driving skill have been discussed predominantly in relation to younger drivers' over-representation in collision statistics. Several authors have proposed that acceptance and misperception of traffic risk may lead to false feelings of security and the adoption of (involuntary) riskier driving behaviour, as drivers can only take steps to protect themselves from the harmful consequences of collisions if they perceive the risks they face (Brown & Groeger, 1988; DeJoy, 1989; Kuiken & Twisk, 2001; Siren & Hakamies-Blomqvist, 2004). One study was also identified that explicitly investigated self-bias in older drivers (Holland, 1993). One of the early studies compared American and Swedish (n_{total}= 161) students' perception of their own skill and safety (Sevnson, 1981). Participants rated both qualities in comparison to other people in a test room. The results showed that participants strongly believed to be safer and more skilful than the average driver.

A similar, cross-cultural comparison of self-perception as a driver including German, American and Spanish drivers was conducted by Sivak, Soler and Tränkle (1989b). Sixty participants in each country, aged 18-21, 35-45 and 65-75 completed a 14-item questionnaire which included 5-point semantic scales to describe themselves as drivers and to describe themselves as drivers in comparison to the average driver in their

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[9] Rothman, Klein & Weinstein (1996) refer to this as 'relative bias'.

[10] Matthews & Moran (1986) correlated self-ratings to previous accident involvement. A series of cross cultural studies Sivak, Soler et al. (1989a, b, c) collected information on self-assessment, assessment of risk of traffic situations and risk acceptance in a simulated driving task, but did not link the findings from these different studies.

country. The assessment dimensions included being predictable, safe, relaxed, wise, considerate and responsible. Analyses of variance indicated significant age effects for 12 of the 14 items. Of all three age groups, the oldest drivers rated themselves most positively as drivers, both, when making absolute judgements about themselves and when judging themselves in comparison to the average driver in their country. Because of the difference in driving experience, the authors attempted controlling for the influence of experience, which led, because of its high correlation with age, to the disappearance of most effects, indicating that a differentiation between both factors is neither sensible nor possible.

In a related study which additionally included a sample of 60 Brazilian participants of the same age groups, Sivak, Soler, Tränkle and Spagnhol (1989) compared participants' risk ratings of 100 still pictures of traffic situations on a 7-point scale (1=minimum risk to 7= high likelihood of an accident). Traffic scenes had been selected from a pool of 500 situations and had been coded on 23 dichotomous characteristics including, amongst others, road environment, weather, illumination and traffic density. Each slide was presented for 20 seconds, and for half of the slides, participants received additional information on the driven speeds in the traffic scene (20, 40 or 55 mph). Regression analyses used the 23 scene characteristics as predictors with risk ratings as dependent variables. Additionally, beta weights were used as dependent variables in analyses of variance to evaluate main effects for the different participant groups. The findings indicated that older drivers rated the risk of the traffic scenes on average higher than young or middle aged drivers. The scene characteristics that contributed significantly to the differential risk ratings of participant age groups included speed and road surface friction. Older drivers were more sensitive to high speeds than young and middle aged drivers, but less sensitive to road friction than both younger driver groups. In a third study on a simulated gap acceptance task displayed on a computer screen with the same sample Sivak, Soler and Tränkle (1989a) showed that older drivers (aged 65-75 years) attempted intersection crossings significantly less frequently than younger drivers and kept greater safety margins when crossing than younger drivers.

Comparing estimates of predicted collision risk, Finn and Brag (1986) found that young male drivers (aged 18-24 years) judged their risk of being involved in a collision in the following year as significantly lower than that of same aged peers, while older male drivers (aged 38-50 years) judged their risk of collision involvement as comparable to other male drivers their age. Both, young and older drivers recognised the elevated collision risk of young drivers as a group. Risk estimates for ten specific driving situations (presented in still pictures) suggested that young drivers perceived their own risk of a collision as lower than that of their peers and as lower than older drivers' risk in five out of ten situations. Older drivers also perceived their risk of a collision as lower than that of their peers (however, only in 3 out of 10 situations) and as considerably lower than that of younger drivers. Ratings of risk for video-based driving situations suggested that young drivers rated those situations which they did not perceive to be skill-controlled as riskier. The authors proposed that the discrepancy between perceived risk for the self and the risk perceived for the peer group in younger drivers could explain younger drivers' greater risk taking as they would correctly perceive their age groups elevated risk, but not acknowledge it as something applying to themselves.

Similar findings emerged from a comprehensive study on self-assessment of driving performance and risk perception. Here Matthews and Moran (1986) collected 46 current drivers' (aged 18-24 or 35-50) estimates of (1) predicted collision risk, (2) questionnaire-based ratings of driving performance, and (3) likelihood of a collision and confidence ratings of driving skills for twelve video-based driving situations for the self, for same aged peers and for the other age reference group. Young drivers estimated their own collision risk as comparable to those of middle-aged drivers, but as much lower than that of same age peers. In comparison, middle-aged drivers rated their collision risk as comparable to same age peers, but as considerably lower than that of younger drivers. With regards to driving skills as measured by the questionnaire, younger drivers rated their ability, including vehicle handling and driving judgement as comparable to middle-aged drivers' but as better than that of other male drivers their age. Driving reflexes formed an exception with younger drivers rating them to be similar to those of peers but higher than those of middle-aged drivers. Middle-aged drivers rated their ability, including vehicle handling and driving judgement as similar to that of other male drivers their age but better than that of younger drivers. Their driving reflexes were judged by middle-aged drivers to be similar to those of young drivers, but better than those of same age peers.

The results for risk ratings and confidence ratings in response to for the video-based driving situations that addressed vehicle handling skills, driving reflexes and driving judgement are summarised in Table 3-1. As a group, middle-aged drivers tended to rate risk more highly than younger drivers, but confidence in their driving abilities as similar to that of younger drivers. Biases in the perception of self, expressed in lower risk ratings and higher confidence ratings compared to same age peers were clearly prevalent for younger and, less so, for middle-aged drivers. Judging risk and confidence in relation to the other age group, older drivers consistently rated younger drivers to have a higher risk and were less confident in their abilities. Unsurprisingly, risk ratings and confidence ratings in all video-based driving situations were strongly negatively correlated.

Previous collision involvement was found to significantly correlate with predicted collision risk (r=.73) for the next year only in older drivers. For middle-aged drivers, previous collision involvement was also significantly related to overall driving ability (r=-.61) and confidence in vehicle handling ability (r=-.49). Predicted collision involvement also correlated with overall driving ability (r=-.69) only for middle-aged drivers, suggesting that the drivers interpreted the experience of collision as indicators of sub-standard driving abilities. This finding of a significant and strong association between previous collision involvement and self-rated ability, however, is in contrast with other studies on older drivers, which have found no such association between collision history and self-rated driving abilities (e.g. Marattoli & Richardson, 1998). Self-rated driving ability as measured by questionnaire and risk ratings obtained in the video sequences was not correlated for middle-aged drivers, but showed significant negative correlations for younger drivers.

Table 3-1: Patterns of significant findings for risk and confidence ratings for three categories of driving situations (s=self, p=peer, y=younger, o=older).

	Risk		Confidence	
	Younger	Older	Younger	Older
Vehicle handling skills	 S<P S=O	> S<P S<Y	 S>P	= S>P S>Y
Driving reflexes	 S<P	>	 S>P S>O	< S>P S=Y
Driving judgement	 S<P	= S<P S<Y	 S>P S=O	= S>P S>Y

Matthews and Moran (1986) suggested that younger drivers' awareness of the generally elevated collision risk of young drivers on the one hand but lower risk ratings in specific driving situations on the other might be due to the fact that the two estimates were based on two different sources of information. They proposed that risk estimates in specific situations would be influenced by the personal history of exposure and responses to hazardous situations, that is, the drivers' degree of confidence in their own ability to handle the specific demands of the situation. General risk estimates on the other hand would be predominantly derived from sources that provide information on collision statistics such as newspapers, particularly in the case of younger drivers, where actual experience of situations was limited. The authors also attributed the finding of greater confidence ratings of middle-aged drivers compared to their peers in the video-based study as opposed to the questionnaire data on general driving performance to their greater reliance on implicit knowledge and beliefs of their driving capabilities rather than on externally derived information about their age group in general. This interpretation would suggest that research studies exploring individual drivers' perception of risk or capability should use specific driving situations in which participants will draw on their personal driving experience. Matthews and Moran (1986) suggested that in situations where drivers felt in control, the perceived risk was low whilst in situations where control was low (e.g. because of the driving behaviour of others), the perceived risks were high and thus, belief and confidence in one's capabilities and skills influenced the level of personal risk perceived while driving.

Whilst the previous studies had focused on younger drivers, Holland (1993) investigated if positive self-bias still played a significant role in older drivers' assessments of collision risk, including driving and non-driving accidents. Using a questionnaire survey with 80 healthy drivers over 50 years of age she explored if positive self-bias decreased as a function of age, experience and locus of control. Drivers rated the likelihood of having an accident where they were themselves responsible compared to where someone else was responsible on scales ranging from -5 (less likely) to +5 (more likely). Reference age groups that participants were asked to compare themselves to were 30, 50 and 70 year olds. For driving accidents, participants clearly expected older drivers (70 year olds) to have the highest accident likelihoods. Seventy year olds themselves, however, believed that 30 year old were most likely to have an accident. Participants' estimates of accident likelihoods were fairly accurate when reflecting the overall age group; however, subjects thought themselves to be least likely to have an accident when comparing themselves to the average 70 year old driver, indicating that self-bias was still prevalent in older drivers. When comparing situations where the participant was in control with those where someone else was driving, self-bias in older participants was much reduced compared to younger participants. This was particularly the case if the comparisons with the youngest age group (30 year olds) were taken out. Holland (1993) therefore concluded that the amount of self-bias depends on the type of situation under examination and on the comparison group used. The comparison of controllable and uncontrollable driving situations furthermore indicated that a decline in confidence in one's own abilities occurred for uncontrollable driving situations in the oldest age groups. Seventy year olds felt more at risk when driving themselves in such situations than when someone else was driving, indicating a negative self-bias under such circumstances. The positive self-bias, however, remained even in these situations if older drivers were only compared to same age peers. Holland (1993) concluded that positive self-bias is still prevalent in older drivers, though to a lesser extent than in younger drivers and that this finding might explain why older drivers may not recognise a risk to themselves in some driving situations, even though they might be able to accurately judge the risks of these situations for same age peers.

Rothman, Klein and Weinstein (1996) described two experiments to differentiate between relative bias, namely participants' risk estimates in comparison to same age peers and absolute bias, that is, the degree of bias in relation to the actual risk level for the population. Risk estimates were obtained for a variety of hazards, including illness, road collisions and life changing events. In the first study 282 students had to rate the probability of one of 14 hazards (1-100%) affecting themselves or a college student of the same age. Additionally, they had to rate their own susceptibility to the hazard after having been provided with information of the actual risk level for same age college students. The findings indicated that participants generally overestimated small risks and underestimated large risks. It furthermore showed that self-bias in comparison to same age peers was due to participants' overestimation of same age peers' risk rather than due to underestimation the risk for themselves. The second experiment explored if participants would adjust their risk assessments to maintain their optimism bias in relation to same age peers if they received risk statistics for the average college student that were 50, 100 or 150% of the true values. The findings showed that whilst participants generally aimed to maintain their "below-average" status, risk estimates decreased less than the provided risk statistics. Whilst participants were found to be overoptimistic in the 150% of the true value condition, participants' estimates were actually pessimistic in the 50% condition. Based on the findings, the authors suggested that whilst participants adjusted their own risk estimates reactively to provided risk information, they did not use such information as an anchor for their own risk estimate and may not treat information on the risk levels of the average other as relevant to themselves. They furthermore suggested that in addition to magnitude estimates, participants' perceptions of vulnerability may also be affected by other dimensions of hazards, such as vividness, affective quality and the frequency with which they are reminded of their vulnerability.

Summary

The studies reviewed in this chapter demonstrate ample evidence for the existence of self-bias in young drivers with regards to perceived collision susceptibility. Risk estimates for the self in comparison to same age peers or the average driver consistently show participants' tendency to provide lower risk estimates for themselves than for same age peers. Rothman, Klein and Weinstein's (1996) findings thereby suggest that self-bias is more likely to be due to an overestimation of risk for peers rather than due to an underestimation of risk for the self. For middle-aged drivers findings of self-bias in relation to same age peers are less frequent. Finn and Brag (1986), for example, found self-bias in drivers aged between 38 and 50 years to be prevalent in a smaller number of driving situations. Matthews and Moran (1986) found that 35-50 year old drivers rated their collision risk overall as comparable to same age peers. Holland (1993) found evidence for the existing of self-bias in older drivers over 50 years of age when comparing to a same aged peer, but suggested that self-bias was considerably reduced in comparison to younger age groups and depended to a large degree on the situation under assessment. Comparisons of collision risk between age groups suggest that young drivers tend to rate their risk as comparable to that of middle aged drivers, whereas middle-aged drivers consider their collision risk as significantly lower than that of young drivers (Finn & Bragg, 1986; Matthews & Moran, 1986). Holland (1993) suggested that collision likelihood estimates were fairly accurate when reflecting the overall age group.

Comparing absolute levels of perceived risk in traffic situations, Sivak et al. (1989) found that older drivers (65-75 year olds) rated risk in traffic scenes as higher than young and middle aged drivers did, whereby their sensitivity for speed was higher, but sensitivity to road friction was lower than in both younger age groups. Matthews & Moran (1986) reported similar findings for middle-aged drivers who rated risk more highly than younger drivers.

Fewer studies of self-bias have investigated self-rated driving skill, and findings are somewhat more equivocal. Self-bias has been demonstrated in student populations (Svenson, 1981). Sivak et al. (1989b), using young, middle-aged and older drivers, found self-bias to be particularly prevalent in older drivers. Ratings of ability as a driver were indeed highest in the oldest driver group (65-75 years), including absolute judgements and comparisons to the average driver in the country. It has to be noted that the ability components considered in the study emphasised experience, such as predictability, safety and responsibility, and may therefore have been more appealing to older drivers as dimensions of self-description. Matthews and Moran (1986) who asked for ratings of vehicle handling skills, driving reflexes and driving judgement found that middle-aged drivers judged their skill levels of vehicle handling and driving judgement to be comparable to their peers but higher than younger drivers. Only for driving reflexes, something one would typically associate with youth, middle-aged drivers rated themselves as comparable to younger drivers.

3.10 Synthesis of findings and generation of hypotheses

How can the literature on self-regulation and age differences in the perception of risk be related to the reviewed driver behaviour models? In the field of self-regulation performance dimensions that also appear in the theoretical conceptualisation of the driving task include self-rated confidence and general or specific capability aspects such as visual or cognitive ability assessments. For example, Rimmo and Hakamies-Blomqvist (2002) propose that self-regulation and, ultimately, driving cessation could be linked to Fuller's Threat Avoidance Model or Summala's Zero Risk Model, if the experience of deteriorating health or of age-related driving errors are interpreted as anticipatory avoidance stimuli that lead to experiences of discomfort or fear and, thus, to changes in driving patterns. Fuller himself suggests that drivers' perceived capability, which is a function of estimates of competence and sensitivity to the effects of human factor variables, is, in addition to journey goals and effort motivation, one of the determinants of the upper threshold of the target range of arousal or feeling of risk drivers seek to maintain. Phrased in the terms of the Risk Allostasis Model, the self-regulation literature therefore asks:

- In how far drivers are aware of the effects of age-related deteriorations (the human factors part of the model) on their driving capability;
- What compensatory change to task demand (their driving patterns) they make to account for reduced capability; and
- How successful these changes may be in maintaining driver safety.

It also should be borne in mind that compensatory changes to driving patterns and avoidance of certain situations may lead to reduced exposure to and practice with these situations and may exacerbate the erosion of driver capability.

The studies reviewed in Section 3.9.1 suggest that relationships exist between reported avoidance of and confidence in certain driving situations and measures of visual, cognitive and driving performance. Older drivers frequently report avoiding situations, where particularly visual impairments could put them at risk, suggesting that they may be aware of reduced driver capability as a consequence of age-related deteriorations. However, findings reported by Charlton et al. (2006) and Siren and Kjær (2011) suggest that the avoidance of certain driving situations does not necessarily reflect awareness of functional deficits, but may express simple preferences, may be sought for reasons of increased driving comfort or to control external risks in traffic arising from the behaviour of other road users. Certain traffic situations that present a particular challenge to older drivers, such as intersections, were comparatively rarely reported to be avoided. Furthermore, associations between performance in driving tests and drivers' confidence or self-ratings of ability have been shown to be at best low (Marottoli & Richardson, 1998; Baldock et al., 2006). It remains therefore unclear, as Siren and Kjær (2011) aptly point out, to what extent observed self-regulatory behaviour is indeed linked to active compensation or merely reflects preference and greater choice over the circumstances of the drive. Both formulisations are compatible with Fuller's Risk Allostasis Theory, as it merely posits that drivers will select a range of acceptable task difficulty based on their perceived capability, effort motivation and speed motivation at the time.

Whilst the Risk Allostasis Theory described the nature of the driving task as essentially self-paced, it is worth considering that collisions involving older drivers often occur in complex situations, in which the driving task is not self-paced and where the potential to manipulate the task demand is restricted. If the assumption is made that older drivers cannot increase driver capability *ad libitum*, i.e. through effort motivation, and despite the strategic avoidance of some driving situations, cannot wholly avoid exposure to driving situations where self-pacing is not possible, higher feelings of risk would have to be tolerated and the occurrence of certain collision types would almost be an inevitable consequence of older drivers' movements in traffic. Whilst the findings of comparatively higher instances of "nervousness/ panic" found in the analysis of contributory factors of older driver collisions identified in Section 0 could points in this direction, one would expect older drivers to also rate these situations as more difficult or to avoid them; this, however, is evidently not the case.

The literature on risk estimates reviewed in Section 3.9.2 uses concepts that can be related to the Risk Allostasis Theory such as drivers' estimates of collision risk and self-assessment of driving skills in different driving situations. Fuller refers to drivers' estimates of collision risk as "subjective risk" in his Risk Allostasis Theory and to self-assessment of driving skills as "perceived capability". With the original interest of the literature stemming from the young driver problem, the literature on risk estimates has predominantly investigated how driver capability is influenced by the cumulative effects of driving experience rather than the effect of age.

It is important to consider the role of subjective risk in the Task Capability Interface Model in more detail at this point. A main assertion of the model is that peoples' estimates of collisions when driving are zero and that *it is the feeling of risk* associated with the difficulty of the driving task that determines the way we drive. Several studies testing the contentions of the Task Capability Interface or the Zero Risk Model indeed suggest that estimates of the probability of a collision are of limited use in determining risk when driving (Fuller, McHugh & Pender, 2008; Lewis-Evans & Rothengatter, 2009; Kinnear, Stradling & McVey, 2008), a result that maps well onto the finding that people lack sensitivity to low probability events in general risk estimate studies (Slovic, Finucane, Peters & MacGregor, 2003; McKenna, 1988; Rothman, Klein & Weinstein, 1996). Assuming that drivers have no motivation for a collision, the range of feeling of risk drivers target should always include a task difficulty interval that is below the point where task demand can reasonable be assumed to exceed driver capabilities (see Figure 3-11). In the terms of the Risk Allostasis Theory, research investigating collision risk estimates associated with certain driving situations therefore ask participants to report on their upper task difficulty limit, where the demands of the driving task start to exceed driver capability. According to Fuller, this area of the task difficulty range will rarely be voluntary explored (even though he has discussed the potential influence of individual differences in this context) and thus doesn't characterise normal driving behaviour. However, despite Fuller's (and Summala's) assertion that collision risk rarely enters drivers' minds as a decision making factor, it is noteworthy that participants willingly produce such estimates without apparent difficulty. In the terms of the Risk Allostasis Theory, the literature on self-bias in drivers' assessment of risk asks how different driver groups assess the task difficulty arising from task demand characteristics and own perceived capability. Given that these studies have usually used middle-aged drivers rather than older drivers, perceived capability variations have predominantly been explored in relation to different experience levels rather than differences deriving from age-related deterioration of actual capability.

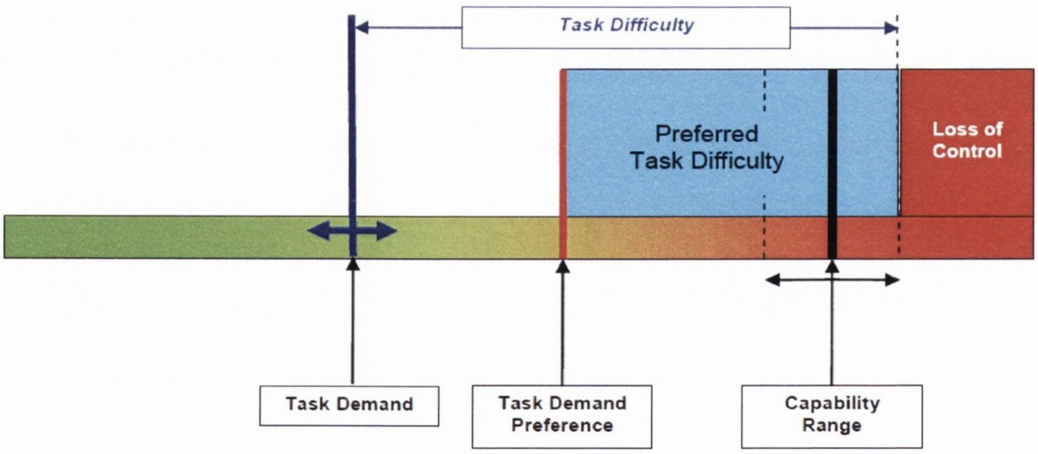

Figure 3-11: The association between task demand, driver capability, and task difficulty in Task-Capability Interface model (Fuller, 2005); adapted from Kinnear (2009), p. 63).

The following overview develops testable hypotheses from the literatures reviewed previously.

Studies exploring age-related differences in risk perception/ driving skill and self-bias have shown that self-bias in middle-aged and older drivers is less pronounced than in younger drivers (Holland, 1993; Matthews & Moran, 1986; Finn & Bragg, 1986). Whilst positive self-bias in young drivers has been interpreted as evidence for an overestimation of skills in younger drivers (as for example suggested by Svenson, 1981), alternative explanations are possible and have indeed been put forward. Groeger and Brown (1989) propose that self-bias may result from the expectations of other road users. Equally likely seems the explanation that it is an artefact of the task (a social comparison). As Sjöberg (2000) points out, risk perception is all about thoughts, beliefs and constructs, and is therefore not so much part of the cognitive domain but part of social psychology. Considering the literature on the importance of additional motives in young drivers (Näätänen & Summala, 1976), it seems reasonable to assume that a young driver's comparison to same age peers may be more heavily influenced by social factors than that of an older driver. The only one study that investigated absolute rather than relative bias (Rothman, Klein & Weinstein, 1996) did not explore age as a factor. It is therefore difficult to speculate about the absolute accuracy of risk estimates of different driver age groups.

Comparing absolute levels of perceived risk in traffic situations (Sivak et al., 1989) found that older drivers (65-75 year olds) rated risk in traffic scenes as higher than young and middle aged drivers did, whereby their sensitivity for speed was higher, but sensitivity to road friction was lower than in both younger age groups. Matthews and Moran (1986) reported that middle-aged drivers rated risk in traffic situations higher than younger drivers, particularly in driving situations, where sudden hazards emerged that could not be controlled by skill, compared to situations, where vehicle control skills played a role. Matthews and Moran (1986) explained this difference with more experienced drivers' longer learning history of probabilities and controllability of certain traffic events.

The same argument of longer learning histories of probabilities, albeit in the opposite direction, has been used by Kinnear et al. (2008) to account for their findings of lower collision risk ratings in experienced drivers compared to inexperienced drivers. The thrust of their argument was that the longer learning histories of experienced drivers should lead them to conclude that instances of high task difficulty relatively rarely lead to the occurrence of actual collisions. A possible explanation for the contradictory findings may be the content of the video scenes presented by Kinnear et al. (2008), which emphasised the manipulation of speed and did not include other sources of risk as Matthews and Moran's (1986) study did. This may have led the experienced drivers to rate the perceived risk as low. Further research is required to systematically investigate this question. In terms of general, non-situation specific, estimates of collision risk, the literature converges in that experienced driver's collision likelihood estimates are lower than those of inexperienced drivers.

Risk perception as a function of age

Fewer studies in the perception of risk literature have investigated self-rated driving skill. In the present theoretical context, absolute ratings rather than relative ratings are of greater interest. Sivak et al. (1989b), using young, middle-aged and older drivers found that ratings of ability as a driver were highest in the oldest driver group (65-75 years), including absolute judgements and comparisons to the average driver in the country. It is interesting that ability components considered in the study were those that emphasised experience, such as predictability, safety and responsibility and may therefore have been more appealing to older drivers as dimensions of self-description. Matthews and Moran (1986) who asked for ratings of vehicle handling skills, driving reflexes and driving judgement found that middle-aged drivers judged their skill levels of vehicle handling and driving judgement to be higher than younger drivers. Only for driving reflexes, something one would typically associate with youth, middle-aged drivers rated themselves as comparable to younger drivers. These findings suggest that drivers perceive increases in driver capability due to the accumulation of experience.

Relating the findings on age effects in risk perception and self-regulations to the predictions of the Risk Allostasis Theory helps to formulate testable predictions and research questions for subsequent studies. Based on the review of these literatures, the following predictions are made:

- Older drivers will report higher risk ratings of traffic scenes than young and middle-aged drivers;
- Older drivers' ratings of their own capability will be as high as those of younger age groups;
- Older drivers will rate driving situations, including driving in bad weather and driving in the darkness, as more difficult than younger age groups.

4 Study 2: Testing Fuller's Task-Capability Model in the context of aging

4.1 Introduction

As outlined in Section 3.5, Fuller's Task Capability Interface Model proposes that individuals establish and maintain a range of task difficulty they find comfortable, based on their capability as drivers, their motivation for the particular journey (and thus in the effort they will be willing to exert) and the goals of the journey in question. The driver's capability is determined by physiological characteristics, which are subject to age-related deteriorations, for example, information processing capacity, particularly executive function and processing speed (McKnight & McKnight, 1999; Daigneault, Joly, Frigon, 2002) as well as reaction time (Quimby & Watts, 1981; Horswill et al., 2008; Anstey, Horswill, Wood & Hatherly, 2012; Reed, Kinnear & Weaver, 2012). It is also influenced by knowledge and skills, which are a result of training and experience, and by more transient influences such as fatigue or distraction. Together, these factors create the driver's capability range. The second study of the thesis investigated several open questions in relation to Fuller's Task Capability Interface Model and its associated Theory of Risk Allostasis (Fuller, 2009). Whilst some methodological issues in relation to previous experimental work on the model have already been discussed in Section 3.8, a more detailed critique of the methods employed is provided below.

4.2 Critique of previous work

This thesis asserts a specific interest in the impact of age on driving-related processes and decision-making. The fact that age is heavily confounded with experience presents a challenge to research. Age and experience are included in all driver behaviour models reviewed in Chapter 3 as factors that influence driving, but none of the models has presented testable predictions about the trade-offs between age and experience or about the point where posited age-related deteriorations in perceptual and cognitive processes start to outweigh the proposed beneficial impact of greater driving experience (e.g. superior internal models of the traffic environment, more anticipatory driving style). Two empirical studies of Fuller's Task Capability Interface Model (Fuller et al., 2008) and Lewis-Evans and Rothengatter (2009) have not explored the impact of age or experience and have used only young student populations with comparatively little driving experience. To investigate the impact of age, the inclusion of a significantly older driver group, where age-related deteriorations of cognitive and perceptual capability have occurred as part of the healthy aging process, is necessary.

Only Kinnear et al. (2008) included experience as an independent variable in their work (participants were up to 62 years old) and found that whilst ratings of task difficulty did not differ between inexperienced and experienced drivers, experienced drivers' subjective risk ratings were significantly lower than those reported by inexperienced drivers. The authors attributed the findings to experienced drivers' better understanding of the contingencies in traffic, based on longer learning histories. In their video-study covering 12 different scenarios, Matthews and Moran (1986) found the opposite result, whereby more experienced drivers rated the collision risk to be higher than less experienced drivers did. It seems plausible that the different findings may be attributed to differences in the content of the traffic scenes, which solely focused on speed manipulations in Kinnear et al.'s (2008) work and comprised a greater range of situations in Matthews and Moran's (1986) work. To shed light on the apparent contradiction and the variables that drivers take into account when rating task difficulty, the introduction and systematic variation of additional task demand components in addition to the usual manipulation of speed is necessary. Neither of the previous studies testing the model has explored the impact of the presence of other road users on dependent variables. For Fuller et al. (2008) and Kinnear et al. (2008), this may have arisen from the necessity to digitally alter video-recorded material (i.e. speed could be easily manipulated through the speeding of the presentation but the addition of other road users would have required the videos to have been reshot), but probably more importantly from the fact that the Task Capability Interface Model asserts speed as the main manipulator of task difficulty. Lewis-Evans and Rothengatter (2009) could have included other road users in the simulator but did not, possibly, to reduce the complexity of the experimental design. Given that occasions, where we drive in different road environments without any other road users present, are comparatively rare, studies exclusively based on such situations lack ecological validity and artificially limit task difficulty to arising from (almost[11]) a single source.

Driving scenes in the studies of Fuller et al. (2008) and Kinnear et al. (2008) were presented as short video clips. To produce several speed conditions of the same scene, the filmed video sequences were digitally speeded up to show the same road scene at different driving speeds. Lewis-Evans and Rothengatter (2009) used a driving simulator, arguing that this would provide an ecologically more valid environment compared to the video-based approach. However, they conceded that the environmental complexity of the simulator compared to video sequences of real roads may be reduced and may

[11] The features of different road environments will act as a second source of task difficulty; however, whilst all studies testing Fuller's Risk Allostasis Model have used a variety of road environments, none of them have discussed explicitly how this may impact participants' ratings.

possibly leave out important cues from the actual road environment. "Organically produced" speeds in a simulator instead of artificially accelerated ones in the video, plus the availability of important cues, such as kinetic feedback during acceleration and engine sound should result in a more realistic feel to the drive in a simulator. Furthermore, Lewis-Evans and Rothengatter's (2009) inclusion of an observation and a driving task in the simulator allows the direct comparison of the ratings in the more engaged driving task with those obtained in the observation only condition. Significant differences emerged, with drivers reporting lower ratings on the dependent variables in the driving task, arguably, because of the less abstract nature of the ratings and participants' ability to draw additional information from their behavioural engagement with the task. Given that according to the Task Capability Interface Model task difficulty arises from the integration of task demand and driver capability, drivers' merely abstract representation of driver capability in the video study is probably detrimental to the effective integration of both variables, thus somewhat biasing the ratings. This assumption receives further support from Lewis-Evans and Charlton (2006) who observed that in their simulator study on the perception of changes in road width, drivers' experience of risk arose from their implicit experience of the simulated road environment rather than from external factors. On the basis of these findings, the use of a driving simulator for a replication study appears preferable over the use of video material. However, as a central component of the Task Capability Interface Model and its testing in this second study is the manipulation and perception of speed (as a determining component of task difficulty), the prerequisite for the use of a simulator is the exclusion of any unsystematic biases of speed perception in the simulator compared to real road environments.

Previous studies (Fuller et al., 2008; Kinnear et al., 2008) have required participants to specify their preferred or maximum driving speed in different road environments, illustrated by still pictures of these environments. Only Lewis-Evans and Rothengatter (2009) obtained behavioural measures of drivers' preferred speed in addition to self-reported preferred and maximum speed (see Section 3.7). The comparison of the self-report measures with actual driven speed suggests that self-report measures of speeds correspond poorly with actual driving speeds and should be replaced by measures of actual driving behaviour wherever possible.

In Kinnear et al. (2008) several variables that could influence driver's risk ratings and preferred range of task difficulty were included in the questionnaire administered at the end of the trial. Furthermore, participants were asked to provide ratings of enjoyment after each video sequence. Lewis-Evans and Rothengatter (2009) gathered effort and comfort ratings in addition to ratings of feelings of risk and task difficulty to explore how the different variables related to each other and speed. The inclusion of additional rating dimensions in the current study is indicated by the literature review of risk perception as a function of age and the findings from the analysis of contributory factors presented in Section 0: a lack of confidence and nervousness about driving emerged as potential influences on driving for the oldest driver group. Thus, additional rating dimensions were included in the current study.

4.3 The present study

Whilst the debate, whether task difficulty and feeling are continuously monitored variables or follow a threshold model, is still on-going, the present study's focus was to advance research on aspects of the model that had not yet been tested and to systematically investigate the impact of age on risk perception (including young, middle-aged and older drivers). Age and experience are typically and intricately confounded, therefore, a complete differentiation between the effects of the two variables is difficult. If experience (and motivation/ journey goals) were held constant, the deterioration of cognitive and perceptual processes that is inevitably related to aging should result in decreased levels of capability in a driver. The Risk Allostasis Theory would predict that if task demand was kept constant, drivers with a lower level of capability, but equal experience should experience higher levels of task difficulty. They should consequently target a preference range of task difficulty that is lower than that of drivers with higher capability. Given that everyday driving is characterised by considerable safety margins, age-related reductions in capability are likely to only become manifest in situations of high task demand. The intention of the current study was therefore to explore age differences particularly at the higher end of task difficulty (e.g. driving fast/ driving under time pressure) and also in situations where the task demand could not be manipulated by the driver (e.g. by reducing speed).

The current study used the Transport Research Laboratory's (TRL) car driving simulator in line with the discussion of the optimal presentation of the stimulus material in Section 4.2. The study explored age-related changes in risk perception in two driving conditions; a fixed speed condition and a free speed condition. In the fixed speed condition, cruise control initially accelerated and subsequently maintained the car at the desired target speed (slow, medium or high), similar to the method employed by Lewis-Evans and Rothengatter (2009). This essentially fixed task demand and reduced the driver's task to maintaining the car position on the road. At the end of the drive participants were asked to provide ratings on the drive they had just completed. In the free drive condition, participants were fully in control of the vehicle and completed a series of drives where they were instructed to drive as fast as possible without crashing and to drive at the speed they would feel most comfortable with. This part served to obtain behavioural measures of the range of task difficulty that drivers are capable of and willing to experience, i.e. maximum speed and preferred speed. The expectation was that in the fixed speed conditions, age should lead to higher subjective risk ratings for older drivers after a threshold level of task demand had been surpassed.

With regards to the impact of driving experience, the literature on skill acquisition in general (e.g. Annett, 1991) and on the learning-to-drive process in particular (Groeger, 2000) suggests that learning curves are negatively accelerated with initially steep increases in learning, which level off with increasing practice until they follow an asymptotic function, whereby continued practice is associated with only minimal increases in learning. With its emphasis on age effects, the present study aimed to exclude inexperienced drivers and only involved participants with at least three years of driving experience. This is in line with the method proposed by Kinnear et al. (2008) and is based on the assumption that by this time further skill acquisition is negligible (see also Hall & West, 1996). It was furthermore stipulated that all participants should be active drivers (and would therefore maintain their skill level) and should not have started learning to drive late in life. Despite these efforts, the fact remains that driving is an on-going, individual and cumulative learning process, where contingencies between driver actions and driving outcomes are continuously modified, as indeed emphasised by the Zero Risk Theory and the Threat Avoidance Model, leading to some inevitable variability in the experience levels of participants.

Following from the discussion in Section 4.2, a further aim of the study was to introduce an additional source of risk (referred to as 'ambient risk' in the following) and to explore, how feeling of risk, task difficulty and collision risk are impacted if risk in driving situations comprises increases in speed and the presence of other road users. To permit unhampered progress through the environment, it was necessary to ensure that other road users would not affect the driver's trajectory, but would merely be present in oncoming or adjacent lanes. Whilst the presence of other road users does not require the driver to "do more", it was hypothesised that their presence would increase task difficulty ratings and subjective risk. To compare the impact of ambient risk in the present study half of the drives did not include any road users; the other half included oncoming traffic (on rural and urban roads) or vehicles in the adjacent lane (dual carriageway).

Fuller et al. (2008) and Kinnear et al. (2008) had presented the video sequence in ascending order of speed within each of the road environments, after testing for order effects had shown these not to be significant (Lynne, 2006, cited by Kinnear et al., 2008). Lewis-Evans and Rothengatter (2009) had argued that the presentation of the stimulus material in randomised order would be better practice and had therefore presented the driving speeds in their fixed speed condition in randomised order. Concurring with Lewis-Evans and Rothengatter's (2009) argument, slow, medium and fast driving speeds in the present study were presented in randomised order.

Several additional dependent variables, including effort, comfort, typicality of the drive (which refers to how typical a drive if in comparison to the participant's normal driving style) and enjoyment of the drive have been included in replication studies of the original research carried out by Fuller et al. (2008). In line with the literature on age-related losses of confidence and increased levels of nervousness, additional rating dimensions were introduced in the present study to test whether age-related differences in the patterns of such variables could be identified.

4.4 Hypotheses

The considerations outlined above led to the formulation of the following research hypotheses:

1. Task difficulty and feeling of risk ratings will be significantly associated with speed and each other across all age groups. Probability estimates for a collision will increase with speed and will have the largest correlation with feeling of risk in the highest speed condition.
2. Ratings of task difficulty, feelings of risk and subjective risk will significantly increase with driver age;
3. In addition to speed, the presence of other road users will significantly increase ratings of task difficulty and feeling of risk. The presence of other road users will also increase subjective risk estimates;
4. Older drivers will adopt lower preferred and maximum driving speeds than young and middle-aged drivers;
5. Older drivers will be more sensitive to speed than young drivers;
6. Ratings of stress, nervousness, effort and danger will significantly increase with age, whereas ratings of enjoyment will significantly decrease with age.

4.5 Method

4.5.1 Participants

Thirty young, middle-aged and older current drivers were recruited from the TRL participant database with roughly equal representation of male and female drivers. The TRL database is a resource maintained for driving-related research and includes approximately 300 people of different age groups living in the vicinity of TRL who have received familiarisation training on the TRL driving simulator and can be contacted for participation in studies. All participants in the simulator study had therefore driven the simulator prior to participation in the study and were familiar with this specialist equipment. Participants received an information sheet and consent form prior to the trial. On arrival at TRL participants were fully debriefed on the purpose of the study, before the consent form was signed by both, participant and experimenter. Participants involved in the study were paid £30 as compensation for their time and expenses incurred by their participation.

To identify current driving patterns and driving experience, participants were asked to complete a brief questionnaire (for a copy of the questionnaire, please refer to Appendix B, Table B-1). Table 4-1 below summarises the sample characteristics and basic information on current driving patterns.

Table 4-1: Sample characteristics.

Group	**Young drivers**	**Middle aged drivers**	**Older drivers**
Group age range	21-25 years	35-45 years	65+ years
Sex	5 females, 3 males	6 females, 5 males	6 females, 5 males
Mean driver age (years)	*M*=23.4 years, *SD*=1.8	*M*=38.5, *SD*=2.6	*M*=67.9, *SD*=2.6
Mean years since licensure	*M*=6.0, *SD*=1.8	*M*=21.4, *SD* =2.7	*M*=48.0, *SD*=5.6
Mean weekly mileage	*M*=95.0, *SD*=60.9	*M*=191.8, *SD*=177.4	*M*=129.5, *SD*=85.5
Mean proportion of motorway driving*	*M*=30.0, *SD*=9.6	*M*=21.4, *SD*=9.2	*M*=18.0, *SD*=12.5
Mean proportion of driving on built-up roads*	*M*=47.5, *SD*=8.8	*M*=51.4, *SD*=18.5	*M*=53.0, *SD*=18.7
Mean proportion of driving on non-built-up roads*	*M*=22.5, *SD*=12.5	*M*=27.3, *SD*=13.7	*M*=27.0, *SD*=14.0

Table continued	Young drivers	Middle aged drivers	Older drivers
Difficulty of driving in darkness	*M*=3.70, *SD*=1.89	*M*=3.36, *SD*=1.36	*M*=3.19, *SD*=1.66
Difficulty of driving in bad weather	*M*=5.60, *SD*=0.52	*M*=4.09, *SD*=1.04	*M*=3.09, *SD*=1.15
Difficulty of driving in heavy traffic	*M*=3.80, *SD*=0.92	*M*=3.27, *SD*=1.49	*M*=2.73, *SD*=1.42
Difficulty of driving long distances	*M*=3.30, *SD*=1.16	*M*=3.09, *SD*=1.70	*M*=2.91, *SD*=1.92
Skilfulness as a driver	*M*=4.50, *SD*=0.71	*M*=5.09, *SD*=1.14	*M*=5.27, *SD*=0.79
Cautiousness as a driver	*M*=4.70, *SD*=1.42	*M*=4.82, *SD*=1.33	*M*=5.55, *SD*=1.04
Confidence as a driver	*M*=5.10, *SD*=1.29	*M*=5.45, *SD*=1.37	*M*=5.64, *SD*=0.92

* Percentage (%) of participant's annual mileage on each of three road environments (adding up to 100%)

The questionnaire also asked participants to rate the difficulty of four driving situations that typically present a challenge to older drivers (driving at night, in bad weather, in heavy traffic, driving long distances) as well as their perceived skill, safety and confidence as a driver. All ratings used seven point Likert scales, where higher numerical values expressed higher perceived difficulty, skill, caution or confidence. One-way analyses of variance showed no significant differences between the variables, with the exception of driving in bad weather (F=11.02, p>.001), which Bonferoni post-hoc test showed to be rated as significantly less difficult by older ($mean_{diff}$=-2.53, p<.05) and middle age drivers ($mean_{diff}$=-1.53, p<.01) compared to younger drivers.

4.5.2 Design

Fixed speed condition

A 3x3x3x2 mixed factorial design was used for the first part of the simulator study, which required participants to complete a series of 18 short drives. The independent variables were:

Between subjects:

1. Age comprising three levels: young (21-25 year olds), middle-aged (35-45 year olds) and old (65+ year olds);

Within subjects:

2. Road environment, with three levels (urban, rural, dual carriageway[12]);
3. Driving speed, with three levels (slow speed, average speed, high speed);
4. Ambient risk, with two levels (other road users present, other road users absent).

To control for order effects of the independent variables, simplified Latin squares were used to permute the order of the road environments and driving speeds across participants. Within each roadway environment participants had to complete six drives at three speeds (slow, medium, fast), with ambient risk either present or absent.

The dependent variables comprised participants' responses to seven questions asked after each drive, using seven point rating scales. Additionally participants were asked to estimate the speed at which they had been driving and the number of crashes they would anticipate if they drove under the same conditions a hundred times (more information on the questions is provided in Section 4.5.5 below). Whilst the first question ("At what speed do you think you have just been driving?") and the ninth ("If you drove on this section of the road at this speed a hundred times, how often do you think you would have a crash?") were always the same, the order of the seven rating questions was permuted using a simplified Latin square to control for order effects. Thus, an individual schedule was produced for each driver stipulating the order of each of the 18 different drives in terms of environment, driving speed and risk condition. Similarly, individual questionnaires and show-cards were produced that contained the seven rating questions in permutated order.

Analyses performed on rating data and drive information included the calculation of correlation coefficients to assess the relationship between the dependent variables as well as mixed factorial ANOVAs to assess the effect of the independent variables. The findings are described in detail in the relevant results sections.

Free speed condition

The second part of the simulator study applied a 3x3x2x2 mixed factorial design, comprising a further four short drives per each of the three road environments where ambient risk was either present or absent. In this part, however, participants were fully in charge of the vehicle and were asked to drive either at the speed they felt most comfortable with or at the maximal speed they could drive at without losing control (as if they were driving to an urgent appointment). The independent variables were:

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[12] Because of the absence of significant differences between straight country roads and dual carriageway in Kinnear et al. (2008) study only bendy country roads were included in the current study.

Between subjects:

1. Age comprising three levels (young (21-25 year olds), middle-aged (35-45 year olds) and old (65+ year olds);

Within subjects:

2. Road environment with three levels (urban, rural, dual carriageway);
3. Driving speed with two levels (preferred speed versus maximum speed);
4. Ambient risk with two levels (other road users present, other road users absent).

Actual speed (as measured by the simulator) and perceived driving speeds were recorded as dependent variables. For the free drives, participants completed all drives relating to one road environment together. Latin Squares were therefore used to determine the order of the road environment (dual carriageway, country road and residential) for each participant, the order of the absence or presence of ambient risk and the order of the speed condition (preferred or maximum speed).

Analyses performed on the speed data comprised mixed factorial ANOVAs, and the results are described in detail in the results section.

4.5.3 Equipment

The TRL Driving Simulator (DigiCar) consists of a medium sized family hatchback (Honda Civic) surrounded by four 3×4 metre projection screens giving 210º front vision and 60º rear vision, enabling the normal use of the vehicle's driving and wing mirrors. The road images are generated by four PCs running SCANeR II software (manufactured by Oktal) and are projected onto the screens by four Digital Light Processing (DLP) projectors at a resolution of 1280×1024 pixels (giving a screen resolution of approx 13 pixels per inch). Images are refreshed at a rate of 60Hz (every 16.7msec) whilst data is sampled at a rate of 20Hz (every 50msec). Electric motors supply motion with three degrees of freedom (heave, pitch and roll) whilst engine noise, external road noise, and the sounds of passing traffic are provided by a stereo sound system. Two studies have demonstrated the validity of the TRL simulator (Duncan, 1995; Sexton, 1997) and it can be assumed that the current simulator system is at least as accurate as that used in the Duncan and Sexton studies.

As discussed in Section 4.2, simulator studies that explore drivers' perception of speed must demonstrate the absence of unsystematic biases of speed estimates to produce valid results. For the TRL simulator the accuracy of speed perception was tested by Diels and Parkes (2010) in a pilot study on speed perception using the simulator's standard configuration (i.e. geometrically correct optic-flow (GFOV/FOV= 1:1)). The results (see

Figure 4-1) indicate that participants consistently underestimated the vehicle speed which led to an overproduction of vehicle speed. The finding was consistent across target speed and simulated environment. The absence of non-linear misperceptions of speed in the simulator suggests that whilst perceived speeds in the simulator are lower than those in real road environments, this error is consistent across the speed range and the road environments and should thus uniformly affect the ratings in the present study.

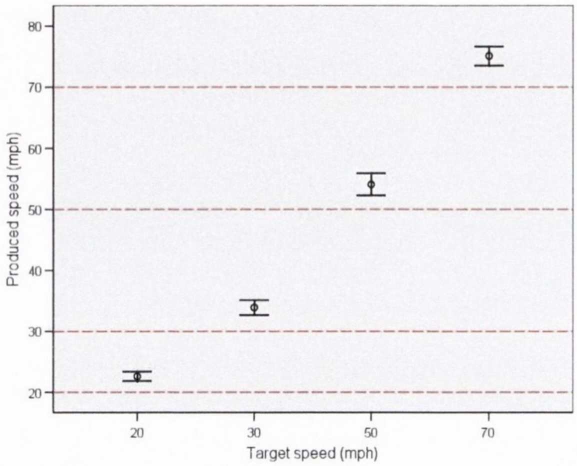

Figure 4-1: Mean produced speed for each target speed using the standard simulator configuration (GFOV / FOV = 1:1). Error bars indicate the Standard Error (SE) of the mean.

4.5.4 Procedure

After instruction and debrief on the purpose of the study participants completed a five minute drive in the TRL car simulator to familiarise themselves with the car controls and dynamic vehicle reactions. During familiarisation, the speedometer was not occluded.

In the subsequent first part of the study participants completed a series of six short drives, each approximately 20 seconds long, in each of the following road environments:

1. Dual carriageway;
2. Rural road;
3. Urban environment.

Drives in each environment had to be completed at three driving speeds. After starting the car, the vehicle was automatically accelerated to the target speed and subsequently held constant by a cruise control system. Participants were thus only required to steer the vehicle. During this part of the study, the speedometer was occluded. The three speeds were selected on the basis of the actual speed distributions on these road types in Great Britain in 2007 (Department for Transport, 2008). Mean speeds for the three environments in 2007 according to the statistics were as follows:

1. Dual carriageway (*M*=69 mph, *SD*=9.92);
2. Rural road (*M*=48 mph, *SD*=9.68); and
3. Urban road (*M*=30 mph, *SD*=6.60).

To obtain a slow, medium and fast speed condition for each of the three road environments in the simulator study, the following rationale was employed:

1. Low speed condition: the speed that represented two standard deviations below the actual mean speed of driving on the particular road type in Great Britain;
2. Average speed condition: the actual speed limit on that particular road type in Great Britain; and
3. Fast speed condition: the speed that represented two standard deviations above the mean speed on the particular road type in Great Britain.

Whilst for dual carriageway and residential roads, the mean speed driven on British roads was (almost) identical with the active speed limit for the respective road environment, the average driven speed on rural roads was considerably lower than the speed limit for this road type. This meant that the three speed conditions in the rural road environment were not equidistant, leading to considerable biases in participant ratings and insufficient differentiation between the middle and high speed condition. During the trial runs participants repeatedly commented that the fixed speeds were inappropriately slow for the road environment. Whilst the rural road environment in the simulator featured road widths that are typical for rural roads, the poor visibility conditions due to hedgerows and bends that characterise rural roads in Britain were absent, which could explain the low perceived ecological validity. The rural road condition was therefore excluded from the analysis.

In each drive, ambient risk, operationalised as the absence or presence of oncoming vehicles (in the urban and rural environment) or as vehicles in the adjacent lane (dual carriageway), was either present or absent, resulting in a total of 18 drives, as illustrated in Table 4-2, whereby the order of the drives during trial presentation was randomised.

Table 4-2: Target driving speeds for the simulator study per road environment and ambient risk condition (the highlighted text indicates that the country road condition was later excluded from the study).

	No ambient risk present	Ambient risk present
Urban road	Three drives at: - 16 mph - 30 mph - 44 mph	Three drives: - 16 mph - 30 mph - 44 mph
Country road	Three drives: - 28 mph - 60 mph - 68 mph	Three drives: - 28 mph - 60 mph - 68 mph
Dual carriageway	Three drives: - 49 mph - 70 mph - 89 mph	Three drives: - 49 mph - 70 mph - 89 mph

After approximately 20 seconds, the experimenter stopped the drive and read out nine questions to the participant via the speaker system. A show-card comprising all the questions also enabled the participants to read the questions themselves and to pick appropriate answer options, which were subsequently recorded by the experimenter.

After completion of the first part of the simulator study, participants were asked to leave the simulator, were offered refreshments and took a short break. In that break participants were asked to complete a brief questionnaire comprising questions on their driving experience.

Participants subsequently completed another 12 short drives in the simulator, four in each of the three road environments. In this second part of the study, participants were fully in control of the vehicle, and no other road users were present. Participants were instructed to either drive at their preferred speed or were asked to drive at the speed they would choose if they were late for a very important appointment (thus aiming to motivate them to drive close to their upper capability limit). After initial piloting showed that some participants drove so fast that they lost control and crashed in response to this instruction, it was added that participants should drive as fast as they would in this situation without losing control over the vehicle. When participants had reached the speed at which they were either most comfortable or which put them at the limit of their capability, they were asked to indicate this by saying "now". The experimenter then started the stop watch, documented the speed and stopped the drive after twenty seconds of driving at target speed. At the end of each drive, participants were asked to estimate the speed they had been driving at just before the task had ended.

4.5.5 Materials

Each participant completed a total of 30 drives in the study. For the first part of the study, 18 drives had been programmed on the TRL car simulator, in line with the specifications shown in Table 4-2. All driving conditions were tested by the experimenter to ensure that the automatic acceleration of the vehicle was working and to obtain an estimate of the overall duration of the trial.

The nine questions that were read out to participants at the end of each drive in the first part of the study can be found in Appendix B, Table B-2.The majority of the questions comprised unipolar 7-point Likert scales, for example:

- *"How difficult did you find it to drive on this section of the road at this speed?"*
- *"How risky did it feel to drive on this section of the road at this speed?"*

Subjective risk of a collision was measured as one's own percentage of expected collisions to avoid the bias (Lewis-Evans & Rothengatter, 2009) had demonstrated for the phrasing used by Kinnear et al. (2008). Participants had to provide a numerical value to the following question:

"If you drove on this section of the road at this speed a hundred times, how often do you think you would have a crash?"

4.5.6 Ethical approval

Ethical approval for the study was gained from the Psychology Ethics Board at Trinity College Dublin and a copy of the Ethics Approval Letter can be found in Appendix B, Figure B-1.

4.6 Results

4.6.1 Data screening

In the first part of the study, each participant (n=30) completed 18 drives per environment, resulting in a total of 540 drives or 180 drives per environment. In the second part of the study, each participant (n=30) completed 12 drives per environment, resulting in a total of 360 drives or 120 drives per environment.

Kolmogorov-Smirnov tests were conducted for all dependent variables associated with the different factor combinations to test if the data were normally distributed. The tests showed that with few exceptions, data significantly deviated from normality. Both non-parametric tests and correlations (i.e. Wilcoxon rank sum tests or Spearman rho correlations) and parametric tests were carried out with very similar findings. Furthermore, the parametric test statistics used in the present study, such as F-test based measures, are considered to be robust to violations of the normality of the data. Therefore, the results from the parametric testing are reported in the following.

4.6.2 Hypothesis 1

Task difficulty and feeling of risk ratings will be significantly associated with speed and each other across all age groups. Probability estimates for a collision will increase with speed and will have the largest correlation with feeling of risk in the highest speed condition

Figure 4-2 illustrates participants' mean ratings and standard deviations for the feeling of risk, task difficulty and probability of having a crash for the three speed conditions separated by road environment (urban roads on the left, dual carriageway on the right).

Different patterns emerged for the mean ratings of task difficulty, feeling of risk and subjective probability of a collision. Ratings increased with speed on all three variables in the urban environments. On the dual carriageway, all three ratings increased with speed; however, considerably less steeply than in the urban road environment. Mean ratings of the feeling of risk were generally higher than those of task difficulty in both road environments. Collision probabilities, expressed as percentages of time when a collision was anticipated, were rated as low for the dual carriageway with only slight increases in the high speed condition. Collision probability estimates in the average and high speed condition of the urban environment were comparatively higher.

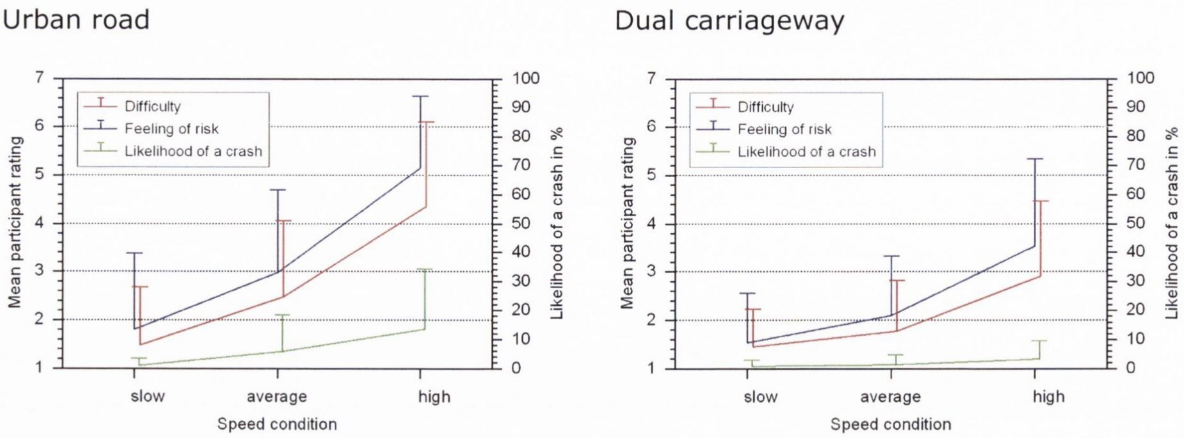

Figure 4-2: Line graphs of participant ratings on feeling of risk (dark blue), task difficulty (red) and probability of having a crash (green).

Pearson Product Moment correlation coefficients were calculated to assess the relationship between ratings of task difficulty and feeling of risk in both road environments and for different speed conditions. The findings are shown in Table 4-3. In line with the first hypothesis the association between the two variables was highly significant for all conditions with the strongest association found in the low speed condition in the urban environment and lowest correlation found in the low speed condition on the dual carriageway. Only on the dual carriageway did the strength of the correlations rise with increasing speeds.

Table 4-3: Correlation coefficients (Pearson) for correlations between feeling of risk & task difficulty and feeling of risk and crash probability ($p<0.01$).**

Pearson Correlation between task difficulty & feeling of risk			
	Low speed	Average speed	High speed
Urban road	0.86**	0.82**	0.81**
Dual carriageway	0.74**	0.82**	0.87**
Pearson Correlation between feeling of risk and crash probability			
	Low speed	Average speed	High speed
Urban road	0.59**	0.70**	0.45**
Dual carriageway	0.14	0.11	0.34**

In the fixed driving condition (part one of the study), participants were asked to assess the drive on several dimensions in addition to the feeling of risk, including perceived stressfulness, danger, effort and enjoyment of the drive as well as feelings of nervousness. Pearson correlations were calculated between these dimensions and perceived task difficulty for both road environments to explore whether any other variable would correlate more strongly with task difficulty. The results (see Table 4-4) suggest that in addition to feeling of risk, feelings of stress are equally highly related to task difficulty. Enjoyment of the drives was negatively correlated to task difficulty perceptions, but the correlations did not reach significance.

Table 4-4: Average Pearson correlation coefficients for correlations between task difficulty and ratings of effort, danger, stress, nervousness and enjoyment ($p<0.01$).**

	Urban roads	Dual carriageway
Risk	.83**	.81**
Effort	.79**	.80**
Danger	.79*	.78**
Stress	.88**	.81**
Nervousness	.80**	.75**
Enjoyment	-.17	-.21

To assess the relationship between speed and task difficulty, speed and feeling of risk and speed and subjective probability of a collision, separate stepwise multiple regression analyses for both road environment were conducted with speed (low, average, high), ambient risk (present, absent) and age (young, middle-aged, old) as predictor variables and task difficulty, feeling of risk and subjective probability of a collision as dependent variables. The findings are summarised in Table 4-5. Arguably task difficulty, feeling of risk and collision probability could also be used as predictor variables. However, the Risk Allostasis Theory asserts that feelings of risk and task difficulty are highly correlated, which would result in a problem of co-linearity. For subjective risk, the Risk Allostasis Theory proposes non-linear increases, thus rendering it unfeasible as a predictor for multiple regression analysis.

Speed emerged as the most important predictor of task difficulty in both road environments. On urban roads it explained 37% of the variance of the task difficulty ratings ($p<0.001$) and 20% on the dual carriageway ($p<0.001$) respectively. As a predictor of feeling of risk, speed explained 42% of the variance in the ratings on urban roads ($p<0.001$) and 25% of the variance on dual carriageways. Regression analysis showed speed to significantly predict subjective probability of a collision on both, urban roads and dual carriageways, even though the association was considerably weaker (12% explained variance on residential roads ($p<0.001$) and 6% on the dual carriageway ($p<0.01$)) than that observed between speed and task difficulty and speed and feeling of risk.

Table 4-5: Regression analyses for task difficulty, feeling of risk and probability of loss of control for both road environments (with *p<0.05; **p<0.01; ***p<0.001)

Task difficulty	Urban roads			Dual carriageway		
	r^2	*Beta*	*t*	r^2	*Beta*	*t*
Speed	0.37***	0.61	10.67	0.20***	0.55	6.68
Age	0.06***	0.25	4.3			
Ambient risk	n.s.			0.04**	0.20	3.15
Feeling of risk	Urban roads			Dual carriageway		
Speed	0.42***	0.65	11.37	0.25***	0.50	7.78
Age	0.06***	0.24	4.45	n.s.		
Ambient risk	n.s.			0.03**	0.19	2.92
Collision risk	Urban roads			Dual carriageway		
Speed	0.12***	0.35	4.90	0.06**	0.23	3.21
Age	0.07***	0.27	3.94	n.s.		
Ambient risk	n.s.			n.s.		

The percentage of participants who rated the probability of a collision as greater than zero was calculated and is shown in Figure 4-3. Similar to Kinnear (2009) who reported that a threshold for probability of a collision was not obvious, because a significant proportion of participants rated it as greater than zero from the first condition onwards, approximately 30% of the participants in this study rated the probability of a collision as greater than zero in the low speed driving condition. In line with prediction, collision estimates increased with speed.

Risk perception as a function of age

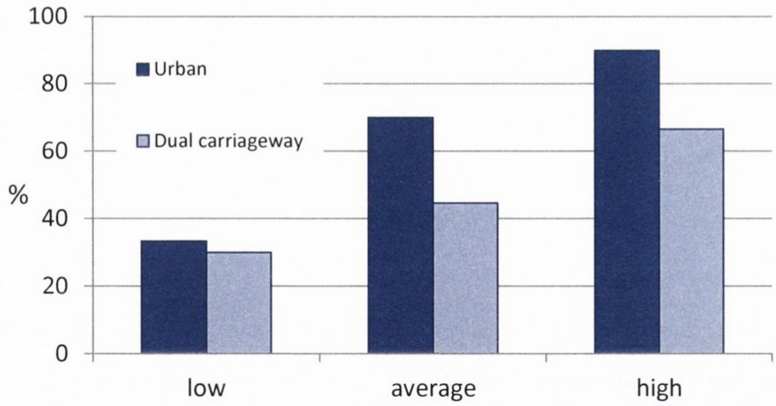

Figure 4-3: Proportion of participants who rated the probability of a collision as greater than zero in low, average and high speed condition of both road environments.

<u>Summary of findings</u>

- The findings overall supported Hypothesis 1.
- Task difficulty and feeling of risk strongly correlated with each other. An increase of the correlations between the two variables with increasing speeds was observed for the dual carriageway environment; for urban roads, the strength of the associated was slightly reduced in the higher speed conditions.
- Collision estimates increased with speed in line with prediction. The correlation with speed only got stronger with speed on the dual carriageway, not on urban roads.
- In line with the hypothesis speed emerged as the most important predictor of task difficulty.
- Significant associations between speed and feeling of risk and speed and probability of a collision were found for both road environments.

4.6.3 Hypothesis 2

Ratings of task difficulty, feelings of risk and subjective risk of a collision will significantly increase with driver age.

To explore age effects on ratings of feeling of risk, task difficulty and estimates of collision likelihood, data obtained in the fixed speed part of the simulator trial, were analysed using split-plot ANOVAs with age group (young, middle aged, old) as between-subjects factor and speed (slow, average, high) and risk condition (ambient risk present, ambient risk absent) as within-subject factors. Separate sets of ANOVAs were carried out for the two road environments and the descriptives can be found in Appendix B, Table B-

3. Significant results are shown in Table 4-6. The analyses found significant age effects for urban roads, including significant main effects of age for feeling of risk and task difficulty and a significant interaction of speed and age for the estimated collision likelihood. As the impact of speed has already been discussed in Section 4.6.2 and the impact of ambient risk is discussed in Section 4.6.4., neither of main effects of speed and risk is discussed here.

Table 4-6: Significant findings from split-plot ANOVAs for feeling of risk, task difficulty and probability of a collision.

		Feeling of risk	**Task difficulty**	**Probability of a collision**
Urban road	Speed	$F(2,27)=51.12$ $p<0.001$ partial $\eta^2=0.65$	$F(2,27)=44.27$ $p<0.001$ partial $\eta^2=0.62$	$F(2,27)=11.51$ $p<0.001$ partial $\eta^2=0.30$
	Age	$F(2,27)=4.75$ $p=0.017$ partial $\eta^2=0.26$	$F(2,27)=3.45$ $p=0.046$ partial $\eta^2=0.20$	
	Risk		$F(1,27)=5.81$ $p=0.023$ partial $\eta^2=0.18$	
	Speed * Age			$F(4, 27)=2.90$ $p=0.03$ partial $\eta^2=0.18$
Dual carriageway	Speed	$F(2,27)= 41.01$ $P<0.001$ partial $\eta^2=0.60$	$F(2,27)= 40.01$ $p<0.001$ partial $\eta^2=0.60$	$F(2,27)=8.25$ $p=0.01$ partial $\eta^2=0.23$
	Risk	$F(1,27)=19.21$ $p<0.001$ partial $\eta^2=0.42$	$F(1,27)=16.90$ $p<0.001$ partial $\eta^2=0.39$	$F(1,27)=7.90$ $p=0.009$ partial $\eta^2=0.23$

Perceived feeling of risk

Age emerged as a significant main effect ($F(2,27)=4.75$, $p<.05$, partial $\eta^2=0.26$) in the urban road environment (see Figure 4-4). A Games-Howell post-hoc test indicated that older participants' feelings of risk were significantly higher than those of young participants across all speed and risk conditions ($mean_{diff}=1.24$, $p<0.05$).

Risk perception as a function of age

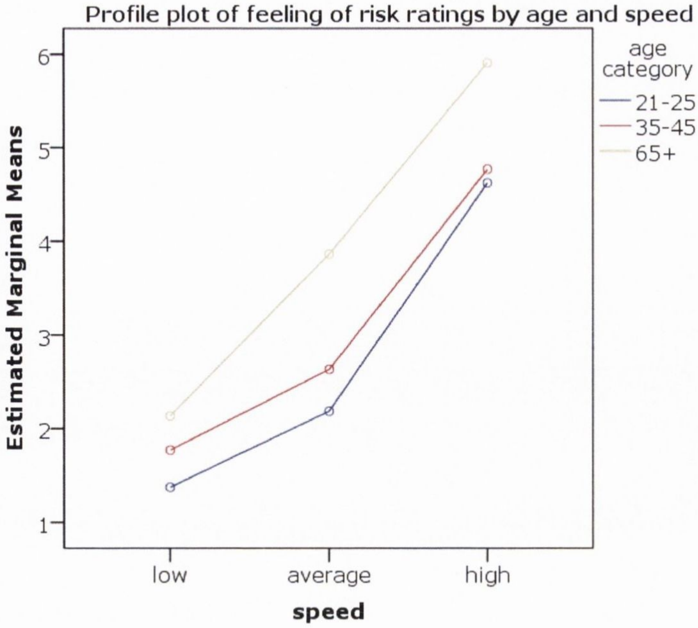

Figure 4-4: Profile plots for feeling of risk on urban roads.

Perceived task difficulty

A main age effect was also found for task difficulty ($F(2,27)=3.45$, $p<0.05$, partial $\eta^2=0.20$) in the urban road environment (see Figure 4-5). The Games-Howell post-hoc test indicated that older participants' ratings of task difficulty were higher than those of young participants across all speed and risk conditions, however, just failed to reach significance ($mean_{diff}=1.17$, $p=0.053$).

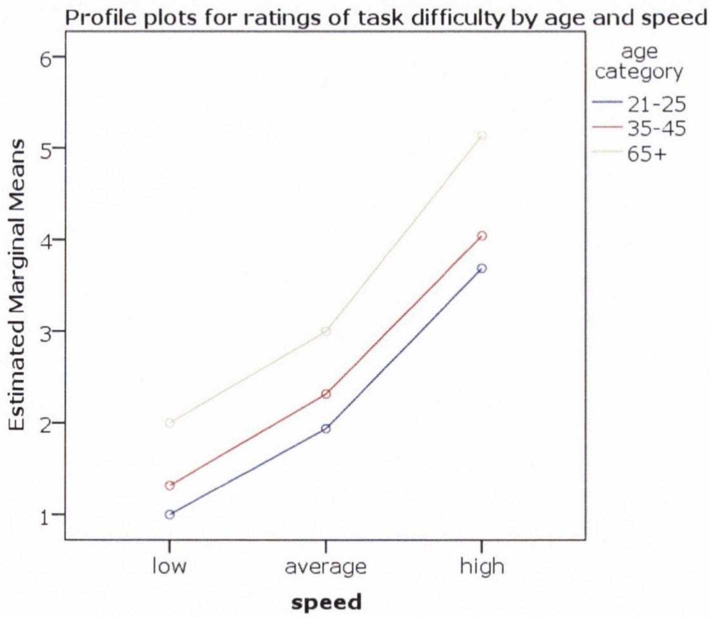

Figure 4-5: Profile plots for feeling of risk on urban roads.

Risk perception as a function of age

Perceived probability of a collision

In relation to participants' estimates collision likelihoods, a significant interaction was found between speed and age ($F(4,27)=2.9$, $p=0.030$, partial $\eta^2=0.18$) in the urban road environment. Simple effects analysis indicated that collision likelihood estimates of older drivers were significantly higher than those of middle-aged drivers in the medium speed condition ($p=0.041$) and than those of middle-aged ($p=0.04$) and young drivers ($p=0.052$) in the high speed condition. Older drivers' ratings in the high speed condition were significantly higher than in the medium speed ($p=0.002$) and the slow speed condition ($p<0.001$). The estimated marginal mean plot is shown in Figure 4-6.

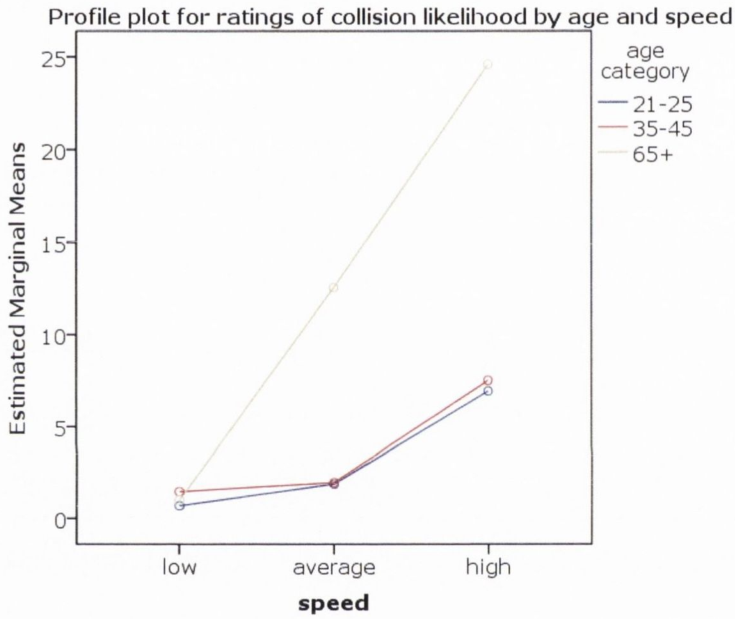

Figure 4-6: Estimated marginal means plots for the significant interaction of speed and age for subjective probability of a collision on urban roads, differentiated by speed.

Summary of findings

- The second hypothesis was partly supported.
- Significant age effects were found for urban roads, but not for the dual carriageway.
- Significant main effects of age for feeling of risk and task difficulty in the urban environment indicated higher ratings for older drivers.
- An age * speed interaction effect emerged for participants' estimate of collision probabilities: older drivers' collision ratings were significantly higher than those of

middle-aged drivers' in the average speed condition and significantly higher than those of middle-aged and young drivers in the high speed condition.

4.6.4 Hypothesis 3

In addition to speed, the presence of other road users will significantly increase ratings of task difficulty and feeling of risk. The presence of other road users will also increase subjective estimates of the likelihood of a collision.

Stepwise linear regressions (summarised in Table 4-5) found no significant effects of ambient risk for the urban road environment. For the dual carriageway the presence of other road users significantly contributed to the prediction of task difficulty and feeling of risk (both $p<0.01$), however, the amount of variance explained remained small (3% and 4% respectively). The association between the presence of other road users and subjective probability of a collision was not significant for the dual carriageway environment.

The results of the split-plot ANOVA reported in Section 4.6.3, Table 4-6, with age as between factor and speed and ambient risk as within factors, found a significant main effect of ambient risk in the expected direction for task difficulty ($F(1,27)=5.81$, $p=0.023$, partial $\eta^2=0.18$) on urban roads and significant main effects for feeling of risk ($F(1,27)=19.21$, $p<0.001$, partial $\eta^2=0.42$), task difficulty ($F(1,27)=16.90$, $p<0.001$, partial $\eta^2=0.39$) and collision probability ($F(1,27)=7.90$, $p=0.009$, partial $\eta^2=0.23$) for the dual carriageway. For these variables, drives where other road users were present attracted higher participant ratings than those where no other road users were present.

Summary of findings

- The findings partly supported the third hypothesis.
- The presence of other road users emerged as a significant predictor of feeling of risk, task difficulty and collision probability on the dual carriageway in regression analyses.
- Split-plot ANOVAs indicated significant main effects for ambient risk for feeling of risk, task difficulty and collision probability on the dual carriageway and identified a significant main effect of ambient risk for task difficulty on urban roads. However, compared to the impact of driving speed, ambient risk impacted ratings considerably less strongly, as attested to by lower effect sizes.

4.6.5 Hypothesis 4

Older drivers will adopt lower preferred and maximum driving speeds than young and middle-aged drivers.

Age-related differences between preferred and maximum speeds were calculated using the data from the free drive condition (gathered during the second part of the trial). The mean driven speeds in both road environments are shown in Figure 4-7.

Urban roads

Dual carriageway

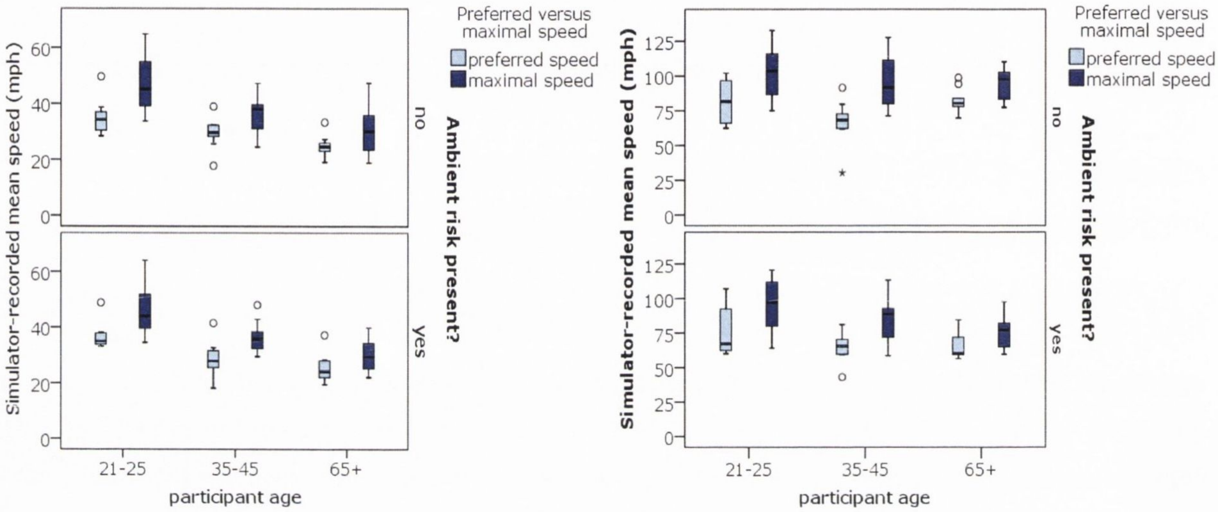

Figure 4-7: Box-plots for the mean preferred and maximum speeds in the free driving condition, differentiated by risk condition and age for urban roads (left) and dual carriageway (right).

Significant findings from separate split-plot ANOVAs for both road environments are summarised in Table 4-7 and indicate significant age effects for both road environments.

Table 4-7: Significant findings from split-plot ANOVAs for age differences in driven speed in the second part of the simulator study.

		ANOVA results for adopted speeds
Urban road	Speed	$F(1, 24)=72.71$, $p<0.001$, partial $\eta^2=0.75$
	Age	$F(2, 24)=13.07$, $p<0.001$, partial $\eta^2=0.53$
	Speed * Age	$F(2, 24)=4.61$, $p=0.028$, partial $\eta^2=0.26$
Dual carriageway	Speed	$F(1, 24)=62.77$, $p<0.001$, partial $\eta^2=0.72$
	Risk	$F(1, 24)=34.17$, $p<0.001$, partial $\eta^2=0.59$
	Risk * Age	$F(2, 24)=3.97$, $p=0.032$, partial $\eta^2=0.25$

On urban roads, Bonferoni post-hoc tests for the significant main effect of age showed that young drivers chose significantly higher speeds than middle-aged ($mean_{diff}=9.77$, $p<0.01$) and older drivers ($mean_{diff}=15.06$, $p>0.001$). Simple effects analysis for the ordinal interaction between speed and age for urban roads (see Figure 4-8) indicated that for preferred speeds young drivers' speeds were significantly higher than middle-aged drivers' ($p=0.008$) and older drivers' ($p<0.001$). For maximum speeds, young drivers' speeds were significant higher than middle-aged drivers' ($p=0.003$) and older drivers' ($p<0.001$) and middle-aged drivers' were higher than older drivers' ($p=0.051$).

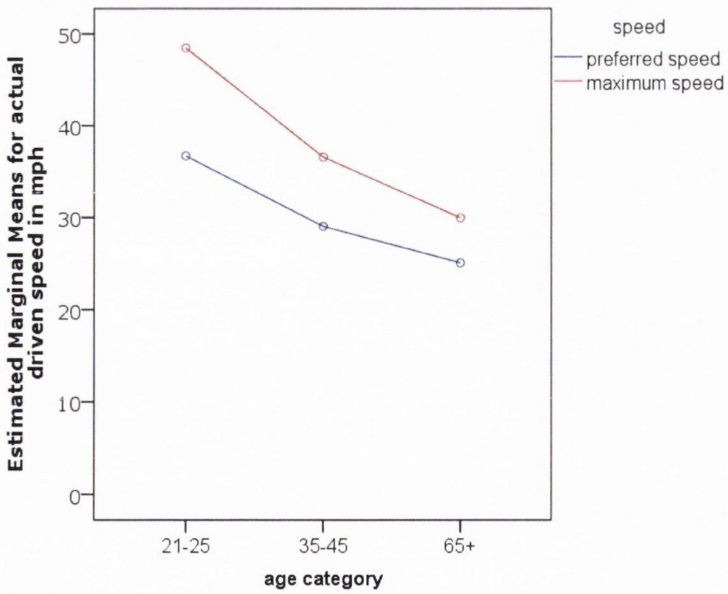

Figure 4-8: Estimated marginal means plots for the mean speeds on urban roads, differentiated by age.

Risk perception as a function of age

For the dual carriageway a significant main effect for speed indicated that preferred speeds were always lower than maximum speeds (see Figure 4-9). The analysis of simple effects for the significant interaction between risk and age found that older drivers' speeds in the presence of other road users were significantly lower than that of young drivers (p=0.046) and that adopted speeds were lower in the presence of other road users for all three age groups (p_y=0.048; p_m=0.025; p_o<0.001).

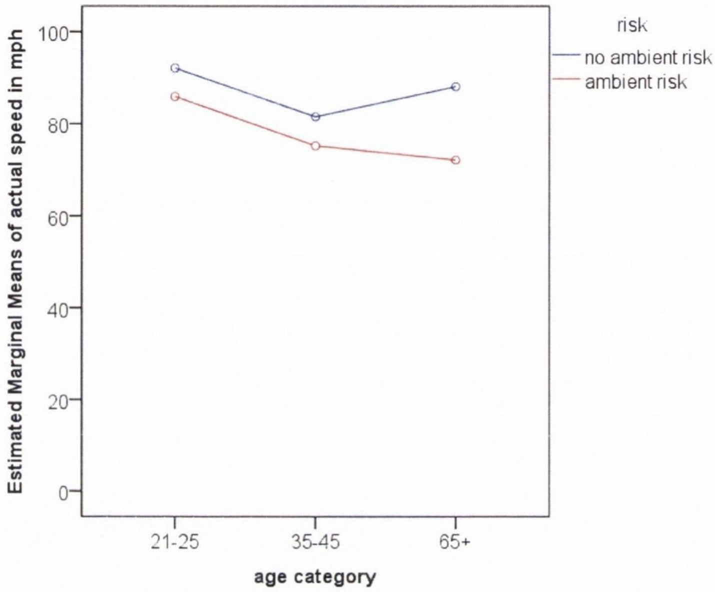

Figure 4-9: Estimated marginal means plots for the mean speeds on the dual carriageway, differentiated by risk condition and age.

Summary of findings

- Findings partly supported the fourth research hypothesis.
- In line with expectation older drivers adopted significantly lower speeds than middle aged and young drivers in the urban environment.
- On the dual carriageway older drivers adopted speeds that were significantly lower than those of young drivers if no other road users were present.
- In the presence of other road users, all driver groups' speeds were significantly lower than in the absence of other road users.

4.6.6 Hypothesis 5

Older drivers will be more sensitive to speed than young drivers.

For the assessment of participants' accuracy of speed judgements, two sets of data were used, one from the first and one from the second part of the simulator study. The first dataset comprised the differences between the estimated speed reported by participants at the end of each drive and the actual target speed of the cruise control system in the respective condition of the fixed speed part of the simulator study. These differences are displayed in Figure 4-10. Values below zero indicate that participants reported a perceived speed that was higher than the actual fixed speed in the condition and therefore imply an overestimation of the actual speed. Values above zero imply an underestimation of the actual speed.

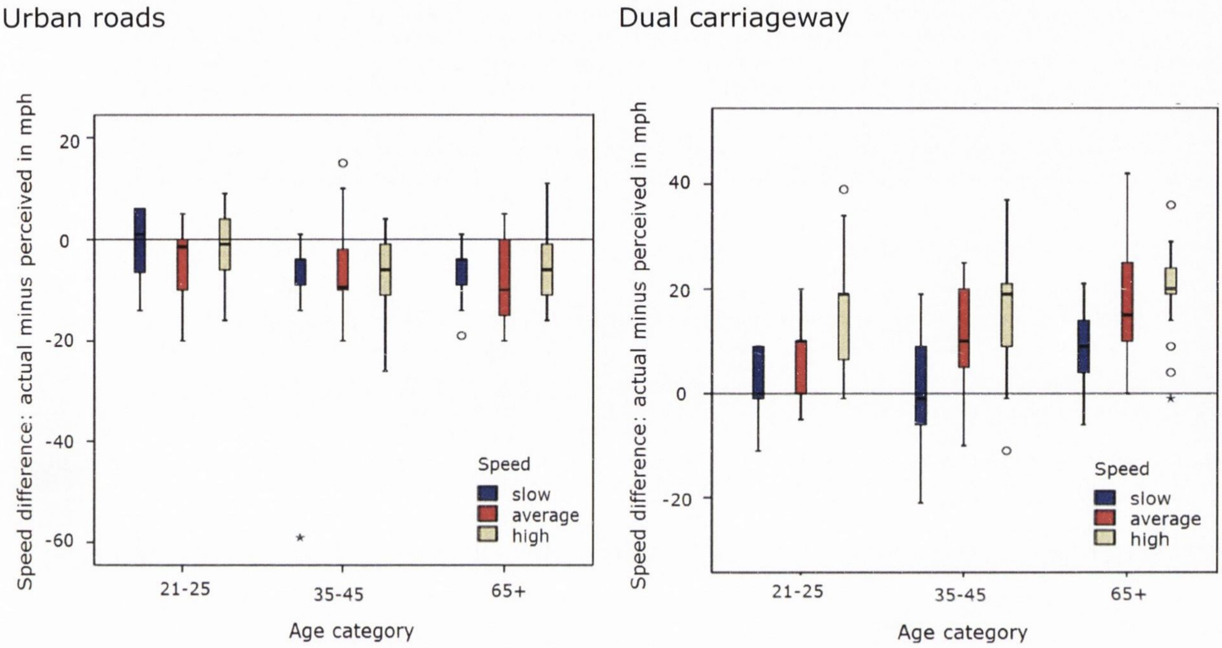

Figure 4-10: Box-plots showing the difference between actual speed and perceived speed in the fixed driving condition (first part of the simulator study) differentiated by age, for urban roads (left) and dual carriageway (right).

Difference between the speed estimates of the three driver age groups were analysed using split-plot ANOVAs with age group (young, middle aged, old) as between-subjects factor and speed (slow, average, high) and ambient risk (present versus absent) as within-subject factors. Separate ANOVAs were carried out for both road environments and indicated a significant main effect for speed on the dual carriageway ($F(2,27)=163.43$, $p>0.001$, partial $\eta^2=0.86$), but no significant age effects for either environment in the fixed speed condition.

Speed estimates were also obtained from participants in the free drive condition. In this second part of the simulator study, participants had been instructed to accelerate up to the speed that represented their preferred or maximum speed and to maintain this speed, once reached for approximately 20 seconds after which the experimenter stopped the drive. To check whether participants successfully maintained their preferred of maximum speeds, the distributions of the speed standard deviations of these 20 second interval drives were plotted in Figure 4-11. The graphs indicate that on the whole, participants' deviations from their target speeds were negligible.

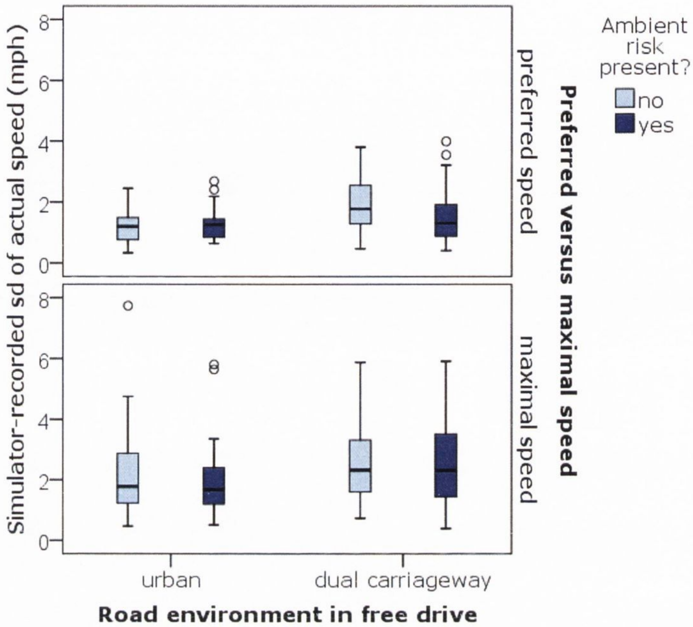

Figure 4-11: Box-plots of standard deviations of speed as recorded by the simulator in the second part of the study, differentiated by road environment and speed condition.

This second data set of speed differences was analysed in the same way as the first: differences between actual speed and perceived or reported speed were calculated and fed into a split-plot ANOVA with age as between-subjects factor and risk, and preferred versus maximum speed as within-subject factors. The resulting distributions of speed differences are displayed in Figure 4-12. Values below zero again indicate that participants reported a perceived speed that was higher than the actual driven speed in the condition and therefore imply an overestimation of the actual speed. The findings suggest that middle-aged and older drivers tended to overestimate speed on urban roads, but they underestimated it on dual carriageways. The young drivers on the other hand consistently underestimated speeds in both environments. However, their speed estimates were also overall more accurate than those of middle-aged and older drivers.

Risk perception as a function of age

Urban roads Dual carriageway

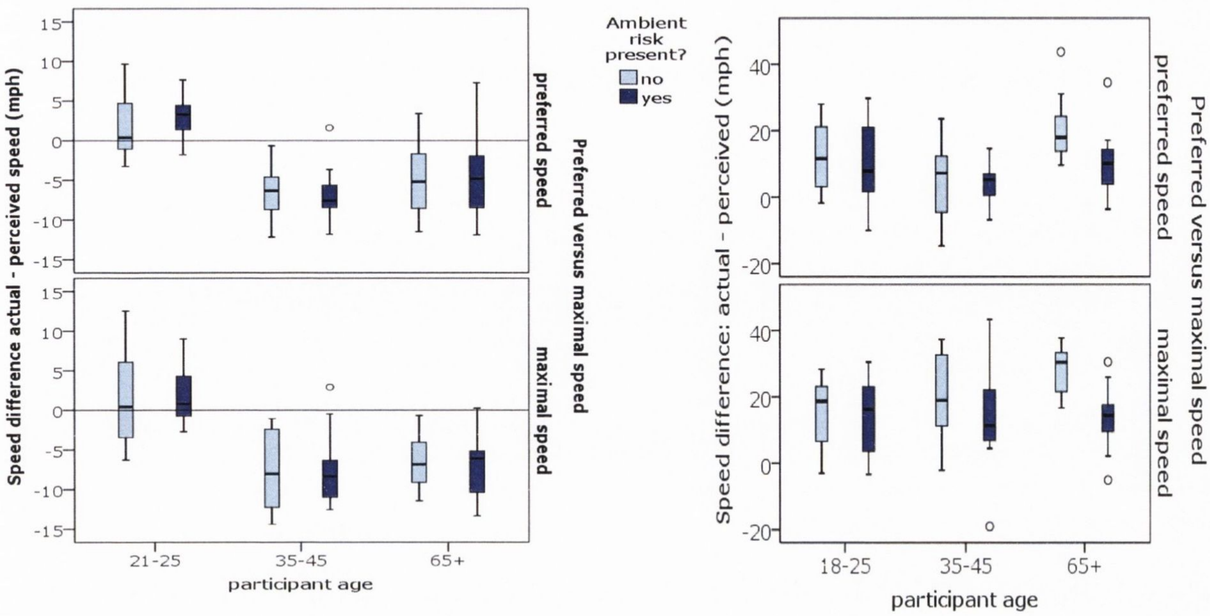

Figure 4-12: Box-plots for the differences between actual and estimated speeds in the free driving condition, differentiated by speed condition and age for urban roads (left) and dual carriageway (right).

Split-plot ANOVAs found significant age effects for both road environments (see Table 4-8).

Table 4-8: Significant findings from split-plot ANOVAs for differences in the accuracy of speed perceptions in the second part of the simulator study.

		ANOVA results for speed difference (actual – perceived)
Urban road	Age	$F(2, 24)= 14.12$, $p<0.001$, partial $\eta^2=0.54$
Dual carriageway	Speed	$F(1, 24)= 17.98$, $p<0.001$, partial $\eta^2=0.43$
	Risk	$F(1, 24)= 33.86$, $p<0.001$, partial $\eta^2=0.59$
	Risk * Age	$F(2, 24)= 8.70$, $p=0.001$, partial $\eta^2=0.42$

On urban roads, Bonferoni post-hoc tests for the significant main effect of age indicated that young drivers estimated their driven speed to be significantly lower than middle-aged ($mean_{diff}=9.43$, $p>0.001$) and older drivers ($mean_{diff}=8.16$, $p>0.001$).

For dual carriageways a significant main effect for speed indicated that preferred speed estimates were always more accurate than maximum speeds. Additionally, a significant main effect for risk was found for the dual carriageway, together with a significant interaction between age and risk. The analysis of simple effects showed that the presence of other road users increased the accuracy of older drivers' ($p<0.001$) and middle-aged drivers' ($p=0.025$) speed estimates and that older drivers' estimated speeds were significantly higher than middle-aged drivers' ($p=0.015$) and young drivers' ($p=0.043$) (see Figure 4-13).

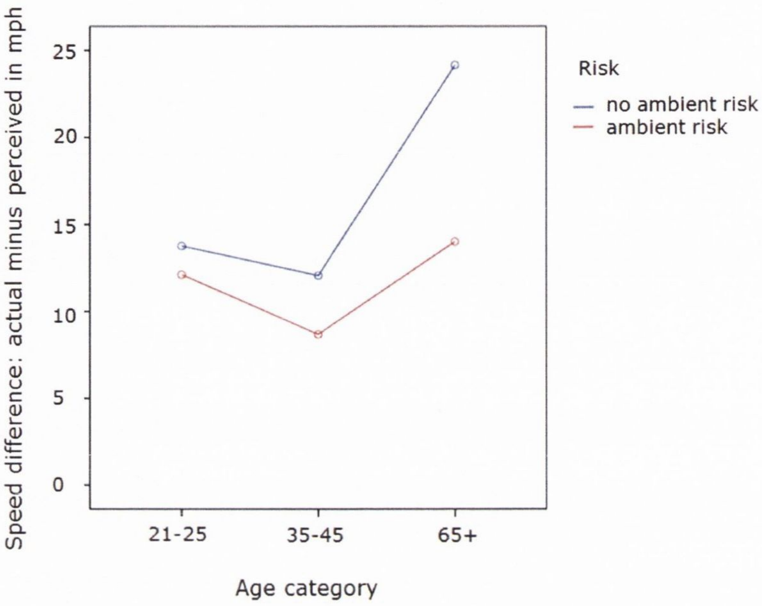

Figure 4-13: Estimated marginal mean plot for the split-plot ANOVA on differences between actual and estimated speeds in the free driving condition on the dual carriageway, differentiated by age.

<u>Summary of findings</u>

- The findings in relation to the fifth research hypothesis were mixed, with the majority of the findings pointing towards the existence of significant age effects for speed assessments.
- No significant age effects were found for participants' speed estimates in relation to actually driven speeds in the first part of the trial (fixed speed condition).
- Significant age effects emerged for both road environments for the second part of the trial (full control of the vehicle):
    - On urban roads, younger drivers' speed estimates were significantly lower (and more accurate) than middle aged and older drivers', who typically overestimated their speed in this environment. Risk or speed condition did not play a significant role in the accuracy of the speed assessments in this environment.
    - A significant interaction for age and risk for the dual carriageway indicated that the presence of other road users improved the accuracy of middle-

aged and older drivers' speed assessments (which typically comprised underestimations of speeds in this environment),and that older drivers' speed estimates were significantly higher than those of middle-aged and young drivers.

4.6.7 Hypothesis 6

Ratings of stress, nervousness, effort and danger will significantly increase with age, whereas ratings of enjoyment will significantly decrease with age.

Figure 4-14 illustrates participants' mean ratings and standard deviations for ratings of stress, danger, nervousness, effort and enjoyment, separated by age and road environment.

Urban roads

Dual carriageway

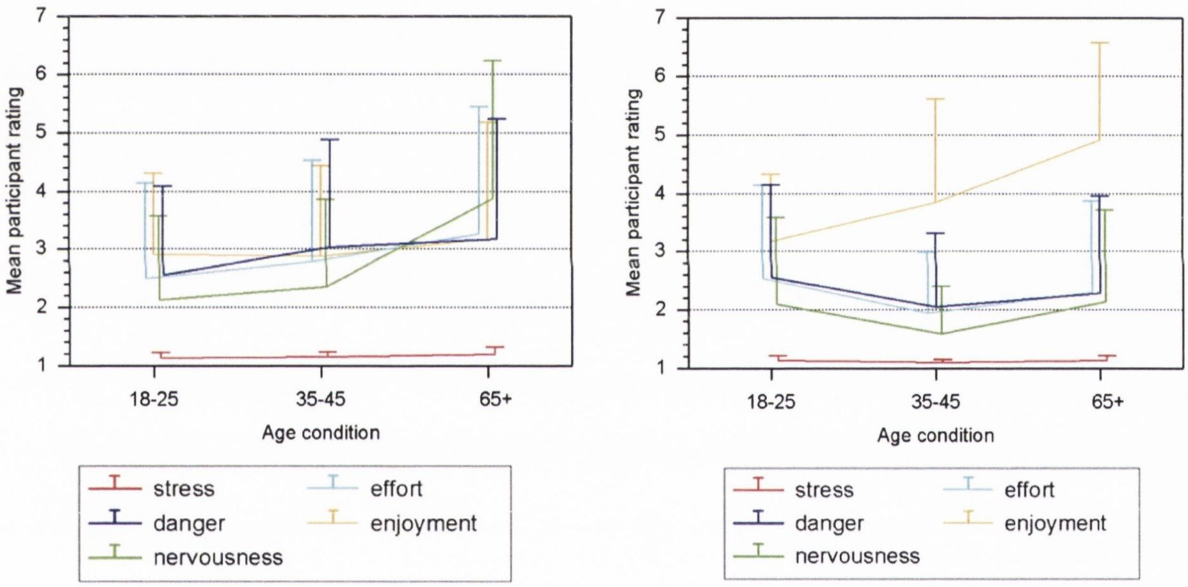

Figure 4-14: Line graphs of participant ratings on danger (dark blue), stress (red), nervousness (light green), effort (light blue) and enjoyment (orange), differentiated by age for urban roads (left) and dual carriageway (right).

Risk perception as a function of age

Split-plot ANOVAs with speed and risk as within factors and age as a between factor were calculated for each of the rating variables and the two road environments. Significant effects are shown in Table 4-9.

Table 4-9: Significant effects of split-plot ANOVAs for participants' ratings of stress, danger, nervousness, effort and enjoyment in the fixed speed driving condition.

Urban roads					
	Stress	**Danger**	**Nervousness**	**Effort**	**Enjoyment**
Speed	$F(2,27)=33.70$ $p=0.001$ partial $\eta^2=0.56$	$F(2,27)=118.29$ $p<0.001$ partial $\eta^2=0.81$	$F(2,27)=54.29$ $p<0.001$ partial $\eta^2=0.67$	$F(2,27)=85.11$ $p<0.001$ partial $\eta^2=0.76$	$F(2,27)=22.25$ $p<0.001$ partial $\eta^2=0.29$
Risk	$F(1,27)=7.65$ $p=0.010$ partial $\eta^2=0.56$		$F(1,27)=4.25$ $p=0.049$ partial $\eta^2=0.14$	$F(1,27)=6.55$ $p=0.016$ partial $\eta^2=0.20$	
Speed *Risk		$F(2,27)=6.00$ $p=0.004$ partial $\eta^2=0.18$	$F(2,27)=3.70$ $p=0.031$ partial $\eta^2=0.12$	$F(2,27)=7.47$ $p=0.001$ partial $\eta^2=0.22$	

Table cont. **Dual carriageway**					
	Stress	**Danger**	**Nervousness**	**Effort**	**Enjoyment**
Speed	$F(2,27)=7.80$ $p=0.001$ partial $\eta^2=0.22$	$F(2,27)=7.66$ $p=0.001$ partial $\eta^2=0.22$			$F(2,27)=4.63$ $p=0.014$ partial $\eta^2=0.15$
Risk		$F(1,27)=9.36$ $p=0.005$ partial $\eta^2=0.26$			
Age					$F(2,27)=5.15$ $p=0.013$ partial $\eta^2=0.28$
Speed*Risk	$F(2,27)=30.66$ $p>0.001$ partial $\eta^2=0.53$		$F(2,27)=27.68$ $p>0.001$ partial $\eta^2=0.51$	$F(2,27)=41.96$ $p>0.001$ partial $\eta^2=0.61$	

The only significant age effect was found for the reported enjoyment of the drive on the dual carriageway. A Games Howell post-hoc test indicated that older participants' feelings of enjoyment were significantly higher than those of young participants across all speeds and risk conditions ($mean_{diff}=1.76$, $p=0.016$).

Summary of findings

- The findings did not support the sixth research hypothesis.
- Significant age effects were only found for the perceived enjoyment of the drive and were in the opposite direction than predicted, indicating that older drivers enjoyed the drive on the dual carriageway significantly more than younger drivers.

4.7 Discussion

The present study tested predictions of the Task Capability Interface Model and expanded on previous replication studies. Based on the model assumption that drivers continuously monitor the difficulty of the driving task (through monitoring feelings of risk) rather than the probability of a collision, Fuller posited a threshold relationship for drivers' subjective likelihood of a collision and linear increases for task difficulty and for feelings of risk with increasing speeds. The current study used the theoretical framework of the Task Capability Interface Model to explore whether age-related changes affect the ratings of feeling of risk as the measure of perceived task difficulty. The reported findings are discussed in the following and conclusions are drawn.

4.7.1 Feeling of risk, ratings of task difficulty and new variables

All previous studies have found feelings of risk to be highly and significantly correlated with ratings of task difficulty. Whilst Fuller et al. (2008) reported correlations of r^2=0.98, Kinnear et al. (2008) found them to range between r=0.71-0.79. Lewis-Evans and Rothengatter (2009) reported correlation coefficients that ranged between r=0.81-0.91. The present study confirmed the posited strong association between task difficulty and feeling of risk with correlation coefficients ranging between r=0.74-0.87, thus closest to those reported by Kinnear et al. (2008). The evidence base to date therefore supports Fuller's posited association between the main variables of the model.

The exploration of additional rating variables carried out in the present study showed that the perceived stressfulness of the drive and (for higher driving speeds) perceived effort, exhibited similar or even higher associations with task difficulty. This could suggest that task difficulty assessments comprise an affective component and a workload component, whereby the workload aspect increases in importance with increasing speeds. The enjoyment of the drives was negatively correlated to task difficulty perceptions, albeit these correlations did not reach significance.

4.7.2 Speed as the main determinant of task difficulty

In line with prediction, speed emerged as the most important predictor of task difficulty; however, the amount of explained variance was considerably lower than that reported by Fuller et al. (2009). The values were closer to those reported by Lewis-Evans and Rothengatter (2009), albeit somewhat lower than those reported for the driving condition on urban roads and dual carriageway in their study.

In line with expectation, the current study found task difficulty and speed to be significantly related on urban roads and the dual carriageway. Speed and collision risk were also significantly associated on urban roads and the dual carriageway; however, the association was, in line with expectation, much lower than those found for speed and task difficulty. The findings from the current study therefore support the notion that speed acts as a main determinant of task difficulty.

4.7.3 The impact of age

As this thesis explores age-related changes on the perception of risk in driving, the investigation of age effects on the main variables of Fuller's Task Capability Interface Model, including ratings of task difficulty, feelings of risk and likelihood of a collision, was a central question of the study. Age-related differences in adopted driving speeds as a measure of participants' preferred range of task difficulty and participants' degree of accuracy in assessing task demand by comparing drivers' perceived speed to their actual driven speed were also explored.

Perceived driver capability was measured through the questionnaire participants completed as part of the study, i.e. ratings of participant confidence, skilfulness and cautiousness of a driver. Drivers also had to rate the perceived difficulty of four driving situations that are frequently cited in the literature as situations that are typically avoided by older drivers (see Section 3.9). The only significant difference found on those variables was higher ratings of the difficulty of driving in bad weather by young drivers, compared to middle-aged and older drivers (a result that was contrary to expectation), given that the literature indicated frequent avoidance of these driving situations by older drivers. This suggests that the older participants in this study did not perceive any age-related reductions in their driving capability. Whilst the absence of perceived age-related reductions in capability is consistent with the literature (Section 3.9.1), it must also be borne in mind that the sample size for the study was very small and that the older driver participant group may be more practised and self-assured about their driving skills than older drivers who would not put themselves forward to volunteer in a driving study.

Significant age differences emerged for the fixed driving part of the study for urban roads. Observed effects were in line with expectation: task difficulty and feelings of risk were rated as significantly higher by older drivers. For estimates of collision likelihood, a significant age * speed interaction effect indicated that older drivers' collision ratings were higher than those of middle aged drivers in the average speed condition and higher than those of middle-aged and young drivers in the high speed condition. No significant age effects were found for the three variables on the dual carriageway. New variables (stress, nervousness, danger, effort and enjoyment) that had been introduced to the study, based on the research by Kinnear et al. (2008) and Lewis-Evans and Rothengatter (2009), only showed a significant age effect for enjoyment on the dual carriageway, where older drivers' reported feelings of enjoyment were significantly higher than those of young drivers.

Significant age effects were also found for the free driving component of the study. On urban roads, older drivers chose significantly lower preferred and maximum speeds than young drivers. On the dual carriageway the speed older drivers adopted (be it preferred or maximum speed) was found to be significantly more influenced by the presence of other road users than that of young drivers. The presence of other road users on the dual carriageway also had an effect on the accuracy of older drivers' speed assessment in the free drive condition: it improved the accuracy of their speed assessments significantly more than that of young and middle-aged drivers. This would suggest that for older drivers, other road users provide an important cue for speed estimates and speed selection on the dual carriageway. For both road environments, older drivers' speed estimates were significantly higher than those of young drivers. Generally middle-aged and older drivers overestimated their speeds in the urban environment and underestimated it on the dual carriageway, whereas young drivers consistently underestimated their speed, but were on the whole more correct in their estimates than the other two age groups.

Significant increases of reported task difficulty, feeling of risk and collision likelihood with age were only observed for the urban environment. No significant age effects emerged for any of the three variables on the dual carriageway. The Task Capability Interface Model would predict that driver capability should reduce with age in the absence of significant differences in driving practice. The finding of older drivers' significantly higher ratings on urban roads supports the Model, if the assumption is accepted, that even the slow speed condition in the urban environment presented a level of task difficulty that teased out age-related reductions in driver capability. An absence of age-related differences, as observed for the dual carriageway, would also be compatible with the Model, if the absence of significant age differences is interpreted as the result of the low task demand of this road environment compared to urban roads and its associated failure to tease out age-related capability differences between the groups. It is interesting in this context that the absence of significant age differences in the post-drive questionnaire suggests that if such age-related decreases in capability were prevalent in the sample, they were not perceived and reported by the older participants in this study. At the same time, older drivers did, as predicted, adopt lower preferred and maximum driving speeds than young drivers on urban roads and on the dual carriageway in the free drive condition; in the latter environment, however only, when other road users were present (a detailed discussion of the influence of other road users is presented in the following Section). In Fuller's terminology this would point to a lower preferred task difficulty range of older drivers compared to young drivers. The pattern of age-effects in this study resonates with the evidence reviewed in Section 3.9, for example the research by Charlton et al. (2006). Here, 80% of older drivers reported that the quality of their driving had not changed, but at the same time 40% reported to have reduced their driving speed compared to what it had been five years ago. Similarly, Marottoli and Richardson (1998) suggested drivers' confidence or self-ratings of ability were independent of actual objective measures of capability. As the current study did not include objective tests of driver capability, conclusions on the influence of actual, age-related differences in capability cannot be drawn, and further research will eventually need to address this question. However, objective measures of capability and difficulty do not enter a driver's decision making process in Fuller's model (as discussed in Section 3.5 and illustrated in Figure 3-7); therefore, the question of how well subjective and objective capability parameters match is not a focal question for this study.

Age-related differences in the perception of speed appear to mediate task difficulty and risk assessments of older drivers. The results indicate overestimations of speed by middle-aged and older drivers in environments that are busy and cluttered (urban roads) and an underestimation of speed and absence of age-related effects on Fuller's main three variables in uncluttered environments (dual carriageways). This would suggest that older drivers are more reliant on speed cues than young drivers, who were on the whole more accurate in their estimates than older drivers. This could support the notion of older drivers becoming more sensitised to task difficulty changes arising from other sources than just speed, a finding that sits well with Ball et al.'s (1998) notion that older drivers avoid driving in situations where rapid or unexpected events occur in a visually cluttered environment and the adoption of slower speeds as a typical strategy of the older driver population in general (see Section 3.9.1).

Overall, the findings are mostly compatible with predictions of the Task Capability Interface Model and could suggest that the main pathway for age-related increases in task difficulty and lower adopted task difficulty ranges in the free driving condition is a perception of increased task demand, without a concomitant perception of decreased capability. This notion would map well onto the synopsis from the literature presented in Section 3.10. The findings are, however, also compatible with the assumption of a general sensitisation to risk with increasing age that is prevalent in situations of high task demand and a greater preferences for increased safety margins, reflected in the adoption of comparatively lower driving speeds.

4.7.4 Other road users' impact on task demand and speed perception

Studies testing the Risk Allostasis Theory have so far focussed on the exploration of speed not only as the main determinant of task demand, but almost as the exclusive one (the only other manipulation being the use of different road environments). It could therefore be argued that the observed high association between speed and task difficulty is an artefact of the way the empirical studies testing the association have been set up. This study introduced the presence of other road users as an additional variable that was predicted to increase participants' perception of task difficulty. Other road users in the urban environment were simulated as oncoming traffic and as other vehicles in the adjacent lane on the dual carriageway. Regression analyses showed that in the fixed speed condition, ambient risk increased participants' ratings in the dual carriageway environment, but explained considerably less variance than speed (4% versus 20%). Split-plot ANOVAs confirmed the findings for the dual carriageway, but also found a main effect of ambient risk on task difficulty for the urban road environment, again in the predicted direction. In the free drive condition, the presence of other road users led to significantly lower driven speeds (both, preferred and maximum speeds).

Overall, the findings of the present study indicated that other road users only really impacted, if they could be reasonable expected to enter the driver's (anticipated) trajectory. It seems plausible that participants' estimates of collision probability should rise in the presence of other road users, as these provide an additional "opportunity" for crashing, which in the absence of other road users is limited to colliding with fixed stationary objects. A possible explanation for why increases on the Model variables were predominantly limited to the dual carriageway may lie in the operationalisation of ambient risk used in the current study: on the dual carriageway other road users (cars) were positioned on the adjacent lane, whereas on urban roads they were operationalised as oncoming traffic. Whilst a collision with a vehicle on the oncoming lane was theoretically possible (given the absence of a central reservation), the findings could indicate that participants felt this possibility to be too remote to have an impact on their ratings. Only vehicles in the adjacent lane appeared to have presented a potential risk factor. The findings suggest that ambient risk will only lead to increases of perceived task difficulty, feelings of risk and likelihood of a collision if there is a realistic expectation to impact the driver's action and trajectory.

This interpretation, if correct, has implications for future operationalisation of ambient risk. The investigation of speed as a manipulator of feeling of risk required participants' uninterrupted driving in the present study. However, if ambient risk as an additional component of task demand is to be explored, ways need to be found to include other road users in the experimental setting that are perceived as relevant to the drivers' decision making without directly impacting it. Cars in the adjacent lane are one possible method, pedestrians crossing the path of the vehicle in the distance or vehicles waiting at crossroads may be another. Alternatively a set of drives could be included in the simulator study where road users in adjacent or oncoming lanes do cross the trajectory of the driver and required him to take action (reduce speed) to avoid a collision, thus instilling a feeling of relevance of these road users to the driving task. These drives could subsequently be removed from analysis.

In addition to the impact of other road users' presence on task demand (and thus, task difficulty), the analyses of the accuracy of speed assessments in the second part of the trial (the free drive condition) indicated an impact of ambient risk: Speed assessments became more accurate in the presence of other road users on the dual carriageway (but not on urban roads). This could mean that only such "relevant" road users are processed as useful information about the environment, e.g. as cues when assessing speed. An alternative explanation would be pre-existing differences in the road environment itself: whereas urban roads in the simulator are framed with buildings, road furniture and (static) pedestrians, the dual carriageway was comparatively 'empty'. This could mean that participants had more visual cues in the urban road environment, so that the absence or presence of other, moving road users, had less of an impact than in on the dual carriageway, where these other road users carried comparatively more information as a cue for speed.

4.7.5 Video scenes versus simulated scenes

The present study found coefficients that were closer to those reported by Lewis-Evans and Rothengatter (2009), who also used a driving simulator, than those reported by Fuller et al. (2008) and Kinnear et al. (2008), who both used video-recorded material. Two potential explanations for this difference spring to mind, without the possibility of determining their relative impact on the current findings. Differences may either be due to the difference in the methodology, namely the use of a driving simulator as opposed to video-scenes of a drive. Alternatively, the difference could be attributed to the fact that both, the present study and Lewis-Evans study randomised the speed conditions, which in Fuller et al.'s (2008) and Kinnear et al.'s (2008) research, were presented in ascending order. Whilst the authors of both studies refer to a study that implied that order effects in speed presentation were negligible, it seems plausible to assume that a presentation of videos by increasing speed should impact participants' expectations about each subsequent video and therefore, their ratings. The findings from studies that presented speeds in randomised order should therefore be more reliable than those that did not.

4.7.6 Linear increase versus threshold of collision likelihood

As the discussion of previous studies testing the Risk Allostasis Theory (see Section 3.8) has shown, there is an on-going theoretical debate over the question whether driver ratings follow a threshold model or linearly increase from the very lowest speed condition onwards. The Risk Allostasis Theory posits that drivers continuously monitor their feelings of risk, which is linearly associated with the difficulty of the driving task, but not with the probability of a collision; therefore Fuller posited a threshold relationship only for drivers' subjective likelihood of a collision, but linear increases for task difficulty and feelings of risk. Findings from Fuller et al.'s (2008) two video-based studies corroborated the posited associations and supported his assertion that the driver's focus is on the maintenance of control rather than on the probability of a collision. However, since these two earliest studies, further research evidence has emerged that paints a less clear picture. Kinnear et al. (2008) found no clear thresholds for participants' estimates of collision likelihoods. Instead, these probability estimates increased linearly from the lowest speed condition onwards, even though considerably less strongly than task difficulty and feeling of risk did. Lewis-Evans and Rothengatter (2009) observed threshold relationships for all of his dependent variables, including task difficulty, feeling of risk and probability of a collision. They interpreted this as evidence for the Zero Risk Model which posits that driving is typically characterised by the absence of risk and as evidence contradicting the assumption of continuous monitoring of feeling of risk. Because the present study only used three speed conditions (low, average, high) the data did not permit a full exploration of the question, whether the dependent variables linearly increased or followed a threshold model. However, some conclusions can be drawn. A considerable proportion of drivers (approximately 30%) rated the probability of a collision as greater than zero in the lowest speed condition in both road environments. This eithers contradicts Fuller's assumption that driving is typically characterised by the absence of consideration of the likelihood of a collision or means that even the lowest speed condition was already above the participants' collision probability threshold. However, the findings of the current study also point toward a third possible explanation. Reported collision probability estimates in the current study were in some instances as high as 80%, suggesting that participants believed that they would have a crash 80 out of 100 times if they drove at a particular speed in a particular environment. However, no collisions occurred throughout the entire length of the study, and road traffic collision statistics indicate that collisions are generally rare events.

The most parsimonious explanation for the contradictory findings regarding drivers' estimates of collision likelihoods would appear to be their poor ability to assess statistical risk, leading to considerable variation in collision estimates. This conclusion echoes other researchers' notion of people as poor intuitive statisticians (Kahneman, 2011; Slovic, Finucane, Peters & MacGregor, 2004) who do not have sensitivity to low probability events (McKenna, 1988; Rothman, Klein & Weinstein, 1996). It is ultimately also in line with both, the Risk Allostasis Theory and the Zero Risk Model, which both suggest that collision risk does not influence driver decisions.

4.7.7 Limitations of this study

The fact that the current study relied exclusively on subjective measures of driver capability has already been discussed in Section 4.7.3. It therefore cannot answer the question whether observed, age-related adaptation in driving behaviour are the result of a greater preference for comfort, as suggested by some authors, or are the reflection of objective age-related reductions in driver capability, that older drivers are unaware of and therefore do not report. This remains a question for further research. As the self-assessment data from the driving questionnaire indicated, the older drivers in the sample did not report any age-related limitations of their capability. It is possible, that the present sample, recruited through a TRL volunteer database, was more confident of their driving skills than non-volunteers in driving research would be. However, given that age-effects emerged despite of this self-selection for research, this limitation does not call the findings into question, but, if anything, lends additional support to the findings.

The present study exclusively relied on self-report as a measure of perceived risk and difficulty. However, as discussed earlier, feelings may not always be conscious and may therefore be difficulty to cognitively assess and report. Given that the results of the present study point towards the contribution of an affective component in task difficulty assessments (i.e. stress), future studies should include physiological measures in addition to self-report measures. General concerns over self-report as a measure, e.g. the requirement for participants to be honest, and well-established biases such as the halo effect should also be mentioned regarding the limitations of the present study.

Similar to other empirical work testing the tenets of the Task Capability Interface Model, the present study focused very much on speed as the main manipulator of task difficulty, and empirical findings are likely to reflect this. Whilst the current study made an attempt to explore the contribution of other sources of risk, further studies need to include appropriately operationalised sources of risk.

The sample size for the current study was small, leading to comparatively low statistical power and its associated problem of potentially not detecting significant effects. Whilst university-based research provides relatively easy access to large numbers of study participants, the current study was carried out on a limited budget from a private research company and had to compete with other, commercial project for time in the company's driving simulator. The extension of the study for additional data acquisition to increase the statistical power of the analysis was therefore not possible.

The study may furthermore lack generalisability of results to the wider population of drivers. As a standard procedure, participants in the TRL participant pool are familiarised with the simulator before they take part in any studies using this tool and therefore have prior experience with simulators that is not typical of the general population. It can furthermore be argued that participants who put themselves forward for participation in driving-related research are more confident of their driving skills than the general population, where a proportion of drivers may be hesitant to drive 'under scrutiny'. Particularly older drivers frequently voice concerns in relation to procedures where they perceive the maintenance of their driving licence under theat. Whilst it was made clear during participant recruitment that participation in the trial would not impact licence status, it appears reasonable to assume that the obtained, self-selected participant sample may have been fitter and more at ease with driving than the average driver. This could to some degree account for the relative high reported confidence levels, particularly in the older participant group.

Finally, data acquisition in the current study predominantly comprised the gathering of subjective rating data. Some influence of the common method bias therefore has to be expected and emphasises the need to collect additional measures of risk perception to develop our understanding of these processes in older drivers.

5 Exploring new theoretical avenues for research: Affect and driving risk

Several results from the previous study stand out and are briefly repeated here to guide the direction of further research in this dissertation:

- Ratings of feeling of risk were found to track ratings of task difficulty, as shown in previous studies testing Fuller's Task Capability Interface Model. Ratings of effort, stress, danger and nervousness show similarly high correlations with task difficulty, particularly in high demand situations.
- Ratings of task difficulty, feeling of risk and likelihood of a collision were higher for older drivers than young drivers in busy, cluttered road environments, and their perceptions of driven speed were higher than those of younger driver. Older drivers' adopted speeds on these roads were comparatively lower than those of younger drivers.
- The presence of other road users significantly improved older drivers' accuracy of speed perceptions on the dual carriageway.
- Ratings of likelihood of a collision are readily produced by all age groups, but support the notion of humans as poor intuitive statisticians and appear inappropriate as a parameter capable of guiding driving decisions.

To facilitate the interpretation and theoretical embedding of these findings, as well as to develop the direction of further research as part of this dissertation, the next chapter outlines the literatures on the role of affect and decision making and age differences in emotional reactivity.

5.1 The importance of affect for risk perception

To briefly repeat, Fuller's Risk Allostasis Theory posits that the feeling of risk is the variable that ensures that perceived task difficulty remains within the acceptable range and influences driving decisions. According to Fuller, both parameters are integrated in a comparator which comprises a meta-cognitive process and is sensitive to the degree of deviation from sub-goals of the driving task (see Figure 5-1). Driving goals are feelings-motivated and involve both positive, approach-motivating feelings, associated with the achievement of the mobility goal and negative, avoidance-motivating feelings, associated with collisions or road run-offs. Whilst those latter feelings of risks are continuously monitored according to Fuller, they may only become salient in the driver's conscience, once a certain threshold has been exceeded and provide a fast heuristic for decision making in the dynamic road environment. Fuller suggested that further research to clarify the interplay between affective and cognitive appraisal components in this context is required.

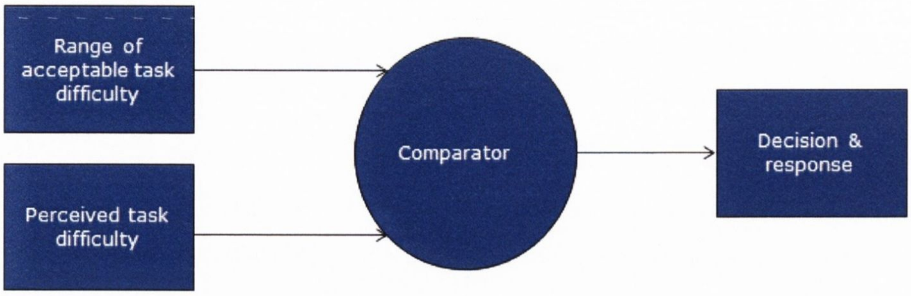

Figure 5-1: Comparator element of Fuller's Risk Allostasis Theory.

Lewis-Evans and Rothengatter (2009) have criticised Fuller's conceptualisation of feeling of risk as a variable that is continuously monitored, but is at the same time frequently unconscious, and have argued that *"In psychology, a feeling is a subjective and conscious experience of an emotion, with emotions being seen as objective physiological and mental states."* (p. 1054). The apparent contradiction in what constitutes a feeling somewhat resonates with Sjöberg's (2006) criticism that the terms "feelings", "affect", "liking" and "emotion" are frequently not tightly defined, used interchangeably and have led to an overestimation of the role of emotion for risk perception. Whilst Wardman (2006) agrees that definitions of affect, emotion or feeling have proven difficult to isolate in the existing body of research, he argues that this is in part due to the theoretical focus that has guided research today, which has emphasised the study of factors that underlie subjective experiences of emotion (e.g. cognitive appraisal models). However, several definitions of the various terms have been put forward. Slovik et al. (2004), p.312) characterise affect as a "faint whisper of emotion" which describes the quality of "goodness" or "badness", (1) is experienced as a feeling state (with or without consciousness) and (2) demarcates a positive or negative quality of a stimulus. Furthermore, Figner and Weber (2011) differentiate affect into:

- Integral affect, which describes the influence of subjective experiences directly relevant to present judgements, e.g. an emotion that is experienced from evaluating a situation at hand or anticipated as a consequence of an action;
- Incidental affect, which comprises the influence of subjective emotional experiences which are unrelated to the situation at hand, but which may have direct or indirect impacts on present judgements.

Bechara and Damasio (2005, p.339) define an emotion as *"a collection of changes in body and brain states triggered by a dedicated brain system that responds to specific contents of one's perceptions, actual or recalled, relative to a particular object or event"*.

Emotionally relevant stimuli cause a change in somatic state, ranging from endocrine release, heart rate change, muscle contraction to facial expression and specific behaviours such as freezing, fight or flight. Physiological responses lead the brain to respond by releasing neurotransmitters through the central nervous system, activate somatosensory maps or modify the transmission of signals from the body to the somatosensory regions. According to Bechara and Damasio (2005), the ensemble of all these enacted responses in the body and in the brain constitutes an emotion. Feelings on the other hand are defined as the mental representations of the physiological changes that characterise and are consequent upon processing emotion-eliciting objects or states in the individual in whom they occur (Damasio, 1999, 2003; Dolan, 2002). According to Epstein (1994), feelings that guide associative decision making are so subtle that people may not be aware of them. After this brief clarification of terms, a brief review of the emerging literature on affect and decision making is provided to facilitate a deeper understanding of the findings summarised at the beginning of this chapter, but also to inform the further progression of this dissertation.

According to Loewenstein, Weber, Hsee and Welch (2001), the topic of judgement and decision making under risk and uncertainty has been one of the most active and interdisciplinary research topics in judgement and decision making in recent years. Considerable attention and research has been targeted at Subjective Expected Utility (SEU) Theory, the testing of its assumptions and the exploration of the wide range of deviations from its predictions. Proponents of SEU theory and, as Loewenstein et al. (2001) put it, subscribers to "consequentialist" perspective assume that people make decisions based on the assessment of severity and likelihood of consequences of possible choice alternatives and integrate this information through some type of expectation-based calculus to arrive at a decision. Decision making under this framework is an essentially cognitive activity, and the study of emotion, if considered in this context, has been restricted to emotions which are anticipated to occur in the future as a potential consequence of a decision, such as disappointment or regret. However, the research evidence in the area of risk perception and decision making suggests that under certain circumstances, people's judgements can considerably diverge from consequentialist judgements (for example, see Alhakami & Slovic, 1994). This strand of research emphasises the importance of anticipatory emotions to risk and uncertainty, which are described as immediate, visceral reactions of fear, anxiety or dread and which direct the individual's best course of action (Loewenstein et al., 2001).

The importance of affect for decision making was emphasised as early as 1960 in a publication by Mowrer who proposed that conditioned emotional responses to images (such as hope or fear) in terms of prospective losses and gains guided performance in an adaptive manner and served as motivating states, leading to action. Simon (1967) suggested that rapid emotional reactions served as a mechanism to interrupt and redirect cognitive processing toward potential sources of danger. Similarly, Zajonc (1980) suggested that affective reactions to stimuli occurred rapidly and automatically, thus serving as an orientating mechanism that guided subsequent information processing and judgement. A succinct overview on enhancement of attention, perception, memory and learning through emotion and the brain areas and neurological pathways involved has more recently been presented by Dolan (2002).

Concomitant with research into the circumstances under which Expected Utility predictions fall short of predicting actual decision making, there is a growing body of evidence from social psychology and neuroscience that lends support to dual-process models of thinking, knowing and decision making. Smith and DeCoster (1999) suggest that existing dual-processing models share a set of common features and differentiate between two basic systems of decision making:

- One type of processing that involves the use of simple, well-learned and readily available decision rules (so-called heuristics), is fast and requires little effort;
- One type of processing that is slow, rational and requires active, effortful scrutiny of all available information, thereby demanding considerable cognitive capacity.

Existing models differ in whether they assume that the two processing modes operate simultaneously, in sequence or as alternatives, and in whether motivational or capacity determinants of more effortful processing are emphasised (Smith and DeCoster, 1999). For example, Sloman (1996) has outlined a two-process model of reasoning and problem solving, which comprises an "associative" and a "rule-based" process. Associative processing is quick, intuitive and relatively effortless as it relies on retrieval of information that has become associated with currently available cues as a result of learning. In contrast, rule-based processing involves the use of symbolically represented rules to manipulate problems and derive solutions. As these rules are abstract, they can be bound to specific contents. According to Sloman (1996), both modes usually work together, not as alternatives. Nobel Laureate Daniel Kahneman (2011) recently produced a comprehensive and fascinating account of the scientific basis of several decades of cognitive research into judgement and decision making and proposed a dichotomy between two modes of thought in his book "Thinking, fast and slow". The so-called System 1 is fast, experiential and emotional; System 2 is slower, more deliberative and more analytical. Based on Loewenstein et al.'s (2001) work, the first mode of dual processing models has been characterised as "Risk as feeling" and the second mode "Risk as analysis" (Slovic et al. 2004; Finucane & Holup, 2006).

According to Epstein (1994) the associative or experiential mode of thinking is intimately associated with the experience of affect, which he describes as subtle feelings of which people are often unaware. The posited mechanism for the associative or experiential mode of thinking is the automatic search of memory, triggered by an emotionally significant cue that is salient in the current context, for knowledge or affective reactions that have become associated with this cue. If the feelings are pleasant, actions and thoughts are activated that are anticipated to reproduce these feelings. If the feelings are unpleasant, then actions and thoughts are activated that are anticipated to avoid the feelings. Sloman (1996) emphasises that the learning of associations requires repeated experience over a long time. Epstein (1994) suggests that the activation process is assumed to be automatic and pre-conscious, so that it becomes subjectively part of the stimulus information (rather than being part of the perceivers' own evaluation or interpretation of it). These descriptions of affective learning by cued activation of affect and knowledge also resonate with neuroscientist Damasio's Somatic Marker Hypothesis (see also section 3.5) which originated from research into changes in the decision making processes of patients with damage to their prefrontal cortex. According to his hypothesis, cognitive images become marked over time by positive and negative feelings linked directly or indirectly to somatic or bodily states. When triggered, these markers send an affective signal (a gut feeling) which precedes and guides subsequent decision making, thereby increasing the accuracy and efficiency of the decision making process. The absence of such markers in patients with damage to the prefrontal cortex leads to an inability to recognise emotion and to degraded decision performance. Damasio concluded that these patients had to rely on a cost-benefit analysis which degraded the speed of deliberation and the adequacy of the choice (Damasio, 2003). The research base and lively debate in relation to the Somatic Marker Hypothesis has inspired further work into the role of affect.

Building on Damasio's work, Finucane, Alhakami, Slovic and Johnson (2000) posit that all images in people's minds are tagged or marked to varying degrees with positive or negative affective markers of varying intensity, and that people consult this affect pool in making judgements, if fast and efficient processing is required or when mental resources are limited. Affect therefore provides important cues for many judgements (including probability judgements), in addition to factors such as imaginability, memorability and similarity. The authors called this fast judgement mechanism, which relies on affective cues the "affect heuristic" (see also Slovic et al., 2004; Finucane & Holup, 2006). Drawing on Alhakami & Slovic (1994) who suggested that affect preceded cognition, when judging the risks of a particular activity or technology, Finucane et al. (2000) tested the affect heuristic in two studies that illustrated the inverse relationship between judgements of risks and benefits of different technologies. In the first study 54 students judged various technologies (23 items) on 7-point scales (ranging from 'not at all risky/ beneficial' to 'very risky/ beneficial'), either under time pressure or not. The authors expected participants to rely more heavily on the affect heuristic when their opportunity for analytic deliberation was reduced and an efficient mode of judgement was needed. In line with predictions, correlations between risks and benefits were negative, and were stronger under conditions of time pressure.

Their second study tested whether the manipulation of the overall affective evaluation (which the affect heuristic posits to precede) would change the assessment of risk and benefit. The overall affective evaluation was manipulated by providing participants with four pieces of information on three different technologies:

- Risk is high;
- Risk is low;
- Benefit is high;
- Benefit is low.

The authors posited that if participants used cognitive analysis, then the provision of information on one aspect (risk or benefit) should not change the perception of the other. Ten point scale ratings were collected from 213 students once before the information manipulation and once after. The results indicated that when the information manipulation was successful, the effect on the non-manipulated attribute was in the anticipated direction in 45% of the cases. No change in the non-manipulated variable was observed in 31% of the cases, and a change in the non-anticipated direction occurred in 23% of the cases. Based on these findings, the authors concluded that participants displayed a tendency towards affectively consistent judgements and that the findings did not fit with a merely cognitive approach to risk perception, but that perceptions and judgements were linked by an affective communality.

In their synopsis of research on affect and decision making, Finucance and Holup (2006) conclude that converging evidence is needed for the hypothesised effects of affect and analysis on risk perception and that multiple dependent variables and methodological approaches should be used to provide conclusive evidence and to enable testing of alternative explanations of results. The authors present Bechara, Damasio, Tranel and Damasio's (1997) study as a good example of the required multi-measure approach. The methodology applied in the study of affective and analytic evaluation processes involved in gambling decisions included behavioural measures, psychophysiological measures (skin conductance responses) and subjective reports and enabled the exploration of the interplay between non-conscious signals and overt knowledge. Participants in this study received $2000 in facsimile notes and were asked to maximise wins and minimise losses in their gamble by selecting from four decks of cards. Sampling from decks A and B was rewarded with wins of $100, sampling from decks B and C led to $50 wins. However, unpredictable for participants, decks A and B also held cards that brought high penalties, whereas in decks C and D these penalties were smaller. Drawing from decks A and B led to an eventual overall loss, whereas playing from decks C and D led to an overall gain (the game ended after 100 card selections). Bechara et al. (1997) compared the performance of 10 normal participants and 6 patients with bilateral damage of the ventromedial sector of the prefrontal cortex and decision-making defects. To explore whether and when the participants became aware of the nature of the game, they were asked after each turning of 10 cards, what they thought was going on in the game and how they felt about the game. Anticipatory skin conductance responses to the disadvantageous decks A and B began to develop after approximately 10 cards in normal participants. Skin conductance responses in these participants were greater when selecting a card from the risky decks. However, subjective reports indicated that these participants only began to develop a hunch about the nature of the game by card 50. By card 80, seven of the ten participants had developed a full understanding, whilst the remaining three participants continued making advantageous choices without understanding why. Three of the participants with brain damage on the other hand, who eventually understood the nature of the game, continued to make disadvantageous choices, and none of the participants with brain damage developed anticipatory skin conductance responses to the disadvantageous decks. Bechara et al. (1997) interpreted these findings as evidence that autonomic responses acted as non-conscious signals, which had been acquired through prior conditioning and the affect associated with it and facilitated the efficient processing of knowledge and logic necessary for conscious decisions. Since this early study, many replications and variations of the original paradigm have been carried out, including a study by Denburg, Tranel and Bechara (2005) with a sample of 80 young (26-55 years) and old (56-85 years) healthy participants, which indicated an unexplained age-related decline in the gambling performance of a subset of the older participant group. The hypothesis and associated empirical body have been subject to extensive debate and some criticism of method and interpretation (see Kinnear, 2009 for an excellent review), most importantly in relation to how participants were asked about their knowledge of the decks and the question, whether skin responses truly preceded understanding (Maia & McClelland, 2004). Using more direct questions in their replication study, Maia and McClelland (2004) found that participants' advantageous performance on the task was almost always accompanied by verbal reports that indicated understanding and therefore suggested that a non-conscious bias was not necessary to explain the findings. In response, Bechara et al. (2005) adjusted their initial position and proposed that emotion-related signals assisted, rather than guided cognitive processes, even when they were non-conscious, and this tenet that emotion-related signals assist and improve cognitive processes, even when they are non-conscious, seems to be holding (Bechara & Damasio, 2005; Kahnemann, 2011).

Driving is a task that requires constant monitoring and frequently quick decision making to avoid collisions in a dynamically changing environment. In comparison to the highly-controlled decision making experiments in the emerging affect and decision making literature where risks, consequences and contingencies are clearly defined and can be systematically manipulated, driving behaviour research is downright messy in comparison. Nevertheless, the review of the emerging research in the field of decision making ties in with previously reviewed (Chapter 3) theories of driving risk, which have also implicated emotional reactions such as anxiety, tension and fear in driving; however, mostly without detailed accounts of the hypothesised brain structures involved and of the underlying neurological pathways. The exception is Fuller, who, starting from his initial position of conditioned fear responses (see Section 3.4), attempted to integrate the Somatic Marker Hypothesis in his later theoretical work. The emerging neuroscience research provides interesting and fruitful inputs for driving research, where the accurate perception of risk if of obvious relevance. Naturally, a lot of the recent research on the role of affect in decision making to date has focused on the question of how non-conscious, affective reactions/ markers are initially established. However, the interest of this thesis lies in the question of how risk perception changes with age, and hence, the focus of this thesis is to identify, how the contribution of affective reactions to decision making processes may change over the course of the lifespan, rather than addressing the process of their initial acquisition.

Evidence that can further inform the development of research hypotheses in this context comes from the currently small body of literature that has investigated age-related difference in the emotional reactivity, predominantly in Germany and the United States. The concept of emotional reactivity thereby relates to *'the characteristics of emotional responding including the threshold of stimuli needed to generate emotional response and the intensity of the various components of the emotional response'* (Carthy, Horesh, Apter & Gross, 2010, p. 24). As discussed earlier, emotional responses comprise a set of components such as facial expression, physiological response and subjective experience which can have, according to Davidson (1998), different thresholds within the same individual. Of particular interest in the current context are age-related changes in the subjective experience and of physiological reactions evoked in response to emotionally significant stimuli.

Based on the review of studies on emotional reactivity, Kunzmann, Kupperbusch and Levenson (2005) suggest that the three different response systems of an emotion show different age trajectories: autonomic reactivity in older adults has reliably been found to be diminished, due to the decrease of sympathic and parasympathic innervation, whereas subjective and behavioural reactions to emotion-arousing stimuli seem to be undiminished in old age (including amongst others, anxiety, fear, stress and engagement). Richter (2009) paints a slightly more complex picture for experienced emotions, and suggests that if the emotional stimuli are age-relevant, their subjective experience may even be stronger for older people. There appears to be consensus that the basic capacity to react to emotion-inducing events on a subjective and behavioural level remains intact, despite older adults' lower physiological reactivity (Richter, 2009).

Streubel and Kunzmann (2011) state that age-related differences in affective information processing are well established, including the so-called "positivity effect" which describes older adults' greater preference for positive and/or avoidance or diminished processing of negative information in comparison with young adults. Positivity effects have been speculated to derive from the limited future time perspective in older adults which promotes the optimisation of emotional satisfaction in the present moment (Scheibe & Carstensen, 2010). Positivity effects in older adults have been demonstrated in attention, memory and decision making tasks (Mather & Carstensen, 2005), have been replicated several times and are reported to occur on all levels of information processing and emotional outcomes (Scheibe & Carstensen, 2010). However, whilst the effect has been repeatedly demonstrated, there is an on-going debate over its reliability and its underlying causes. Neuroimaging studies have demonstrated increased activation in response to positive stimuli and decreased activation in response to negative stimuli. Brain regions involved in the processing of emotional stimuli include the amygdala and cortical and subcortical regions, associated with regulatory control. Scheibe and Carstensen (2010) argue that as the activation of the involved brain structures is modifiable through experimental manipulation, it is unlikely that the phenomenon of positive affect trajectories, observed in the positivity effect, are the result of a structural degradation of brain regions responsible for the processing of negative material. In a study with 52 young adults (18-30) and 52 older adults (61-80 years) which gathered subjective ratings of pleasantness/unpleasantness, arousal and intensity of experienced emotion in reaction to 172 colour pictures, Streubel and Kunzmann (2011) were able to demonstrate that arousal played a mediating role for subjective emotional reactions and observed positivity effects in older age. The picture stimuli covered a wide semantic content (including families, babies, food, nature and animals, erotica, physical attacks, illness and death, pollution, mutilation) and a range of emotional qualities (namely sadness, anger, disgust, fear and joy) for all permutations of pleasantness/

unpleasantness and high versus low arousal. The findings supported the notion that positivity effects in older adults' emotional reactivity were reduced under conditions of high emotional arousal and high age-relevance of stimuli. In their discussion, the authors concluded that future research needed to include measures of the autonomic nervous system such as heart rate and electro-dermal activity, particularly, since those measures are known to somewhat dissociate with age. An overview of skin conductance as the physiological measure that has received particular attention in the affect and decision making literature, is provided in the following.

5.2 Skin conductance

5.2.1 Anatomy and pathways

According to Boucsein (1992) the terms 'electro-dermal activity' (EDA) and 'skin conductance' (in older terms "galvanic skin response") are often used interchangeably. Both describe momentary changes in electric conductance of the skin in reaction to external or internal stimuli that are physiologically arousing. EDA responses are sensitive to stimulus novelty, intensity and significance, and the EDA system has been linked to the psychological concepts of arousal, emotion and attention. 'Arousal' is thereby used as a broad term which refers to overall and non-specific activation. It constitutes an important component of an emotional response, as already mentioned in Section 5.1. Arousal has also been found to be a strong predictor of attention and memory. In simplified terms, EDA responses are a result of eccrine sweat gland activation, changing moisture levels of the skin surface and a resulting potential change (Kucera, Goldenberg & Kurca, 2004). Approximately 3,000,000 sweat glands cover the human body; their predominant function is thermoregulation via evaporative cooling. Sweat glands are embedded in the human skin, which is composed of three layers, the epidermis, the dermis and the subdermis. As shown in Figure 5-2, the secretory part of the eccrine sweat gland is located in the subdermis, and a long sweat duct leads through the dermis and epidermis to the skin surface, where it opens into a sweat pore.

Whilst all sweat glands play a role in thermoregulation, sweat glands on palmar and plantar surfaces have been associated with grasping behaviour, and it has been suggested that they are more sensitive to emotional than to thermal stimuli (Edelberg, 1972a, cited by Dawson et al. 2000), e.g. in states of high activation and stress. The density of sweat glands is greatest on the forehead (360 per cm^2), palmar (233 per cm^2) and plantar (620 per cm^2) surfaces.

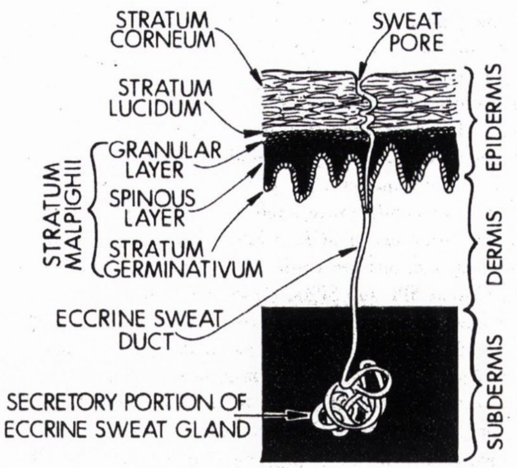

Figure 5-2: Skin layers and anatomy of the eccrine sweat gland (Dawson et al. (2000), p. 202).

Skin-conductance responses are mediated by the sympathetic part of the autonomous nervous system; however, whilst noradrenaline is the neurotransmitter typically associated with peripheral sympathetic activation, the neurotransmitter involved in electro-dermal activity is acetylcholine. Research today suggests that the innervation of sweat glands involves several complex neural pathways that are distributed across different parts of the brain. Boucsein (1992) suggests three relatively independent pathways that lead to the production of skin conductance responses.

- The first level comprises excitatory influences from the Hypothalamus which are believed to serve thermoregulative sweating and excitatory as well as inhibitory influences from the limbic system; the excitatory influences originate from the amygdala and are assumed to be responsible for EDA activation in affective processes; the inhibitory effects originate from the hippocampus.
- The second level involves influences from the contralateral cortical and basal ganglions; excitatory control originates from the premotor cortex and is assumed to elicit EDA responses in situations that require fine motor control; excitatory and inhibitory influences originating from the frontal cortex are assumed to occur during orientation and attention reactions.
- The third and lowest level comprises excitatory pathways from the reticular formation in the brainstem and an inhibitory pathway in the bulbar level of the reticular formation.

These findings paint a complex picture of the central control of sweat gland activity and its different functionalities. Research has also investigated the peripheral mechanisms that underlie the occurrence of changes in skin conductance in response to internal or external stimuli. Following the presentation of such stimuli sweat rises in the long part of the sweat gland, the sweat duct. As sweat fills the ducts, this creates a more conductive path through the relatively resistant corneum. The higher the sweat rises, the lower the electrical resistance in that sweat gland. Each of the sweat ducts therefore acts as a variable resistor. Together the sweat glands, which are densely dispersed across the skin, act as variable resistors wired in parallel. The level of skin resistance or conductance the skin displays at a given moment in the absence of an arousing stimulus is the so-called tonic level or SRL (skin resistance level)/ SCL (skin conductance level). The skin conductance level relates to the slower acting components and background characteristics of the EDA and is believed to reflect general changes in arousal (Braithwaite, Watson, Jones & Rowe, 2013). Whilst the corneum is always partially hydrated, it can become drier, for example because of aging, in which case the tonic skin resistance increases. Phasic decreases of skin resistance (increases in conductance) occur in response to internal or external stimuli like wavelets, superimposed on the constantly moving baseline of the tonic level. They relate to the faster changing elements of the signal and are referred to as skin resistance response (SRR) or skin conductance response (SCR).

Electro-dermal activity has been the subject of research for a considerable amount of time. In 1888 Fere found that when passing a small electrical current across two electrodes placed on the surface of the skin, one could measure momentary decreases in skin resistance to a variety of stimuli. Since this early research EDA measures have been applied to a wide variety of questions, ranging from basic research examining attention, information processing and emotion to more applied clinical research, examining the predictors and/or correlates of normal and abnormal behaviour. According to Dawson et al. (2000) the wide application of EDA in research is in part due to the relative ease of measurement and quantification.

Two methods of measuring EDA are used in research, the exosomatic and the endosomatic method. According to Dawson et al. (2000) the exosomatic method of measuring skin resistance is the prevailing method used in current scientific research, partly, because the passive electrical properties of the skin system have a simpler form than endosomatic ones. When the recording of skin potential response does not involve the application of an external current and only considers active electrodermal phenomena, this is referred to as the endosomatic method. When skin resistance (or its reciprocal, skin conductance) is measured via the exosomatic method, a small external current is applied across the skin and the skin's passive electrical properties are investigated. Exosomatic measurements utilise Ohm's law, which states that the current passed through a conductor between two points is directly proportional to the potential difference across the two points (Boucsein, 1992). The resistance of the conductor, the skin resistance (*R*), is then equal to the voltage (*V*) applied between two electrodes placed on the skin surface, divided by the current (*I*) being passed through the skin: $R=V/I$. This equation means that if the current is held constant, then the voltage between the electrodes varies directly with skin resistance. If the voltage is held constant, then one can measure the current flow which will vary directly with the reciprocal of the skin resistance, skin conductance. Constant-voltage systems are recommended for the exosomatic direct measurement of skin conductance units as the preferred method (over constant-current systems).

5.2.2 EDA measurements

Several authors recommend the use of silver-silver chloride cup electrodes (Dawson et al., 2000; Fowles, Christie, Edelberg, Grings, Lykken & Venables, 1981). The electrodes should be affixed to the skin with double-sided adhesive collars that help to control the size of the skin area that comes into contact with the electrode paste. Electrode paste used for skin conductance measurements should resemble the salinity of the skin and should preserve the bioelectrical properties of the system under study (Christie, 1982). According to Dawson et al. (2000) and Fowles et al. (1981), acceptable exosomatic EDA measurement sites include either the volar surfaces of the medial or distal phalanges or the thenar and hypothenar eminences of the palm (see **Figure** 5-3). Boucsein (1992) recommends the use of the non-dominant hand, as it tends to be less callous and because the risk of movement artefacts is lower. Electrode cables should be secured to the wrist with adhesive tape to further minimise the risk of movement artefacts and the displacement of electrodes.

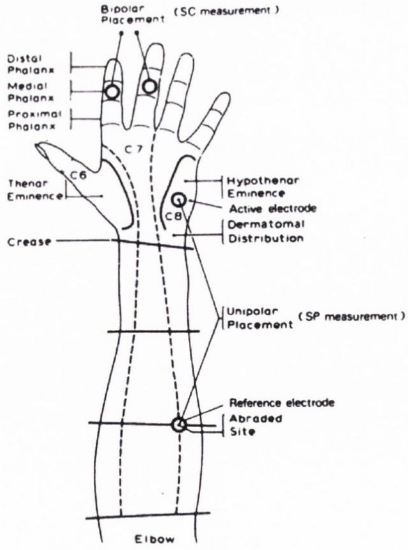

Figure 5-3: Alternative electrode placement sites in EDA measurement (Christie (1981), p. 619).

Researchers' recommendations regarding the pre-measurement treatment of the electrode sites vary in that Boucsein (1992) recommends washing them with lukewarm water and wiping them with ethanol; in contrast, Dawson et al. (2000) suggest that the placement sites should be clean and dry and that no harsh soaps or alcohol should be used that could destroy the electrodermal properties of the skin. Kucera, Goldenberg and Kurca (2004) furthermore point to the importance of the ambient and body temperature for SCRs and suggest that the room temperature of the experimentation room should be kept constant at approximately 26 degrees. Given nowadays data storage capacities, Figner and Murphy (2011) recommend the use of a 1kHz sample rate for EDA measures. EDA responses are characterised by considerable intra- and inter-individual variability. For tonic SCL, Dawson et al. (2000) report a typical range of 2-20 micro siemens. SCL gradually decreases at rest and rapidly increases when new stimuli are introduced, leading to a phasic EDA response, the so-called specific SCR. Historically, amplitude changes of 0.05 micro siemens in conductance have been set to count as an elicited SCR (a visible deflection in old paper chart records). With the advent of modern analysis software, values of 0.02 micro siemens for an elicited SCR are not uncommon in the contemporary literature (Braithwaite, Watson, & Jones, 2013). Stimulus repetition leads to eventual habituation, and habituation is reported to occur between 2-8 stimulus presentations. Kucera, Goldenberg and Kurca (2004) also report a time-on-task effect of SCRs and report significant drops in amplitude after 15-20 minutes of examination. They recommend limiting any test involving SCRs to fifteen minutes, irrespective of the type of stimulus used.

The graphical illustration of a phasic EDA response is shown in Figure 5-4. After a latency period of typically 1-4 seconds, the typical amplitude of a phasic SCR (onset to peak) ranges between 0.2 -1.0 micro siemens; the time elapsed between the onset of a phasic SCR and its peak ranges between 1-3 seconds. The ER SCR recovery time is 2-10 seconds (50% recovery of SCR amplitude).

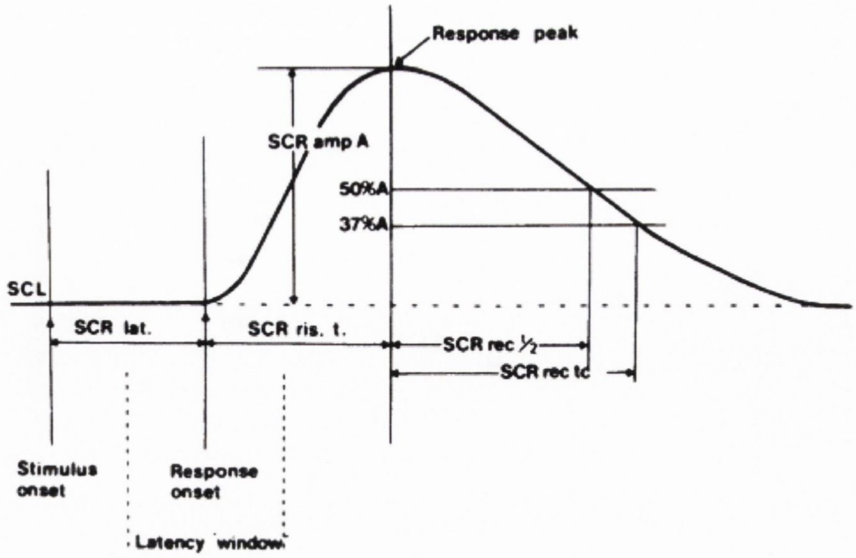

Figure 5-4: Illustration of a phasic SCR (Christie (1981), p 617).

From phasic components, different parameters can be obtained, including:

- Frequency (SCR freq)= number of EDRs in a given time window
- Amplitude (SCR amp)= the height of a single response
- Latency (SCR lat)= the time from stimulus onset to reaction onset in case of a specific EDR
- Rise time (SCR ris.t.)= the time from the onset of a reaction to its maximum
- Recovery time (SCR tec.t/2.) indicating the time that is needed to recover 50% of the amplitude
- Recovery time (SCR tec.tc.) indicating the time that is needed to recover 63% of the amplitude

If SCRs occur in the absence of an identifiable stimulus, they are referred to as non-specific (NS) or spontaneous SCRs. NS-SCR activity is usually measured as a rate per minute. One to three NS-SCRs per minute are typical when the participant is at rest. However, NS-SCRs can also be elicited by deep sighs, deep breaths or body movements. Tonic electrodermal measures are obtained either as EDLs in reaction-free recording intervals or as the number of non-stimulus specific EDRs in a given time window.

Quantifying SCR components can be difficult because of the large variability due to extraneous individual differences. Therefore, the observed change in amplitude in a specific SCR varies with the subject's range of SCLs. Dawson et al. (2000) suggest that it is possible to account for inter-individual differences by computing a relative change as a percentage of the overall range of the individual's range: (SCL-SCLmin)/ (SCLmax – SCLmin). For SCR data, the minimum can be assumed to be zero and the maximum can be estimated by a strong, startling stimulus. Each SCR can then be corrected for individual differences in range by dividing each SCR by that subject's maximum SCR. Range corrections, can, however, be inappropriate where two groups being compared have different ranges. Also, the range correction procedure relies on adequate and reliable estimates of maximum and minimum values, yet estimates of these values can be extremely unreliable. If mean amplitudes of specific SCRs are calculated, non-responders must be excluded from the analysis and logarithmic transformation of amplitude and frequency of specific SCRs are advisable when the data is considerably skewed.

As the EDA is sensitive to a wide variety of stimuli it is not a clearly interpretable measure of any particular psychological process (Figner & Murphy, 2011). Dawson et al. (2000) suggest that the psychological meaning of SCRs can be derived from the experimental paradigm in which it occurs and the stimulus condition used. The authors interpret the fact that EDA is reliably elevated during task performance as evidence that tonic EDA is an index of a process related to energy regulation or mobilisation. They argue that stress and affect are associated with heightened autonomic activation. Alternative explanations are attention and resource allocation associated with effortful processing (e.g. Helander, 1978) and decision making (Bechara, Damasio, Damasio, & Anderson, 1994). Individual differences in EDA have been summarised under the concept of electrodermal lability. Electrodermal labiles (responders) show high rates of NS- SCRs and/or slow SCR habituation, electrodermal stabiles (non-responders) are those with few NS-SCRs and/or fast SCR habituation. Labiles outperform stabiles on tasks that require sustained vigilance. The proportion of non-responders in the normal population is approximately 25%.

5.2.3 EDA and age

When considering the use of EDA measurements in a study investigating age effects on risk perception in driving, previous research findings on age effects on the electro-dermal system are of obvious importance. The review of studies that have explored age effects on EDA measures is, however, fraught with the difficulty of extracting and generalising robust findings from predominantly small scale studies with contradictory findings. On the one hand, aging is associated with a decrease in the number of active eccrine sweat glands and the sweat quantity per gland as well as the salt content of the sweat. However, Boucsein (1992) points out that observed decreases in SCL and increases in SRL in old age are not well understood, as epidermal changes in aged skin are too small to account for observed increases in skin resistance. In their review of the literature Kucera, Goldenberg and Kurca (2004) report contradictory research findings on the impact of age on amplitude and latency in SCR responses: Whilst Drory et al. (1993) report a significant decrease in SCR amplitude in participants over 60 years, no such decreases were observed by Baba et al (1988). In the same study Drory et al. (1993) observed 50% non-responses in participants aged sixty years or older, when measurements were taken from upper extremities. However, Braune et al. (1997) observed 100% SCRs in participants older than sixty. Regarding SCR latency the balance of the evidence reviewed by Kucera, Goldenberg and Kurcae (2004) suggests that age does not significantly affect the latency of the SCR response. Boucsein (1992) indicates that a differential sensitivity of the SCR might exist between young and old participants. He quotes a study by Plouffe and Stelmack (1984) which explored electrodermal orientation responses to pictoral stimuli combined with either familiar or unfamiliar word names for 30 young (17-24 years) and 30 old (60-88 years) women. The young participants showed a higher SCL during baseline and larger SCRs compared to the old participants. However, older participants displayed larger SCR amplitudes to recalled unfamiliar word names in a subsequent recognition memory test. The review of several studies by Eisdorfer (1978) indicates a higher electrodermal reactivity in older subjects for stimuli that are emotionally charged, but not during learning tasks or under relatively nonthreatening conditions. Similarly, a study by Silvermann, Cohen and Shmavonian (1958) found greater SCR amplitudes in older participants for emotionally meaningful stimuli compared to neutral ones. In his conclusion on the effects of age on EDA, Boucsein (1992) recommends that age-related changed in physiology and psychology should be considered as possible causes for decreases in SCL and amplitudes in older participants.

5.2.4 The use of EDA in driving studies

A number of early on-road studies in the field of safety engineering have used skin conductance as a measure of psychophysiological responses to driving. Particularly the study by Taylor (1964), which was already discussed in Section 3.1 and which posited that feelings of anxiety underpinned the perception of risk in driving, inspired subsequent theoretical developments on the role of risk in driving by Wilde, Fuller and Summala and Nätäänen.

An earlier on-road study by Michaels (1960) with ten participants linked skin conductance responses to traffic events on two urban test routes that participants had to repeatedly complete at different times of day over a two-week period. The findings showed that 85 percent of traffic events generated measurable SCRs, predominantly to those caused by other vehicles in the traffic stream (60 percent of all events). Events that generated the greatest mean skin conductance response involved maximum speed differentials between the object and the test vehicle (such as turning manoeuvres, crossing and merging). Events that induced the weakest responses were related to fixed objects in the environment such as parked vehicles or traffic islands. Michaels concluded that EDA was directly linked to the complexity of the traffic environment and also found that drivers preferred the route with approximately 40 percent lower SCR rates per minute.

A small scale on-road study by Franklin and Cleveland (1964) with four male student drivers measured skins conductance response frequencies and magnitudes in reaction to different illumination levels at intersections. The authors found an inverse relationship between skin conductance responses and illumination levels (no illumination, point illumination and continuous illumination) as well as a positive relationship between skin conductance responses and complexity of the intersection. EDA at the time of these earlier studies was discussed in the context of tension and startling responses.

The publication by Taylor (1964) covered two on-road studies that used skin conductance measures. In the first study 12 participants (21-58 years; five females, seven males), participants completed a 62 mile drive, divided into 40 homogenous sections with regards to the nature of the road condition in a suburban area twice on day-time off peak hours on different days. The primary independent variable was the collision rate of the participants, based on the police recorded number of injury collisions over a two-year period prior to the experiment and expressed as the collision rate per vehicle mile travelled. In the second study eight participants (28-58 years, all female) completed a 16 miles drive, divided into 19 homogenous sections, three times, once during day-off peak hours, once in twilight rush hour and once at night in off peak hours. The independent variables used in this study included various features of the road environment such as the number of lanes or turns along the route. The main dependent variable in the first study was specific SCRs, in the second study SCL was added as an additional measure. Multiple regression analyses were conducted to explore relationships between both EDA measures and collision rates and road environment features. Taylor reported that overall EDA response rates during driving were approximately 50 times higher compared to EDA rate at rest. Whilst most SCRs occurred in reaction to an external traffic event, multiple regression analyses between collision rates/ various road conditions and EDA response rate (calculated as the rate of responses per minute) did not find any significant relationships, even though a significant correlation between skin conductance level per mile and collision rate per mile was reported. As already mentioned in Section 3.1, Talyor concluded from the findings that the EDA rate acted as an indicator of subjective risk which drivers endeavoured to keep constant (and which therefore tracked collision rates) and that drivers were generally accurate in perceiving and adjusting to objective risk. As practical implications of his findings he suggested artificially increasing subjective risk and increasing the salience of hazards in the road environment that drivers may naturally overlook.

Helander (1978) applied skin conductance as a measure of mental load associated with different traffic situations in an on-road study with sixty Swedish drivers. With the aim to differentiate between mental and physical workload in response to fifteen driving situations, Helander obtained heart rate, skin conductance responses and electromyogram of two leg muscles, one measuring the release of the accelerator, the other measuring the application of the brake pedal. The findings indicated that the difficulty of a traffic event as measured by the skin conductance response was strongly associated (r=0.95; p<0.001) with braking as a preventive action (rather than steering). Based on the results of a time-sequence analysis Helander suggested that muscular activity had little (if any) influence on the skin conductance response and that SCRs reflected relative increases in task demand, regardless of the initial level of task demand. He also suggested that task difficulty in driving was two-dimensional and included external events that forced themselves on the driver and internal events that reflected deliberate decisions by the driver.

5.3 Summary

The review of the emerging literature in decision making and risk perceptions emphasises the role of affect in assisting, if not guiding, human judgement under conditions of uncertainty as an adaptive response that is learned over time and is characteristically impaired in people with certain types of brain damage, i.e. damage to the pre-frontal cortex. Dual process theories of information processing differentiate between an affect-based, intuitive mode and an analytical, effortful mode. Research has explored the conditions under which the activation of one or the other system is more likely and how the systems work together. There is some evidence to suggest that reliance on affective processing is greater under conditions of time pressure and if the emotional stimuli are high in arousal.

Whilst particularly the Somatic Marker Hypothesis has sparked a lively scientific debate and has inspired research into the question, how affective markers are initially acquired, the interest of the current thesis lies in age-related changes in the perception of driving risk over the life-course. Findings from the limited available literature on emotional reactivity in older adults suggest a decrease in the strength of the physiological component of emotional reactions, whereas no such decreases have been observed for the subjective reaction to emotional stimuli, particularly where fear, anxiety or stress are concerned. Age differences have also been observed with regards to information processing, whereby older adults under conditions of low arousal demonstrate preferential processing of positive stimuli and diminished processing of negative stimuli. However, these observed positivity effects in older adults appear to be associated with the controlled processing mode and are reduced under conditions of high arousal.

Depending variables in the context of affect research, including predominantly (but not exclusively) behavioural and subjective indicators, have been measured in the context of gambling tasks, pictorial stimuli or emotion-inducing videos to date without reference to driving. Whilst researchers in the area of driving risk have posited a role of affect in the wider sense, such as tension (Taylor, 1964; Fuller, 1984), arousal (Wilde, 1982; 1988; 1989; Fuller, 1984; 2000; 2009), fear (Summala & Näätänen, 1988; Fuller, 1984) and feeling of risk (Fuller 2000; 2009), measurement of the different components of an affective reaction has to date been predominantly limited to subjective experiences. Whilst there are studies that have measured physiological responses in driving (such as Taylor, 1964 and Helander, 1978), they are somewhat devoid of theoretical embedding of the measures gathered. Therefore, the systematic research on the importance of affect in driving decision making is very much in its infancy, and it is still an open question whether the posited relations identified in laboratory tasks will transfer into the driving context as highly dynamic task that is characterised by continuously modified learning experiences through reward and punishment. The importance of employing methodological approaches that span a range of dependent variables to converge evidence has been emphasised by several authors in the field.

It is interesting to review the findings from the previous simulator-based study against the predictions from emerging affect research. The analysis of the additional variables included in the study indicated a significant main effect of age only for the enjoyment of the drive on the dual carriageway, where older drivers rated their enjoyment as significantly higher than young drivers. Arguably, as the road environment with the higher degree of complexity compared to the dual carriageway, the urban road environment should be associated with greater demand and thus elicit higher arousal in participants (the higher demand was indeed reflected in participants' higher task difficulty ratings in comparison to the dual carriageway). In addition to stronger affective reactions across all participants on urban roads compared to the dual carriageway, higher arousal associated with driving in the urban environment should lead to diminished positivity effects in older participants only. This could explain the emergence of significantly higher enjoyment ratings from older drivers for the dual carriageway across all speed conditions and could also account for the absence of significant age differences for enjoyment on urban roads. If the observed higher task difficulty and comparatively lower enjoyment ratings of older drivers in the urban environment arose from an arousal-related suppression of positivity effects in the older drivers, this would provide an alternative to the interpretation put forward by the Task Capability Interface Model. Whilst the Model would attribute observed age effects to age-related reductions of driver capability, nothing in it would predict greater enjoyment of the drive for older drivers compared to young drivers in a low demand traffic environment.

Integrating the measurement of additional components of affective reactions in the further progression of the thesis can elucidate our understanding of the role of affective reactions in driving decisions and also acts on the recommendations from the research community (e.g. Finucance & Holup, 2006). The review of skin conductance and its application in driving related studies thereby suggests that skin conductance is an easy-to-apply and fast reacting measure that reflects changes in arousal and task demand. Available studies on the impact of age on the physiological component of affective reactions and on skin conductance in particular point towards a somewhat reduced reactivity in older people regarding SCL and SCR amplitudes. However, given the somewhat inconsistent findings reported in the literature, it is difficult to predict the size of such age-related reductions in physiological reactivity and how they may play out against the observed age-related increases on subjective measures of risk perception in previous experimentation.

5.4 Synthesis of findings and outline of the third study

The further progression of the thesis aims to bring together the different findings so far and to expand the research of age-related changes by adding measures the affective responses to risk in driving. The main points are briefly summarised in the following before the methodology for the next study is outlined.

5.4.1 Situations that are more difficult for older drivers

The review of the literature in Chapter 1 and the analysis of collision patterns of older drivers described in the first study (Chapter 2) has shown that despite their comparatively low collision rates, older drivers are over-represented in particular collision types, frequently including give-way situations at (t-)junctions, crossroads and road entrances. The analysis of contributory factors in the collisions of older drivers also denoted failures of the assessment of other road users' path or speed and failures to look properly, as well as vision problems as particularly challenging for this driver group. Additionally, the literature of compensatory changes in driving behaviour reviewed in Section 1.8 suggests that older drivers frequently report to avoid certain driving situations, including situations with reduced visibility and also of situations that require rapid decision making, visually cluttered environments and intersections. Whilst avoidance behaviour relating to certain driving situations would suggest a degree of awareness in older drivers for the higher difficulty of these situations, the literature shows that reports of avoidance do not necessarily coincide with an awareness of greater risk in these situations as a result of natural, age-related declines. The intention for the third study was to include a greater range of driving situations (including those that present a particular challenge to older drivers and those that do not) and to collect subjective and physiological responses to risk.

5.4.2 Feeling of risk and task difficulty

The second study in this thesis lent support to the posited close association between task difficulty and feelings of risk and the weaker relationship between task difficulty and estimated collision likelihood. Feelings of stress, nervousness, danger and effort were found to be similarly strongly associated with task difficulty in the second study of this thesis. Whilst several models of risk in driving posit an influence of negative affect (such as fear, tension and anxiety) in their proposed risk assessment processes, very little research has been undertaken to specifically explore the role of affect and to capture the different components of an affective response. Emerging research in decision making, however, emphasises the role of affect in informing, if not guiding decision making; studies that used skin conductance in addition to subjective reports and behavioural measures in a gambling task, underpinned the development of the Somatic Marker Hypothesis (Damasio, 2003), which emphasised the advantage of quick access to previous experience through activation of acquired signal stimuli.

5.4.3 Identified age differences

Age effects in the second study of this thesis emerged for the arguably more demanding traffic environment, the urban roads, where older drivers' rated feelings of risk and task difficulty were significantly higher than those of young drivers and where older drivers adopted significantly lower speeds in the free drive condition. Findings also suggested that the presence of other road users in the driving scene improved the accuracy of older drivers' speed assessments on the dual carriageway. These findings were consistent with the literature on self-awareness and risk perception in older drivers, reviewed in Sections 3.9.1 and 3.9.2, which indicated higher ratings of risk for older drivers, comparable self-ratings of capability as a driver and a greater sensitivity to different sources of risk in a traffic scene, potentially brought about by their comparatively longer learning histories or alternatively diminished positivity effects. Older drivers reported to enjoy driving in the less demanding road environment, the dual carriageway, significantly more than young drivers.

6 Study 3: Age-related differences in responses to traffic situations

6.1 Introduction

To further explore age-related changes in the perception of risk a video-study was designed that would permit the inclusion of skin conductance measures (in addition to subjective ratings) whilst avoiding potential movement artefacts arising from movements associated with actual driving activity. Whilst the comparison of rating data gathered in a video study with data collected in a driving simulator study suggested that ratings were higher in the video study, the overall profile of the ratings was comparable (see Section 3.7). For this reason the use of a video-study was deemed appropriate.

<u>Age-relevance of driving situations</u>

The selection of driving situations to be captured in the videos was informed by the analysis of collision patterns carried out in the first study of this thesis (Chapter 2) and the review of the literature of older drivers' collision involvement (Chapter 1, Section 1.6). Half of the driving situations selected comprised scenarios in which collision statistics show older drivers to be overrepresented in or which the literature shows them to avoid; half of them comprised scenarios where this is not the case. An interaction effect was predicted whereby older drivers' subjective and physiological reactions to situations that carry an age-relevant risk would be significantly higher than those of young drivers, but would not be significantly different for situations that were not associated with a higher collision risk for older drivers. The hypothesis was therefore that older drivers are aware of the relatively higher difficulty of certain situations. To exclude potential differences due to age-related deteriorations of the visual system (such as glare sensitivity) alone, all situations filmed showed driving in daylight in dry weather conditions.

<u>High versus low task difficulty</u>

Age-related deteriorations of driver capability should, according to Fuller's Task Capability Interface Model, emerge in driving situations where task demand approaches the upper level of capability of the driver, but should not become apparent in situations where capability well exceeds task demand. Significant age effects had indeed emerged for the urban road environment of the second study of this thesis (Chapter 4), where older drivers' ratings of task difficulty and feeling of risk were significantly higher than young drivers' ratings. However, and against expectation, the findings indicated that older drivers' ratings of task difficulty and feeling of risk were significantly higher than those of younger drivers across all speed conditions (low, medium and high), not merely the high speed condition. This could alternatively be explained with a general sensitisation to risk with increasing age in situations where task demand is not only influence by speed, but also by other demand components. To further test this, the video study attempted the manipulation of task difficulty, this time by creating pairs of driving situations showing the same driving manoeuvre in comparable road environments (e.g. in either residential, urban or non-built up areas), under high versus low task difficulty conditions.

The experimental work testing Fuller's hypotheses to date has predominantly focussed on speed as the main manipulator of task difficulty. The second study in this thesis (Chapter 4) had included an additional manipulation of task difficulty by adding other road users into the simulated traffic scene. The findings, however, indicated that other road users only appeared to affect drivers' risk ratings when there was a possibility that the road users would cross the drivers' trajectory. To further expand on the impact of task demand factors other than speed, traffic scene pairs of high versus low task difficulty were created that would vary the following three variables:

- The driving speed of the vehicle shown in the videos;
- Static clutter: the amount of road furniture and static objects in the traffic scene;
- The presence of other road users (other moving vehicles or pedestrians) in the traffic scene.

Following the predictions of the Task Capability Interface Model, an interaction effect was predicted whereby older drivers' subjective and physiological reactions to high difficulty situations were expected to be significantly higher than those of middle-aged and young drivers, but not significantly different for low difficulty situations.

Incremental difficulty versus emerging hazards

Fuller's concentration on speed as the main manipulator of task difficulty and his empirical studies in which he incrementally increased driving speeds can give the impression that task difficulty is a parameter that increases gradually and linearly. This operationalization of task difficulty as "the more there is going on in the traffic scene and the higher the speed, the more difficult it is" strongly resembles the workload concept, which Fuller does touch on in his work (Fuller, 2000). However, in his theoretical conceptualisations, including the Threat Avoidance Model and the Task Capability Interface Model, Fuller also talks about sudden occurrences of hazards that shape the learning experiences of a driver and require immediate driver action to avoid a collision. In these instances, the occurrence of unexpected hazards leads to sudden spikes in task difficulty in the way the hazard perception literature conceptualises risk in traffic. Fuller has never explicitly addressed these differences in the conceptualisation of task difficulty. The current study attempted to differentiate between incremental and sudden increases in task difficulty in the stimulus material by selecting eight pairs of driving situations, showing the same driving manoeuvres either in a low or in a high difficulty version as described earlier on and an additional four situations which showed an unexpected, potentially hazardous development in the traffic situation. In contrast to the situation pairs, situations comprising potentially hazardous events did not have a low difficulty equivalent, as these situations are of an all-or-nothing nature. Significant age effects were predicted to emerge in the hazardous driving scenes and in the high difficulty variants of the eight driving situations.

Driver physiology

The importance of collecting different measures of participants' affective reactions in further research has already been expanded on, and it has been shown that a number of driving studies have used skin conductance as a simple to apply and fast acting physiological correlate of arousal. If skin conductance is indeed the correlate of subjective feelings of risk as asserted by the Risk Allostasis Theory, we would expect – in the absence of any significant differences in driving experience, which have been suggested to lead to a dissociations of subjective and physiological responses by Kinnear (2009) - physiological responses to track participants' feeling of risk ratings. Increasing subjective ratings should be associated with stronger physiological responses. Additionally, older drivers' physiological response to high difficulty situations are predicted to be stronger than those of young and middle-aged drivers, reflecting the comparatively higher experienced task difficulty resulting from age-related deteriorations of driver capability in this age group and the suppression of positivity effects in high arousal conditions. The third study therefore included the measurement of skin conductance to explore whether subjective and physiological measures of difficulty and risk concur for young, middle-aged and older drivers and whether age effects can be discerned.

Because several authors have pointed out that physiological responses, and the skin conductance response in particular, may attenuate with age, a pilot study with six older participants (3 males, 3 females, all aged 65 years or older) was undertaken to check whether older drivers show distinctive physiological responses to traffic scenes. In the pilot, participants were asked to watch a Hazard Perception Video published by the Driving and Vehicles Standards Agency whilst their skin conductance was measured through two electrodes applied to the distal phalanxes of the index and middle finger of the non-dominant hand. Distinct skin conductance responses to developing hazards were observed for all six elderly participants in reaction to hazards occurring in the video and therefore the measure was deemed appropriate for inclusion in the third study. Based on the outcomes of the pilot, it was accepted that the age-related attenuation of physiological responses may somewhat reduce the size of any age effects; however, it was hypothesised that these effects would outweigh any age-related attenuation of the measure.

Whilst skin conductance has been used as the physiological indicator in the reviewed literature on affect and decision making, measures of cardiac activity are well-established as indicators of arousal and have been employed in empirical work on risk taking over many years. Trimpop (1994), Pribam and McGuiness (1975), Rabbitt (1979), and Van der Molen, Somsen, Jennings, Nieuwboer and Orlebeke (1987) successfully used heart rate as a relatively crude, but consistent and easy applied measure of arousal in relation to risk taking. However, greater accuracy in detecting momentary changes arousal lies in the measurement of heart rate variability (Mulder, 1979). The Heart Rate Variability (HRV) is a measure of the continuous interplay between sympathetic and parasympathetic influences on the heart rate and reflects the degree to which cardiac activity can be modulated to meet changes in situational demands. HRV decreases with higher situational demands which, in the context of the current study, should be driving situations of high task difficulty. Heart Rate measurements were collected in the current study in addition to the skin conductance measure.

Research questions

The third study built on the previous research undertaken and expanded it in several ways. It aimed to explore the following research questions:

- Whether previously found correlations between task difficulty, feeling of risk and collision likelihood would emerge with a new and more diverse set of stimuli;
- Whether drivers' perceptions of situational difficulty relate to a systematically composed score of difficulty;
- Whether there are significant age-related differences with regards to perceived difficulty and risk of a particular driving situation;
- Whether the physiological response, namely the skin conductance response and heart rate variability corresponds with the subjective assessments of difficulty and risk;
- Whether the situations that are rated as most difficult by older drivers are also those where they tend to be over-represented in collisions or which many older drivers report to avoid; and whether such a pattern is different to that seen in young or middle-aged drivers.

6.1.1 Hypotheses

The research questions outlined above led to the formulation of the following research hypotheses:

1. Ratings of task difficulty and feelings of risk will be highly correlated, whereas task difficulty and likelihood of a collision will not be as strongly correlated; collision likelihood estimates will be subject to considerably greater variability than task difficulty and feeling of risk, reflecting people's limited ability to assess statistical probabilities of rare events correctly.
2. Older drivers' feeling of risk and difficulty ratings of high difficulty and hazardous situations will be significantly higher than those of young and middle-aged drivers, but will not significantly differ for low difficulty situations. Collision likelihood ratings will not show significant age effects and be subject to considerable variability.
3. Older drivers' increase in Skin Conductance Level (SCL) and Heart Rate (HR) from baseline will be significantly larger and Heart Rates Variability (HRV) will be significantly smaller than that of middle-aged and young drivers in situations of high difficulty and potentially hazardous situations; increases in SCL and HR and decreases in HRV from baseline will not significantly differ by age in low difficulty situations;
4. Age-relevant driving situations will attract significantly higher ratings and larger physiological responses (increases SCL and HR and decreases in HRV) from older drivers than from young and middle-aged drivers.

6.2 Method

6.2.1 Preparation of stimulus material

Selection of driving scenes

Based on the review of the scientific literature and the findings of the analysis of older driver collision patterns carried out previously, a catalogue of situations was compiled, including:

- situations in which older drivers tend to be more collision involved or situations which they report to frequently avoid;
- situations where they are not over-represented in collision/ they do not tend to avoid; and
- situations that comprised a sudden potentially hazardous event.

Situations that at least partly rely on monitoring the rear view, such as changing lanes, were excluded, as this could not appropriately represented in a video study. The final selection of driving situations to be filmed for the purpose of the study included:

Age-relevant situations that may present a particular challenge to older drivers:

1. Turning right onto a major road at a t-junction;
2. Turning left onto a major road at a junction;
3. Turning right at a roundabout;
4. Drive straight across a roundabout;

Situations that should not present a challenge to older drivers:

5. Negotiating a bend;
6. Following a vehicle;
7. Overtaking[13];
8. Pedestrian crossing the driver's path.

To explore differences between incremental versus sudden increases of task difficulty, four driving scenes were selected from the filmed material that showed potentially hazardous situations:

- Driving past a bus stop where a bus is waiting;
- Motorcycle overtaking from behind;
- Vehicle in front suddenly braking;
- Oncoming vehicle suddenly starting to turn across the driver's path.

Filming and replay

The exploratory nature of the study and resource limitations meant that the filming of footage had to rely on naturally occurring situations in traffic and could not stage driving situations to systematically produce scenarios of high and low difficulty.

The study had to provide participants with the same view a car driver in his vehicle would have to enable them to sample all information relevant to a car driver's perception of risk in the traffic scene displayed (for example, crossing traffic from left and right when intending to cross a junction). This required filming a Field of View (FOV) of

[13] The inclusion of overtaking as a manoeuvre that should not present a challenge to older drivers has, since the initial submission of the thesis, rightly been called into question. Whilst overtaking manoeuvres do not appear as a frequent collision situation for older drivers, an instrumented vehicle study by Reimer, Donmez, Lavalliere, Mehler, Coughlin & Teasdale (2013) with young (20-29 years), middle-aged (40-49 years) and older (60-69 years) drivers suggested more conservative driving styles and fewer lane changes (including overtaking manoeuvres) in older drivers compared to younger age groups.

approximately 150°. Whilst filming videos at this angle with a single camera is possible[14], initial video piloting showed that wide-angle camera settings led to a considerable distortion of the video and did not provide a realistic impression of the driving scene. It was therefore decided to capture driving scenes by using three cameras, each of them capturing video in the narrow setting.

Different camera positions were extensively tested during piloting to create a Field of View that would compare to a car driver's normal view of the road environment (allowing slight head movements to the left and the right). The cameras were affixed to the top of the bonnet of the experimenter's car, slightly offset to the left to provide a realistic driver's view. The middle camera faced forward (12 o'clock), the two other cameras left (approx. 10 o'clock) and right (approx. 2 o'clock) respectively. Piloting different camera positions also served to ensure that the captured video from of each camera could be combined into an approximate representation of the road environment when simultaneously replayed on three separate screens. An example of the full Field of View produced through simultaneous replay of the left, middle and right video channels on three different screens is shown in Figure 6-1.

Figure 6-1: Example of the view produced by the three cameras used for filming.

As the intention was to replay the videos to the drivers on three large computer-screens to facilitate realism and immersion, video clips were recorded in high fidelity.

The creation of the high difficulty versions of all driving scenes was undertaken in line with ethical considerations: Because of the potential risk of excessive speeds to other road users in naturally occurring traffic, the experimenter's driving speed during the filming of the high difficulty situations was capped at the prevailing speed limit posted on the road. In the low difficulty condition, the experimenter drove considerably more slowly than the prevailing speed limit to enable clearly discernible differences on the speed factor in the filmed situation pairs. To ensure comparability of the situation pairs,

[14] The GoPro High Definition HERO2 Motorsports Edition cameras used in this study permits video capture at three angles, wide (170°), medium (127°) and narrow (90°) as well as the audio track.

all pairs were selected showed the same driving manoeuvre in a comparable road environment (e.g. residential area, urban roads or single carriageway in a non-built up area). Because the differences in road environment, visual clutter and speed, the length of the high and low difficulty version of the same situation, as well as the length of the videos of different situations differed, with the overtaking manoeuvre videos being the shortest at 13 seconds and driving straight across a roundabout manoeuvres being the longest at 40 seconds.

All video and audio footage was downloaded and saved as MP4 High Definition video files. Several versions for the twenty driving situations (eight low difficulty, eight high difficulty and four hazardous videos) required were cut from the footage obtained, to enable the selection of the most suitable pairs and hazardous situations[15]. Cutting the videos for all three channels had to be highly exact to ensure that they would be exactly synchronous when replayed together. For each situation the video footage from each camera was cut in such a way that it comprised a short lead-up to the manoeuvre (for example, driving along a road towards a pedestrian crossing), the manoeuvre itself (decelerating and stopping to let pedestrian cross, before continuing the journey) and a few seconds after the completion of the manoeuvre (driving away from the crossing). Finding a way to replay the three separate video streams in a synchronised fashion represented a significant challenge. The initial intention was to build a computer with three graphic cards that would correctly initialise the left, middle and right video stream simultaneously. However, the consultation of several software and IT specialists showed that this was not viable. Conversations with BMW's Research and Development group led to the adoption of a DVD based solution, whereby three sets of DVDs were created, each containing the videos for either, the left, the middle or the right camera recording. Between each of the 20 driving scenes used in the study, a 30 second interval was interspaced, showing a blue screen before the next driving scene started. Two sets of three DVDs were created for the main study, which replayed the 20 driving situations in different order to counterbalance order effects in the presentation of the stimulus material.

To enable synchronised replay three identical DVD players were purchased. A single remote control allowed the simultaneous start of the replay. The driving videos were replayed on 32" LCD television screens that had been rented for the duration of the current study, including piloting. A picture of the set-up of the three screens is provided in Figure 6-2. For the trial participants were seated approximately 50cm in front of the screens on a chair and instructed "to find a position in which they were comfortable and which would mimic what they would normally do in their car". The review of participant

[15] Xilisoft software was used for this purpose.

comments showed that the majority of participants commented on the risk of children running onto the street. The children in some of the videos used in the study were all located on the sidewalks. Participants' commenting on the children's' potential impact on their driving suggests that they were using the left and right screen to assess hazards in the periphery of their vision, as a driver would in the vehicle.

Figure 6-2: Illustration of the set-up of the three screens for the replay of driving scenes in the current video study.

An overview of the driving situations used in the study, is provided in Table 6-1.

Table 6-1: Overview of the 12 driving situations selected for use in the video study (age relevant situations include those that should present a greater challenges to older drivers).

No	Age relevant (Y/N)	Manoeuvre
1	Y	Turn left onto a major road at a junction
2	Y	Turn right at a roundabout
3	Y	Turn right at t-junction
4	Y	Drive straight across roundabout
5	N	Follow a vehicle
6	N	Overtake a vehicle in front
7	N	Pedestrians crossing the road in front
8	N	Negotiate a bend
H1		Oncoming vehicle suddenly turning across
H2		Drive past a bus at bus stop where a bus is waiting
H3		Motorcyclist overtaking from behind
H4		Vehicle in front braking to turn right

Validation of difficulty manipulation

For the eight pairs of footage representing high versus low difficulty versions of the same driving manoeuvre, all situations extracted were rated on three point scales (score 1= low, score 3= high) by two independent observers on the following three dimensions:

- Speed;
- Static clutter;
- The presence of other road users.

Ratings on the three variables were thereby made relative to the road environment of the filmed situation pair; for example, the range of driven speeds on a single carriageway in a non-built up area is relatively higher than those in a residential area (whereby both, the high and low difficulty pair of a situation were always filmed in the same road environment). The highest composite difficulty score for a situation was nine, when all three variables were rated as high; the lowest difficulty score was three, when all three variables were rated as low.[16] Subsequently, situation versions were selected that best represented a high and low difficulty version for the eight situation pairs of interest. The eight situation pairs and the scores allocated by two independent observers are shown in Appendix C, Table C-1. The four potentially hazardous situations were not scored on the three dimensions, as the focus here was on the emergence of a sudden and unexpected potential hazard rather than on a composite score of task difficulty. As a measure of inter-rater agreement a Pearson correlation coefficient was calculated for all 16 driving situations rated, resulting in r=0.88, indicating good agreement in the scoring of the situations by both raters[17].

To further ascertain whether the aim of creating pairs of high versus low difficulty situations had been achieved, a sample of nine current drivers (minimum age 18 years, maximum age 78 years, mean age 46.5 years, SD=24.4 years) viewed and rated the difficulty of each situation, presented in random order on a 7-point Likert scale, whereby 1 represented the lowest and 7 the highest possible difficulty. Descriptives for the piloting of the stimulus material with the sample of nine drivers are shown in Table 6-2. In line with expectation the findings suggest that all low difficulty situations were rated lower on difficulty than their high difficulty counterpart. The ratings, however, also

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[16] It is important to note that high scores on all three dimensions are difficult to achieve as for example the presence of other road users in the trajectory of the filmed vehicle is likely to slow down speed. However, for the purpose of this study it was deemed sufficient to achieve situation pairs that would be sufficiently different in difficulty to be classed as high and low difficulty.

[17] The figure is somewhat inflated because it does not take into account the slight differences between the raters on each of the three dimension.

reflect the fact that difficulty scores allocated to the high difficulty situation were overall low, most likely owing to the fact that they had to be recorded in actual traffic conditions and in compliance with safe driving rules, rather than being staged. Therefore, differences between the high versus low difficulty situation pairs were smaller than desirable.

Table 6-2: Situation pair ratings of difficulty by nine current drivers.

Age typical?			Situation	*m*	*SD*
Y	H	1a	Turn left onto a major road at a junction	2.06	1.94
	L	1b	Turn left onto a major road at a junction	1.17	0.35
Y	H	2a	Turn right at roundabout	1.50	1.00
	L	2b	Turn right at roundabout	1.17	0.35
Y	H	3a	Turn right at junction	1.28	0.44
	L	3b	Turn right at junction	1.06	0.17
Y	H	4a	Drive straight across roundabout	2.28	1.25
	L	4b	Drive straight across roundabout	1.50	1.32
N	H	5a	Follow a vehicle	1.50	0.87
	L	5b	Follow a vehicle	1.06	0.17
N	H	6a	Overtake	2.25	1.07
	L	6b	Overtake	1.50	1.06
N	H	7a	Pedestrians crossing the road	1.94	1.67
	L	7b	Pedestrians crossing the road	1.17	0.35
N	H	8a	Negotiate a bend in the road	1.28	0.67
	L	8b	Negotiate a bend in the road	1.17	0.44

6.2.2 Participants

The three groups of current drivers (young, middle-aged and older) were recruited to participate in the main study from the TRL participant pool, which includes current drivers of all age groups who live in the vicinity of TRL: Seven young drivers, 12 middle aged drivers and 15 older drivers. All 34 participants were current drivers and had at least three years of driving experience. The mean ages for three groups are shown in Table 6-3. Oversampling for the oldest age group was undertaken to allow for the likely higher proportion of non-responders in the older participant group with regards to physiological measurements, based on the reviewed evidence of attenuation of physiological responses with age in the literature (see Section 5.2.3).

Participants received an information sheet and consent form prior to the trial. On arrival at TRL participants were fully debriefed on the purpose of the study, before the consent form was signed by both, participant and experimenter. Participants involved in the study were paid £30 as compensation for their time and expenses incurred by their participation. As in the previous study, participants were asked to complete a brief questionnaire (see Appendix B, Table B-1; four additional rating questions were added to the questionnaire for the purpose of the current study). Table 6-3 below summarises the sample characteristics and basic information on current driving patterns.

Table 6-3: Sample characteristics.

Group		**Young drivers**	**Middle aged drivers**	**Older drivers**
Group age range		21-25 years	40-55 years	65+ years
Sex		5 females, 2 males	6 females, 6 males	8 females, 7 males
Mean driver age (years)		*M*=22.71, *SD=1.70*	*M*=45.92, *SD*=4.21	*M*=70.71, *SD*=4.67
Mean years since licensure		*M*=6.0, *SD*=1.8	*M*=26.69, *SD* =3.28	*M*=46.5, *SD*=5.47
Mean weekly mileage		*M*=198.57, *SD*=159.73	*M*=180.00, *SD*=104.40	*M*=110.00, *SD*=79.73
Percentage (%) of participant's annual mileage on each of three road environments (adding up to 100%)	Mean proportion of motorway driving	*M*=27.86, *SD*=17.76	*M*=22.31, *SD*=16.78	*M*=21.00, *SD*=16.33
	Mean proportion of driving on built-up roads	*M*=51.43, *SD*=6.90	*M*=52.31, *SD*=19.32	*M*=55.40, *SD*=20.10
	Mean proportion of driving on non-built-up roads	*M*=20.71, *SD*=15.39	*M*=23.85, *SD*=8.45	*M*=24.50, *SD*=10.43
Difficulty of driving in darkness		*M*=2.43, *SD*=0.98	*M*=3.38, *SD*=1.45	*M*=3.43, *SD*=1.74
Difficulty of driving in bad weather		*M*=4.14, *SD*=0.69	*M*=4.46, *SD*=1.76	*M*=3.86, *SD*=1.70
Difficulty of driving in heavy traffic		*M*=3.00, *SD*=1.16	*M*=2.85, *SD*=1.28	*M*=3.50, *SD*=1.61
Difficulty of driving long distances		*M*=2.86, *SD*=1.22	*M*=3.23, *SD*=1.54	*M*=2.93, *SD*=1.39

Table cont.	Young drivers	Middle aged drivers	Older drivers
Difficulty of making right turns	*M*=2.29, *SD*=0.95	*M*=2.00, *SD*=0.91	*M*=1.71, *SD*=0.73
Difficulty of using roundabouts	*M*=2.00, *SD*=1.00	*M*=2.00, *SD*=1.00	*M*=1.93, *SD*=0.73
Difficulty of crossing intersections without traffic lights	*M*=3.14, *SD*=1.07	*M*=2.77, *SD*=1.17	*M*=2.64, *SD*=1.39
Difficulty of driving in busy town centres	*M*=3.00, *SD*=0.82	*M*=3.08, *SD*=1.32	*M*=2.86, *SD*=1.56
Skilfulness as a driver	*M*=4.86, *SD*=0.69	*M*=4.46, *SD*=0.97	*M*=4.58, *SD*=1.08
Cautiousness as a driver	*M*=4.71, *SD*=1.25	*M*=4.77, *SD*=1.36	*M*=4.31, *SD*=1.32
Confidence as a driver	*M*=5.14, *SD*=0.69	*M*=4.92, *SD*=1.12	*M*=4.92, *SD*=1.61

One-way ANOVAs did not find any significant differences between the three groups regarding weekly mileage, perceived difficulty of the eight driving situations or regarding the self-ratings of skilfulness, cautiousness and confidence as a driver.

6.2.3 Design

A 3x2 mixed design for the main analysis of the eight situation pairs was used. The between-groups factor was age (young, middle aged, older) and the within-group factor was the difficulty level (low versus high). To test the fourth hypothesis, a 3x2 mixed design with age as between factor and age relevance as within factor (situation represents one where older drivers are typically over-represented in collisions versus one where they are not over-represented) was used.

One-way analyses of variance with age as the between-group factor were used for the analysis of the four potentially hazardous situations.

6.2.4 Materials

Participants watched the 20 driving situations described earlier, which were presented on three 32'' flat screens, all interspersed with 30 seconds of blue screen to ensure that driver physiology parameters could return to baseline before the next video was presented. Two versions of DVD sets were produced to vary the order of the driving scenes shown and allow the exploration of any systematic order effects.

Participants' EDA and heart rate were measured using the PsychLab SC/ECG instrument, PsychLabAcquire software and 8mm silver-silver chloride SC electrodes type EL22, filled with non-saline gel and held in place by double-sided sticky electrode collars. The sampling rate was set to 1kHz, following recommendations by Figner and Murphy (2011). After the main part of the study, participants completed the questionnaire about themselves and their driving history described previously (see Appendix B, Table B-1). Rating data as recorded by the experimenter in the trial sheet were entered into SPSS. The physiology data was analysed with PsychLab 8 software.

6.2.5 Procedure

Upon arrival the Experimenter took participants to the medical treatment room on TRL's premises and debriefed them verbally on the purpose of the study. Participants signed the consent form if they were happy to proceed with the experiment and had no further questions. Subsequently, the Experimenter attached the three heart rate electrodes, as shown in Figure 6-3.

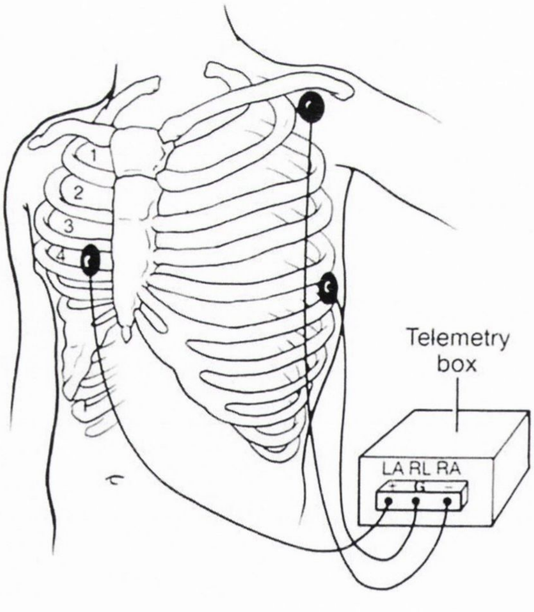

Figure 6-3: Placement of three heart rate electrodes.

Skin conductance electrodes were attached to the volar surface of the medial phalanx of the middle and index finger of the non-dominant hand after briefly swiping the area with small disposable alcohol pads. The electrode cables were secured to the arm with adhesive tape. Figner and Murphy (2011) recommend that electrodes should be affixed approximately five minutes before recording physiological data to ensure a stable electrical connection of skin and electrodes.

Participants were instructed that they would be required to watch 20 short videos of driving scenes, each of them interspersed with 30 seconds of blank (blue) screen. They were asked to imagine themselves as the driver for all videos shown, to sit as still as possible and avoid movement or heavy breathing during the length of the driving video to minimise movement or breathing artefacts. The review of documented participant comments in the trial records suggests, that the instruction to sit still did not interfere head movements to view take in information from the periphery: The majority of participants commented on the presence of pedestrians and children by the side of the road, which would have been mainly visible on the left and right screen. At the end of each scene the screen went blue and participants were asked to rate the scene on three 7-point Likert scales (whereby a score of 1 denoted a very low value and 7 a very high value) on:

- Perceived difficulty of the scene;
- Perceived feeling of risk in relation to the scene;
- Perceived likelihood of a crash if they would drive through the scenario at the shown speed 100 times.

Participants fed their ratings back verbally to the Experimenter who recorded them in the trial protocol (a copy of the trial protocol can be found in Appendix C, Table C-2). A show-card displaying the three questions and rating scales was in front of participants at all times to serve as a reminder of the scales to participants. Prior to the experimental trial all participants practised the approach with two example situations and were given the opportunity to ask any clarification questions they may have. Participants were subsequently taken to the trial room and were seated approximately 60 cm from the three TV screens. Electrodes cables were then connected to the recording equipment (see Figure 6-4) and the recording of physiological signals was visually checked before starting the recording.

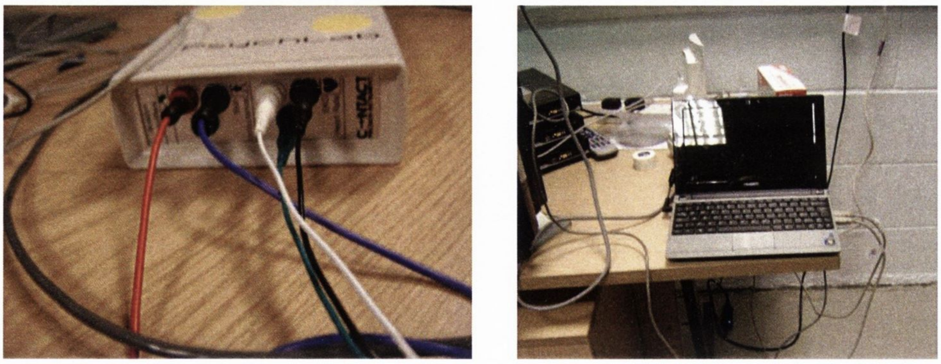

Figure 6-4: Pictures of the physiology data recording devices.

Following recommendations by Naqvi and Bechara (2006) two baseline measures were taken prior to commencement of the trial. The first comprised the recording of a twenty seconds resting baseline where participants were asked to sit still, relax and to breathe normally. This first baseline served to enable the calculation of skin conductance change compared to baseline for each of the 20 videos shown. This approach was based on recommendations from academics at the Biological Psychology Department at Wuerzburg, Germany (personal communication, Conzelmann 28/03/2011). For the second baseline, participants were asked to put on earphones and loud and startling noise was delivered to trigger the maximum SCR and thus enable the identification and exclusion of non-responders from the data set.

To facilitate the separation of physiological data recorded during the video from the data gathered during the provision of feedback in front of a blue screen, the experimenter pressed a button every time a video started and every time it ended. As a fail-safe, the experimenter also made recordings of the exact time when each scene started or stopped (see Appendix C, Table C-2 for an example of a completed recording sheet). The button press triggered the setting of a time marker in the physiological data. The physiological data, including time markers, was subsequently read into excel for analysis.

The trial duration was approximately 20 minutes to avoid habituation. After completion of the experiment, all electrodes were removed and participants completed the questionnaire before receiving their participant payment and leaving.

6.2.6 Ethical Approval

Ethical approval for the study was granted by the Psychology Ethics Board at Trinity College, Dublin and by the Chief Scientist for Safety at TRL where the study was performed (see Appendic C, Figure C-1).

6.3 Results

The analysis of the post-trial questionnaire found no significant differences between participants regarding their self-reported weekly mileage, avoidance of difficult driving situations and self-assessed skilfulness, confidence and cautiousness as a driver.

6.3.1 Data screening

Descriptive statistics were first calculated for the rating data on perceived difficulty, risk and likelihood of a collision across all 34 participants. These can be found in Appendix C, Table C-2. The descriptive statistics showed that in line with expectation, mean ratings of perceived difficulty and perceived risk were higher for all high difficulty situations than for the low difficulty situations. Pairwise *t*-tests across all participants indicated that mean differences of difficulty ratings for the eight situation pairs were significant for all but two of the eight situation pairs: Following a vehicle and negotiating a bend in the road, where difference were in the expected direction but failed to reach significance (see Appendix C, Table C-2). The findings on participants' difficulty ratings therefore suggest that under conditions that do not permit systematic assessment of different aspects of task difficulty in a driving situation, participants' experiential assessment of difficulty are consistent with the outcomes of a more detailed assessment of the difficulty of a situation, based on composite scores for speed, clutter and traffic density.

The inclusion of four situations that showed an emerging hazard had been based on the assumption that the occurrence of a sudden hazard would elicit similarly high ratings, if not for difficulty, then at least for feeling of risk, as the high difficulty versions of the situation pairs. Mean ratings of task difficulty, feeling of risk and collision likelihood for the two different situation types were therefore calculated and compared (see Table 6-4).

Table 6-4: Mean task difficulty, feeling of risk and collision likelihood ratings and *t*-tests for the eight situation pairs versus the four hazardous situations.

	N	*M*	*SD*	*t*	*df*	*p*
Mean difficulty 8 situation pairs	31	2.18	0.84	4.27	30	<0.01
Mean difficulty 4 hazardous situations	31	1.74	0.71			
Mean risk 8 situation pairs	31	2.77	0.99	4.09	30	<0.01
Mean risk 4 hazardous situations	31	2.31	0.94			
Mean collision likelihood 8 situation pairs	32	1.77	2.86	0.84	31	0.41
Mean collision likelihood 4 hazardous situations	32	1.34	2.29			

To test this assumption, three paired sample t-test were performed to check whether the average ratings for the eight high difficulty situations and the four hazardous situations were comparable. Ratings of difficulty (t=4.27; df=30; p=0.01) and of feeling of risk (t=4.09; df=30; p=0.01) of the four hazardous situations were significantly lower than those for the eight high difficulty situations. No significant effects were found for ratings of collision estimates.

One-way ANOVAS with order of the video presentation as the between factor were conducted for task difficulty ratings of the twenty driving situations presented to participants as part of the study to assess whether the order of presentation had affected the ratings. No significant differences between the two orders of presentation were observed, suggesting that the order of the videos did not impact participants' assessment of their difficulty.

Participants' ratings of difficulty, feeling of risk and likelihood of a collision were subsequently each added up to obtain sum scores for difficulty, feeling of risk and collisions likelihood for low difficulty, high difficulty and hazardous situations respectively to facilitate subsequent analysis.

6.3.2 Hypothesis 1

Ratings of task difficulty and feelings of risk will be highly correlated, whereas task difficulty and likelihood of a collision will not be as strongly correlated. Collision likelihood estimates will be subject to considerably greater variability than task difficulty and feeling of risk, reflecting people's limited ability to assess statistical probabilities of rare events correctly.

Table 6-5 illustrates participants' mean ratings for the feeling of risk, task difficulty and probability of a collision for low and high difficulty situations and hazardous situations. As predicted, the mean variability of the collision likelihood estimates was higher than that for ratings of task difficulty and feeling of risk.

Table 6-5: Mean ratings and standard deviations for task difficulty, feeling of risk and collision likelihood for low and high difficulty and hazardous situations.

	Difficulty		**Feeling of risk**		**Collision likelihood**	
	M	***SD***	***M***	***SD***	***M***	***SD***
Low difficulty situations	1.49	0.62	1.82	0.76	0.59	1.04
High difficulty situations	2.18	0.82	2.74	0.95	1.71	2.79
Hazardous situations	0.87	0.35	1.15	0.47	0.67	1.15

Separate Pearson Product Moment correlations were calculated to determine the association between difficulty and risk, risk and collision likelihood and difficulty and collision likelihood for high and low difficulty situations as well as for the four hazardous situations (see Table 6-6). In line with expectation a strong and highly significant correlation between task difficulty and feeling of risk was found for high and low difficulty situations; a slightly weaker correlation emerged for hazardous situations. For difficulty and collision likelihood ratings, only the correlation for low difficulty situations reached significance, but was considerably weaker than the correlation between difficulty and feeling of risk.

Table 6-6: Pearson Product Moment correlations between ratings of difficulty and risk and difficulty and likelihood of a collision for high and low difficulty situations and hazardous situations.

	Difficulty - Risk	Difficulty - Collision
High difficulty situations	0.84**	0.33
Low difficulty situations	0.87**	0.54**
Hazardous situations	0.79**	0.24

***p*<0.05; ***p*<0.01; ****p*<0.001**

The percentage of participants who rated the probability of a collision as greater than zero was calculated and is shown in Figure 6-5. A mean 34.4 percent of participants rated collision risk as greater than zero in the low difficulty versions of the eight situation pairs, and a 31.1% rated collision risk for the four hazardous situations as greater than zero.

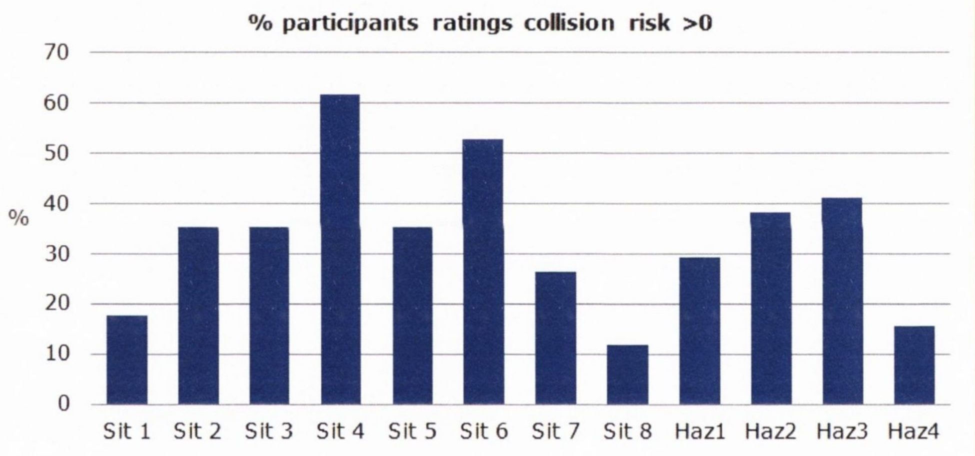

Figure 6-5: Proportion of participants rating collision likelihood as greater than zero for the eight low difficulty versions of the situation pairs and for the four hazardous situations.

<u>Summary and conclusion</u>

- The findings overall supported Hypothesis 1.
- The variability of collision likelihood estimates was greater than that of task difficulty and feeling of risk ratings.
- Task difficulty and feeling of risk strongly correlated with each other; the correlations between task difficulty and collision likelihood were considerably lower.

- Considerable proportions of participants rated collision risk as greater than zero, even for the low difficulty version of the eight driving situations and the four hazardous situations.

6.3.3 Hypothesis 2

Older drivers' feelings of risk and difficulty ratings of high difficulty and hazardous situations will be significantly higher than those of young and middle-aged drivers, but will not significantly differ for low difficulty situations. Collision likelihood ratings will not show significant age effects and will be subject to considerable variability.

Means and standard deviations for the sum scores of ratings of difficulty, feeling of risk and collision likelihood, differentiated by age group are shown in Figure 6-6 for the eight situation pairs and for the hazardous situations in Figure 6-7 (see also Appendix C, Table C-4). The graphs indicate that in line with expectations low difficulty situations were rated lower than high difficulty situations. Inferential testing results are presented for ratings of difficulty, feeling of risk and collision likelihood separately, and only significant effects, including significant interactions are reported.

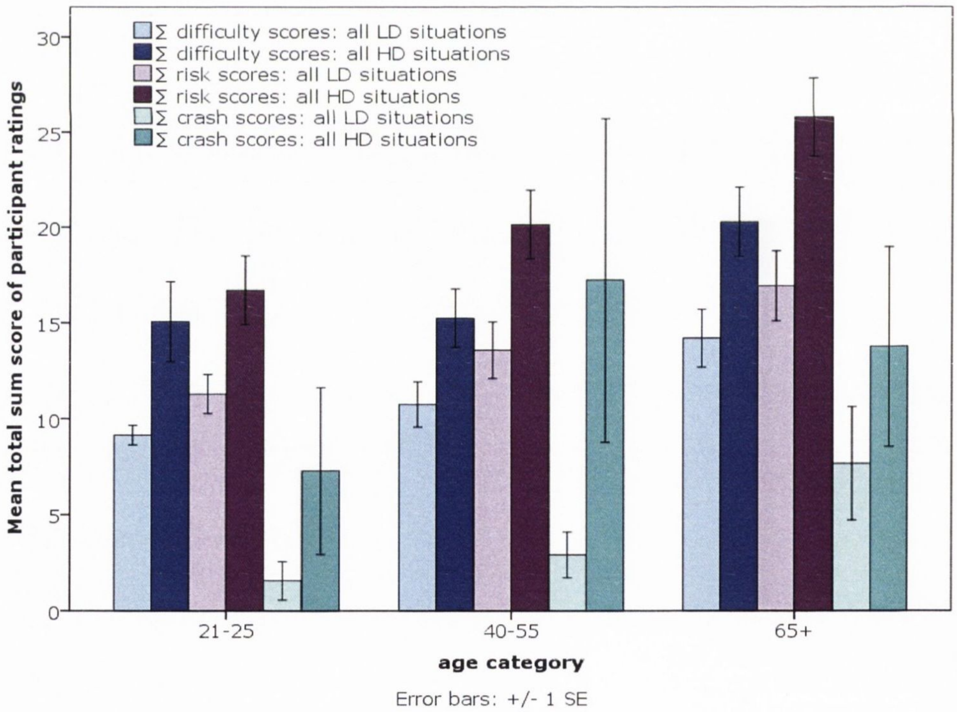

Figure 6-6: High & low difficulty situations: Means and standard errors for ratings of difficulty (blue), feeling of risk (purple) and collision likelihood (green), differentiated by age.

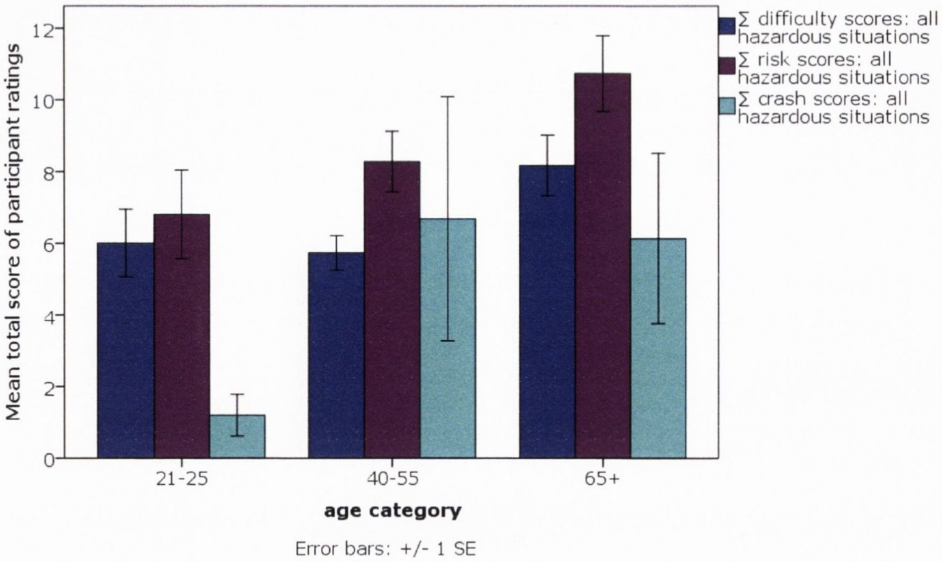

Figure 6-7: Hazardous videos: Means and standard errors for ratings of difficulty (blue), feeling of risk (purple) and collision likelihood (green), differentiated by age.

Perceived difficulty

As a first step, 3x2 split-plot ANOVAs with age as between factor and difficulty as within factor were used to explore differences between the three age groups and the two levels of difficulty for the sum score of ratings of difficulty for the eight situation pairs. Significant main effects were found for difficulty ($F(1,31)=31.19$, $p<0.001$; partial $\eta^2=0.50$) and age $F(2,31)=3.98$, $p=0.03$; partial $\eta^2=0.20$). In line with expectation high difficulty situations attracted significantly higher ratings. An LSD post-hoc test for the main effect of age showed that older drivers' difficulty ratings were significantly higher than young and middle aged participants' ($mean_{diff65+;21-25}=5.14$, $p=0.024$; $mean_{diff65+;40-55}=4.25$, $p=0.028$).

A between subjects ANOVA was used to test for significant age effects for the sum scores of the hazardous videos; however, no significant age effect was found.

Perceived feeling of risk

The analyses of perceived feelings of risk ratings were performed in an analogous manner. For the analyses of the sum scores of risk ratings across the eight situation pairs main effects emerged for difficulty ($F(1,31)=67.62$, $p<0.001$; partial $\eta^2=0.69$) and age $F(2,31)=4.27$, $p=0.023$; partial $\eta^2=0.22$). The post hoc test in this instance showed that older drivers rated feelings of risk significantly higher than young drivers (mean $diff_{65+;21-25}=7.37$, $p=0.010$), whereas the difference between older and middle-aged drivers just failed to reach significance (mean $diff_{65+;40-55}=4.49$, $p=0.057$).

Risk perception as a function of age

No significant differences were found for the sum score of the four hazardous situations.

Perceived likelihood of a collision

For collision likelihood ratings the sum scores of the eight situations showed a main effect for difficulty ($F(1,31)= 6.25$, $p=0.018$; partial $\eta^2=0.17$), but not for age.

As before, no significant effects were found for the sum of hazardous videos.

Summary and conclusion

- The second hypothesis was only partly supported.
- For the sum scores of the eight situation pairs, older drivers rated the perceived difficulty and the perceived feeling of risk significantly higher than young drivers (and middle-aged drivers for the former, but not the latter) in line with expectation. However, age differences did not emerge only in the high difficulty conditions (as a significant interaction effect), but as a main effect of age and were thus prevalent in both, high and low difficulty situations.
- No significant age effects emerged for rated difficulty or perceived feeling of risk for the sum score on the four hazardous situations.
- In line with expectation, no significant age effects were found for ratings of collision likelihood for the sum score of the eight situation pairs or the hazardous situations.

6.3.4 Hypothesis 3

Older drivers' increase in Skin Conductance Level (SCL) and Heart Rate (HR) from baseline will be significantly larger and Heart Rates Variability (HRV) will be significantly smaller than that of middle-aged and young drivers in situations of high difficulty and potentially hazardous situations; increases in SCL and HR and decreases in HRV from baseline will not significantly differ by age in low difficulty situations.

The third hypothesis was tested based on the analysis of participants' recorded EDA and heart rate. The inspection of the physiological data recordings indicated problems with the data of nine older and one young participant; therefore, data from these participants were excluded from the analysis. The findings presented in the following are thus based on 24 participants (six young drivers, 12 middle-aged drivers, six older drivers).

Skin Conductance Level

To calculate average changes in the SCLs for the different age groups, skin conductance recordings sampled at 1 Hz were averaged across the duration of the video clip for each participant to obtain an average SCL level per video and participant. Subsequently the mean SCL level (in micro siemens) obtained for the 30 second baseline measurement at the beginning of the trial was calculated and subtracted from the mean SCL for the video, resulting in the average change from baseline in SCL per video and participant. Missing values in one pair were replaced with the SCL value from the same person for the correspondent situation of the pair. In cases where both SCL values for the pair were missing for a participant, these were replaced by the group averages for the respective situations. Missing values were replaced in 11 cases (out of 384).

The resulting total average SCL differences for the eight high and eight low difficulty situations were added up to two separate sum scores:

- Mean total SCL change for high difficulty situations
- Mean total SCL change for low difficulty situations.

Additional, the mean SCL for the four hazardous situations were added up across participants to provide a mean total SCL change for the four hazardous driving situations Missing values were replaced with the group averages (11 cases out of 96).

Figure 6-8 and Figure 6-9 show the means and standard deviations of the average total SCL changes for high and low difficulty situation pairs (left) and hazardous situations (right). Contrary to expectation low difficulty situations triggered greater SCLs changes than high difficulty situations in young and older drivers and differences in the expected direction were only apparent in the middle-aged driver group (Figure 6-8). However, the large standard deviations for both age groups indicated considerable variation in the data. For hazardous situations younger drivers showed greater changes in SCL level than middle-aged and older drivers; however, the variation in this age group appeared considerable.

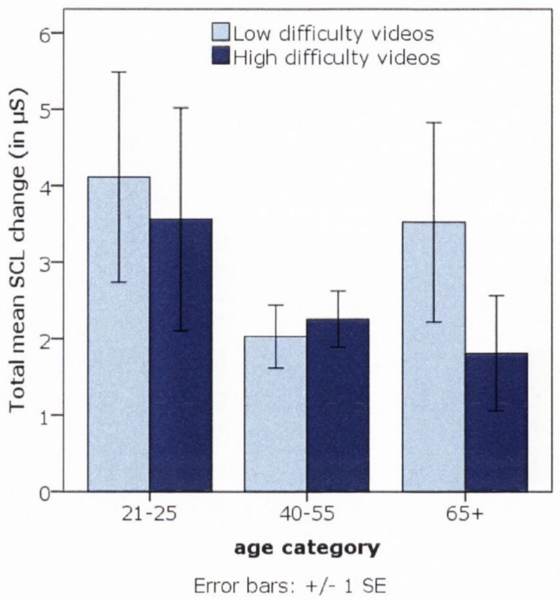

Figure 6-8: Means and standard errors for total SCL change (in µS) in high versus low difficulty driving situations.

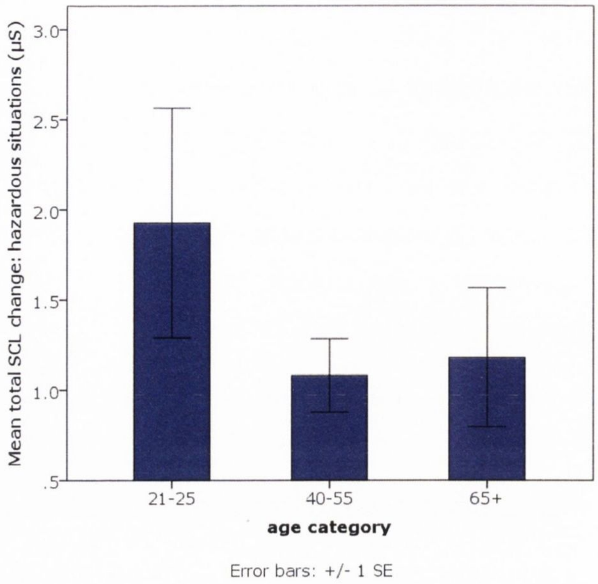

Figure 6-9: Means and standard errors for total SCL change (in µS) for hazardous driving situations.

The sum scores for SCL changes for high and low difficulty situations were fed into an ANOVA with age as the between factor and difficulty as within factor for significance testing. No significant effects emerged for either difficulty or age.

An ANOVA was used to test for significant age effects for the sum scores of SCL changes for hazardous videos. Again, no significant effect was found.

Heart rate

The analysis of the heart rate was undertaken in analogous manner. Missing values were replaced in 10 cases (out of 384 cases) for the situation pairs and in 9 cases out of 96 for the hazardous situations.

Figure 6-10 and Figure 6-11 show the means and standard deviations of the average total HR change from baseline for high and low difficulty situation pairs (left) and hazardous situations (right). Mean heart rate change appeared very similar for high and low difficulty situations. Age effects only seemed apparent for hazardous situations where older participants' heart rate change was smaller than that of other age groups. However, the large standard deviations, particularly for the older drivers indicated considerable variation in the data.

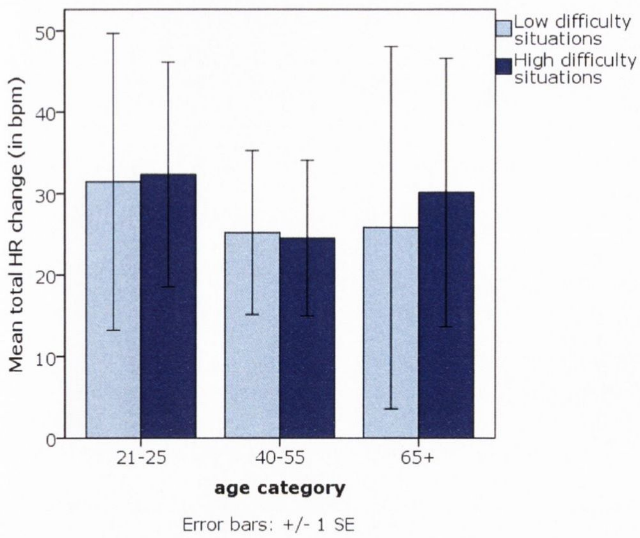

Figure 6-10: Means and standard errors for total HR change (in bpm) in high versus low difficulty driving situations.

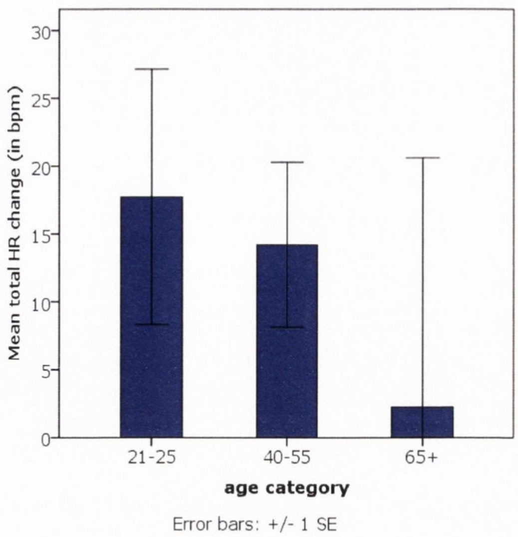

Figure 6-11: Means and standard errors for total HR change (in bpm) in hazardous situations.

In addition to the calculation of change in HR from baseline, mean heart rate variability (HRV) was also calculated and added up for high and low difficulty situations (see Figure 6-12) and hazardous videos (see Figure 6-13). Low difficulty situations triggered greater HRV than high difficulty situations in older drivers, against a backdrop of somewhat lower variability for the two older groups compared to the young drivers. For the four hazardous videos, heart rate variability for the three groups appeared similar.

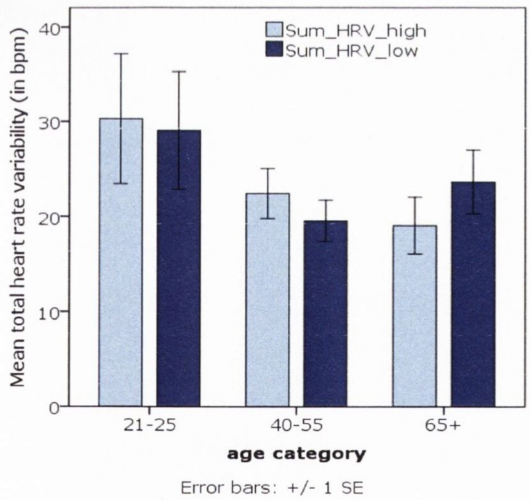

Figure 6-12: Means and standard errors for total HRV (in bpm) in high versus low difficulty driving situations.

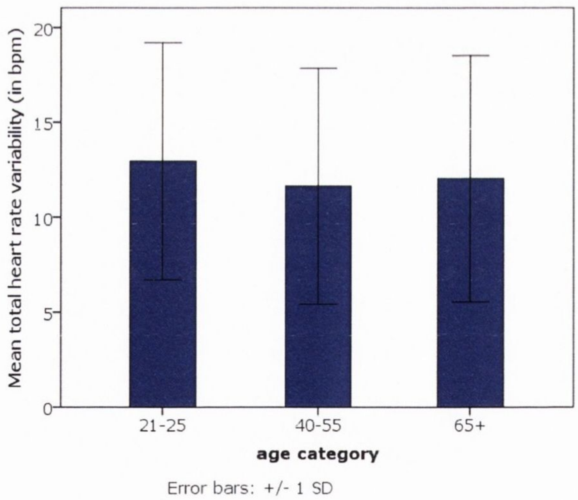

Figure 6-13: Means and standard errors for total HRV (in bpm) in high versus low difficulty driving situations.

Risk perception as a function of age

For inferential testing the sum scores for HR changes and for HRV for high and low difficulty situations were fed into two ANOVAs with age as the between factor and difficulty as within factor. No significant effects emerged for either difficulty or age.

Two ANOVAs were used to test for significant age effects for the sum scores of HR changes and for HRV for hazardous videos. Again, no significant effects were found.

<u>Summary and conclusion</u>

- Based on the findings, the third hypothesis was rejected.
- The data of nine older and one young driver had to be excluded from analysis because of insufficient signal quality. This reduced the sample size from 34 participants to 24 participants.
- Changes in SCL and HR compared to baseline did not systematically differ by age for sum scores of total SCL change and HR change of either situation pairs or hazardous videos. Inspection of the descriptive data indicated that contrary to expectation, young and older drivers' SCL changes were greater in low difficulty situations, but also that there was considerable variation in physiological reactions observed in both groups.
- No significant main effects of age were found for heart rate variability for the eight driving situations and four hazardous situations.

6.3.5 Hypothesis 4

Age-relevant driving situations will attract significantly higher ratings and larger physiological responses (increases SCL and HR and decreases in HRV) from older drivers than from young and middle-aged drivers, whereas no significant differences will be found for situations that are not age-relevant.

The last hypothesis used the eight situation pairs to explore age effects for those situations that present a particular risk to older drivers versus those that do not. Based on the literature review and the analysis of older drivers' collision patterns the following situations that may present a particular challenge to older drivers (and are frequently avoided by them) had been identified:

- Turning right onto a major road at a t-junction;
- Turning left onto a major road at a junction;
- Turning right at a roundabout;
- Drive straight across a roundabout.

Situations that should not present a challenge to older drivers included:

Risk perception as a function of age

- Negotiating a bend;
- Following a vehicle;
- Overtaking;
- Pedestrian crossing the driver's path.

An interaction effect was predicted whereby older drivers' subjective and physiological reactions to situations that carry an age-typical risk would be significantly higher than those of young and middle-aged drivers, but would not be significantly different for situations that are not associated with a higher crash risk for older drivers.

Rating data

For the analysis, ratings of difficulty, feeling of risk and likelihood of a collision for the eight situation pairs were added up to each form a sum score for age-relevant versus non age-relevant situations. Figure 6-14 shows means and standard deviations for all three rating sum scores. It appears that only the middle-aged drivers' ratings consistently differentiated between age-relevant and not age-relevant situations in the expected direction for ratings of difficulty, feeling of risk and likelihood of a collision. No such differentiation was apparent for young and older drivers' ratings of difficulty and feeling of risk. Whilst for older drivers, differences in the rated likelihood of a collision were in the expected direction, the opposite was the case for young drivers. In line with earlier findings (see Section 6.3.3) collision estimates in all age groups were subject to large variation.

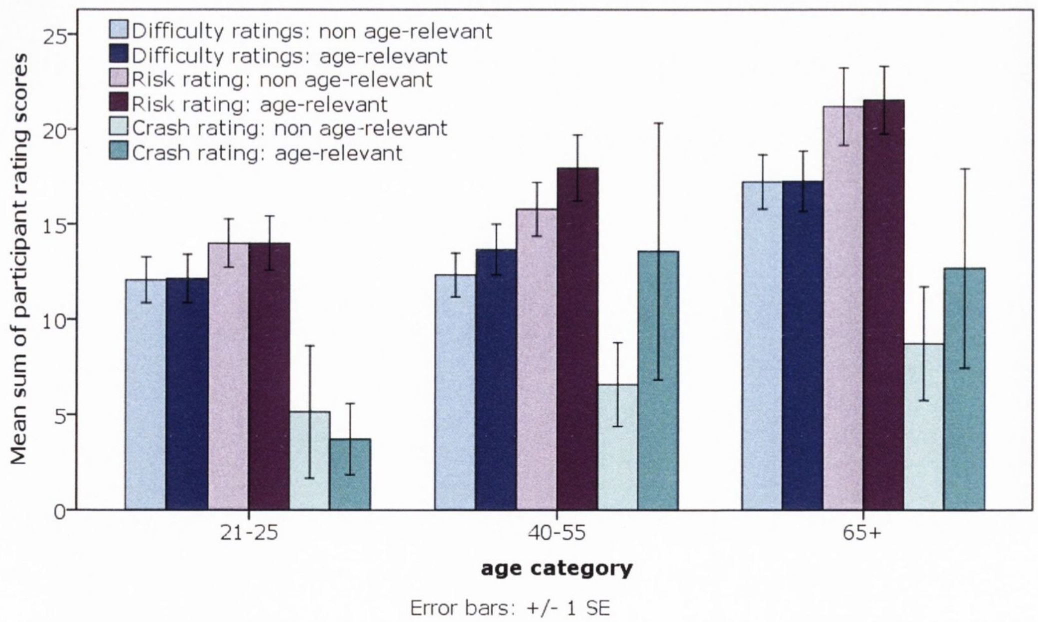

Figure 6-14: Means and standard errors for ratings of difficulty, feeling of risk and crash likelihood for age-relevant versus not age-relevant driving situations.

Risk perception as a function of age

Three ANOVAS were performed with age as the between factor and age relevance as the within factor. For difficulty ratings a main effect of age was found ($F(2,31)=3.98$, $p>0.029$; partial $\eta^2=0.20$). Post-hoc LSD tests showed that older drivers' difficulty ratings were significant higher than younger drivers' (mean $diff_{65+;21-25}= 5.14$, $p=0.024$) and middle-aged drivers' (mean $diff_{65+;40-55}=4.25$, $p=0.028$). A similar main effect for age also emerged for feeling of risk ratings ($F(2,31)=4.27$, $p>0.023$; partial $\eta^2=0.22$) which an LSD post-hoc test showed to be due to older drivers' significantly higher risk ratings compared to those of young drivers (mean $diff_{65+;21-25}=7.37$, $p=0.010$). No significant age effects were found for collision likelihood ratings. Against expectation, age-relevance did not emerge as a significant factor for any of the three subjective rating variables.

Skin Conductance Level

Analogously, for the analysis of physiological data, the total mean SCL change in (high and low difficulty version) for age-relevant situation and not age-relevant situations were added up for subsequent analysis. The means and standard deviations shown in Figure 6-15 below indicate that mean total increases in SCL were greater for not age-relevant situations in young and old participants, whereas SCLs did not differ for middle-aged drivers.

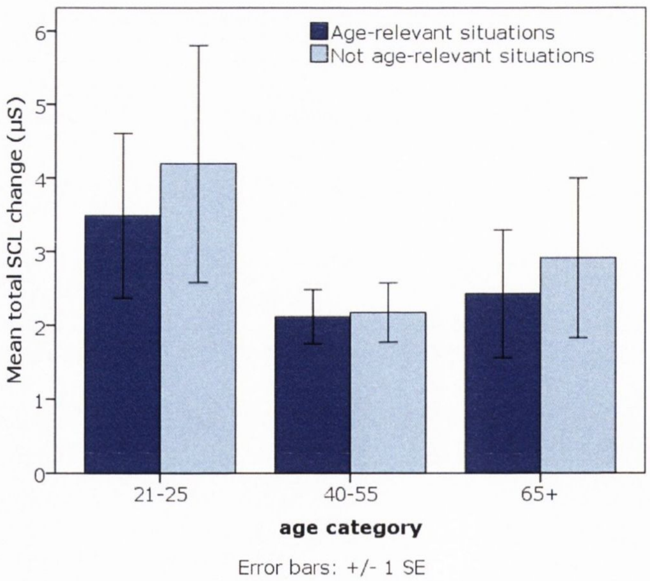

Figure 6-15: Means and standard errors for the total mean change in SCL for age-relevant versus not age-relevant driving situations, differentiated by age.

Both sum scores were fed into an ANOVA with age as between factor and age relevance as the within factor. No significant differences were found for age or age-relevance.

Heart rate

The total change from baseline for the mean heart rate and the mean heart rate variability were analysed in analogous fashion. Graphs of the means and standard deviations for both are shown in Figure 6-16 and Figure 6-17 below. Changes in heart rate were very similar between the three age groups and did not appear to differ between age-relevant and not age-relevant situations.

Contrary to expectation heart rate variability for older drivers (and, to a smaller degree, middle-aged drivers) was higher in situations that were not age-relevant, whereas young drivers showed greater heart rate variability in situations that are particularly challenging to older drivers.

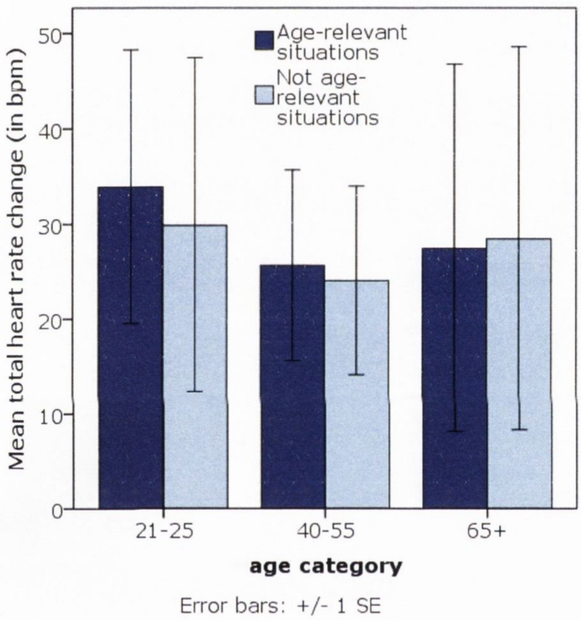

Figure 6-16: Means and standard errors for total mean heart rate change for age-relevant versus not age-relevant driving situations, differentiated by age.

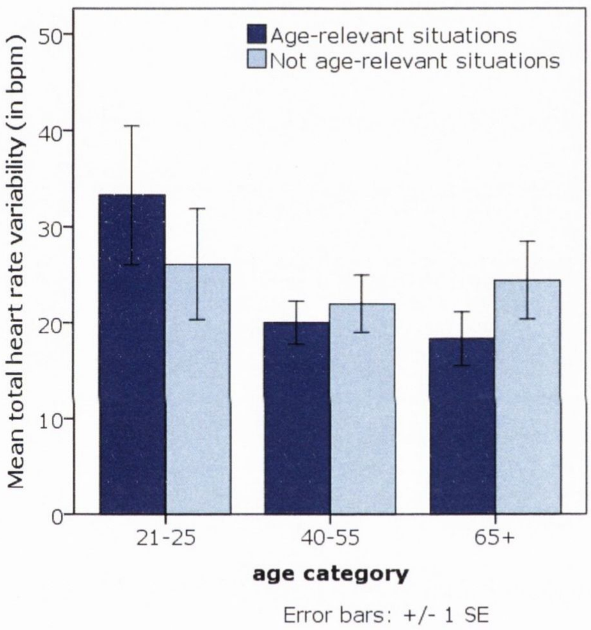

Figure 6-17: Means and standard errors for total mean heart rate variability for age-relevant versus not age-relevant driving situations, differentiated by age.

Sum scores of mean heart rate changes and of mean heart rate variability for age-relevant and not age-relevant situations were fed into split-plot ANOVAs with age as between factor and age relevance as the within factor. No significant differences were found for the mean total heart rate change.

For mean total heart rate variability a significant interaction of age-relevance and age ($F(2,21)=4.35$, $p=0.028$, partial $\eta^2=0.293$) emerged. Analysis of simple effects indicated that younger drivers' total heart rate variability was significantly higher than that of middle-aged (*p*=0.023) and older drivers (*p*=0.027) in response to age-relevant videos and that younger drivers' total heart rate variability was significantly higher in age-typical compared to non-typical situations (*p*=0.041). The estimated marginal means plot is shown in Figure 6-18.

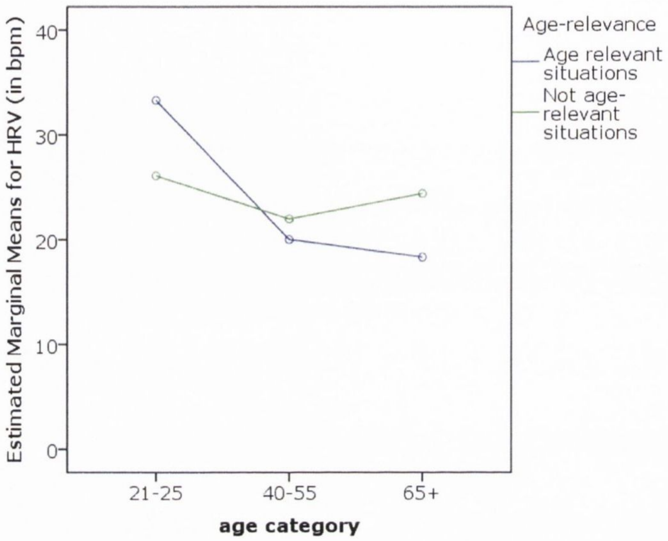

Figure 6-18: Estimated marginal means for significant interaction of age and age-relevance for heart rate variability.

<u>Summary and conclusion</u>

- Based on the findings, the fourth hypothesis was rejected.
- Older drivers' subjective and physiological responses did not differentiate between situations that collision statistics and the literature suggest to be particularly problematic for older drivers. Instead, older drivers were found to generally rate difficulty significantly higher than middle-aged and young drivers and to rate feeling of risk significantly higher than young drivers.
- For physiological data, no significant effects were found for changes in SCL or heart rate. For the heart rate variability, a significant interaction (significant higher heart rate variability in age-typical situations) emerged, but only for young drivers, but not older drivers and in the direction contrary to expectation.

6.4 Discussion

The results of the third study of this thesis replicated some of the findings of the second study which had been carried out in a driving simulator and provided further insight into how risk perception changes over the course of the lifespan.

6.4.1 Age effects in subjective ratings for high-low difficulty situation pairs

Based on the Task-Capability-Interface Model, the second hypothesis predicted that age-related decline (without concomitant decrease in driving experience, i.e. through lack of practice) would only become noticeable in subjective measures under conditions of high difficulty, where this capability decline would manifest in higher perceptions of task difficulty and with that, in feelings of risk. It therefore predicted an interaction effect for older drivers' ratings of perceived task difficulty and feeling of risk. Contrary to expectation and in line with the findings from the previous simulator study, where older drivers' difficulty and feeling of risk ratings were significantly higher than those of young drivers observed in all speed conditions in the urban environment, older drivers in the current video-based study rated task difficulty and their feelings of risk significantly higher than those of young and middle-aged drivers, in both, the high and low difficulty versions of the eight driving situations. A possible explanation for this finding, as discussed in Section 4.7.3, could be that even the low difficulty version of the driving situation was so high in perceived difficulty, that if brought out age-related deteriorations in driver capability and thus, significant differences in the ratings of older versus young and middle-aged drivers. The inspection of the ratings of eight situation pairs, differentiated by age, as shown in Appendix C, Table C-4, however, clearly shows that the difficulty ratings of older drivers on a 7-point Likert scale do not rise much beyond an average value of two, which suggests that the perceived task demand of the low difficulty version of the situations pairs is rated as low by this driver group. At the same time and similar to the simulator study findings, the inspection of self-report data in the driving questionnaire on weekly mileage showed no significant differences between participant age groups, nor were there any significant differences between age groups in the self-assessments of driving skill, confidence, cautiousness or in ratings of the difficulty of driving situations that research frequently reports to be a particular challenge to older drivers. Given the repeated finding of low task demand ratings, coupled with high capability ratings in the older driver age groups, the emerging evidence from the empirical work in this thesis points towards a global sensitisation to risk that manifests with healthy aging and occurs without concomitant self-reports of reduced capability, at least for driving situations that involve sufficient visual cues that put the driving speed of the vehicles in the observed scene into context. Compared to the driving condition on the dual carriageway, shown in the simulator study, driving scenes in the current study presented considerably more contextual information and should have therefore been more likely to enable the older participants to make more accurate judgements on speed. In line with prediction, no significant age effects were found for participants' collision likelihood estimates, which are further discussed in Section 6.4.4.

6.4.2 Age effects on physiological measures for high-low difficulty situation pairs

The third hypothesis speculated that age-related changes on subjective measures would be accompanied by the same pattern of changes on the physiological level. Therefore, an interaction effect was predicted, whereby older drivers would display significantly greater increases in skin conductance level and heart rate variability than middle-aged and older drivers. Unfortunately, the physiology data of almost a third of the original sample had to be excluded from analysis, and this affected in particular the group of older drivers. Based on the review of the literature (see Section 5.2.3) which suggested age-related attenuation of physiological signal and increasing proportions of non-responders, some oversampling for the older driver participant group had been undertaken to compensate for non-responder drop outs; however, the proportion of drop-outs was higher than expected and the remaining sample of older drivers was small. Additionally, and despite using change from participants' initial baseline, instead of the raw data, the inter-individual variability in the physiological data, particularly for the young and the older driver group, was considerable, and any findings for these two groups, such as the higher SCL responses in low difficulty situations for young and older drivers and the higher HRV responses for the low difficulty situations in older drivers, have to treated with considerable caution and require further investigation with larger participant numbers to identify whether these non-expected reaction patterns occur consistently. For the slightly bigger, middle-aged driver group, variability was considerably smaller and the change on the physiological measures, including SCL change and Heart Rate Variability was in the expected direction, whereby high difficulty situations were associated with a greater increase in Skin Conductance Level and greater Heart Rate Variability, albeit not at a significant level. This leads to a general point in relation to the limitations of the stimulus material, i.e. the high and low difficulty situation pairs used in the current study, which is further elaborated in Section 6.4.7. Given the considerable variability in the data, particularly for young and older drivers, it is not possible to draw any conclusions from this study on whether physiological signals correspond with subjective measures or dissociate from them in different age groups. For the biggest participant group, the middle-aged drivers, the findings suggested correspondence between physiological and subjective data.

6.4.3 High workload situations versus emerging hazards situations

In addition to the "incremental" manipulation of task difficulty in high and low difficulty versions of the same driving manoeuvre, through systematic variations in driving speed, static clutter and traffic density, the current study also attempted to explore age-effects for four situations, where a developing hazard led to a sudden spike in task difficulty. These situations were included in the study to explore task difficulty as it would be conceptualised by the hazard perception literature and compare it against the conceptualisation of task difficulty as workload, as it has been used in most of the empirical studies to date. These studies have emphasised increases in task difficulty through stepwise speed increments. It was thereby expected that situations showing an emerging hazard would be perceived to be similarly difficult as the high difficulty versions of the eight situation pairs. Comparisons of mean ratings of task difficulty during data screening showed, however, that hazardous situations were rated as significantly less difficult and less risky by participants than the eight high difficulty driving situations. The fact that subsequent analysis of subjective and physiological measures did not identify any significant age effects for the four hazardous situations is most likely attributable to the low perceived risk and difficulty of the hazardous situations, as significant age effects on subjective measures were found for the eight situation pairs that had been rated as significantly higher in difficulty and perceived risk.

Whilst the investigation of differences between task difficulty as workload and task difficulty as hazard perception had exploratory character in this study, it is suggested that future studies could use stimulus material for hazardous driving situations that has already been created and validated to shed light on these two perspectives on task difficulty. For example, TRL researcher developed a number of hazard perception video clips over several years (Grayson & Sexton, 2002) on behalf of the Driving Standards Agency (DSA) in the context of hazard perception testing of learner drivers. These videos used a mixture of opportunity filming and staged filming. Some of these videos are now used in the British Theory Test or as training material for the Theory Test and can be used for research purposes with permission from the DSA. With its main focus on the investigation of age effects on the incremental manipulation of task difficulty and on the question whether older participants are sensitive to the particular risks that certain situations pose, according to collision statistics, the inclusion of these videos would have been problematic: presentation on three video screens would not have been possible, differences in the look and feel of the videos (they have been filmed more than a decade ago) and potentially the length of the situation development in the clip would have called into question the comparability of the two types of stimulus material and the attributability of any emerging differences in task difficulty to task difficulty as workload versus hazard perception.

6.4.4 The relationship between feeling of risk, task difficulty and collision likelihood

Findings from the present study confirmed the first hypothesis. Ratings of task difficulty and feeling of risk were found to be strongly and significantly correlated whereas the correlations between task difficulty and collision likelihood estimates were considerably weaker, albeit significant for the low difficulty situations. This finding supports the proposition of both Zero Risk Model and Task Capability Interface Model that drivers' decisions are not driven by assessments of collision likelihood. Instead the close association between task difficulty ratings between and feeling of risk in high and low difficulty driving situations suggest that Fuller's proposed parameter of "task difficulty", i.e. how much is "going on" in a driving scene, co-varies closely with feelings of risk.

As in the previous simulator study, participants' collision estimates were subject to considerable variability, and an average proportion of thirty-four percent of participants rated the likelihood of a collision in the low difficulty versions of the eight situations pairs as greater than zero. At the same time, the corresponding difficulty and feeling of risk ratings for these situations were low (see Appendix C, Table C-3) and rarely exceeded a scale point of two (out of seven). Logically, if feeling of risks and task difficulty are rated as very low, the risk of a collision should also be rated as low and thus follow a threshold model, particularly since everyday life experience shows collisions to be relatively rare events. However, whilst participants' estimates of collision likelihood did significantly increase with difficulty, as indicated by the significant main effect for difficulty of the situations, the high proportion of participants who estimate collision risk as greater than zero for low difficulty situations, support the previously discussed notion of people as poor intuitive statisticians.

6.4.5 Age-relevant situations

The fourth hypothesis predicted that older participants' subjective and physiological reactions to situations, which the literature and collision statistics show to present a particular challenge to older drivers, would be stronger than for those that do not. The evidence, however, did not provide support for this prediction. Similarly to their ratings of high and low difficulty situations, older drivers did not differentiate between age-relevant and non-relevant situations, but rated all situations as more difficult than young and middle-aged drivers and as more risky than young drivers did. These findings would suggest that the safety success of older drivers' self-regulatory measures is based, not on the correct recognition and differentiation of task difficulty per driving situation, but a global perception and attribution of higher risk across driving situations and adoption of the same self-regulatory measures across that range of situations to cope with this risk. Put in simple terms, these findings would suggest that the driving world simply looks more dangerous to the older driver in general, at least, those driving environments that encompass a minimum amount of visual cues.

The analysis of the physiological data was hampered by small participant numbers and considerable variability in the data, and no significant effects were found for changes in SCL or heart rate. The only significant effect found was a significantly higher heart rate variability in age-typical situations for heart rate variability in young drivers. Given the limitations in sample size, conclusions on whether physiological reactions converge with the subjective ratings of older drivers, in terms of a generalised higher sensitivity to risk, rather than a differentiation of situations by task difficulty, cannot be drawn on the basis of this study. The pattern of findings for the physiological data, however, seems to indicate that situations, that should not present a particular challenge to older drivers, appear to be associated with stronger physiological reactions. Further research to clarify this is necessary.

6.4.6 Determinants of task difficulty

Whilst previous experiments testing TCI Model predictions have somewhat artificially emphasised the manipulation of speed as the main determinant of task difficulty, the current study demonstrated that a multi-dimensional composition of task difficulty, through the manipulation of speed, presence of other road users and amount of static clutter in the scene, could also lead to the successful differentiation of high and low difficulty situations by normal drivers. The stimulus material was also able to discriminate between the subjective ratings of young, middle-aged and older drivers with regards to their perceptions of task difficulty and feeling of risk. Compared to previous research in the field, the current approach therefore provides us with a richer understanding of the risk perception processes and factors that influence task difficulty assessments. Further research should focus on the analysis of the relative importance of speed, static clutter and traffic density on task difficulty perception.

6.4.7 Limitations of the current study

The current study suffers from two main limitations: the achieved difficulty levels in the stimulus material and the small sample size for the physiological data, in particular in the older driver group, due to problems with the recording. Both are expanded on in the following, but are fundamentally the result of financial and time restrictions. Funding for the current study, including time, facilities and equipment was provided through the TRL reinvestment programme, which awards small research grants to TRL staff, following the submission of a costed research proposal. Any aspect of the study, including the creation of stimulus material, i.e. recording and video-editing, as well as the piloting of materials, participant recruitment, trial completion and renting of physiology data capture equipment had to comply with a strict time and cost schedule. An extension of funds was not possible. This left very little opportunity for adjustments, refinements, changes to the trial schedule or additional data collection.

Regarding the video-recorded driving situations, the available budget for the study meant that filming and extraction of driving situations had to rely on naturally occurring traffic scenes for the four hazardous driving scenes. For the eight high and low difficulty situations the manipulation of difficulty relied on a mixture of active manipulation and opportunity filming. For example, the driving speed was actively manipulated by driving considerably more slowly than normally indicated for the low difficulty situation and to drive at the speed limit for the high difficulty situation. To vary static clutter and traffic density, the experimenter searched for appropriate locations and different times of the day in the driving environment. Overall, the generation of video-recorded stimulus material proved to be a time-consuming process. The significant main effects for difficulty on the three subjective rating parameters (see Section 6.3.3) indicate, that the approach of manipulating task difficulty by selecting high and low difficulty versions of the same driving manoeuvre through composition of speed, static clutter and traffic density was successful: Participants consistently rated perceived difficulty, feeling of risk and likelihood of a collision higher in the high difficulty versions of the situations than in the low difficulty version. However, as both, the pilot data (see Table 6-2) and the trial data (see Appendix C, Table C-3) indicated, mean ratings of the perceived difficulty for situation pairs were relatively close together and very much towards the lower end of the difficulty scale. This suggests that a video study relying on naturally occurring high versus low difficulty versions of the same scenario is limited in terms of the possible differentiation it can achieve between the two, and that existing differences, for example, between different driver age groups, may not manifest, because the upper end of the task difficulty achieved by the stimulus material fails to tease out these differences. However, maximising differentiation also comes at a cost: exceeding the prevailing speed limit on the road or intentionally carrying out risky driving manoeuvres that may put other road users at risk was ethically not justifiable and would have required staging of situations, which was not possible within the allocated budget. For future research that uses a multi-dimensional approach to manipulating task difficulty, producing situation versions that differentiate more clearly and use up a greater part of the difficulty scale could be possible in a driving simulator or using animation, whereby the different aspects of difficulty can be actively manipulated and maximised.

The second main limitation of the study comprised the loss of physiological data for a considerable proportion of the older participant group. Based on the findings from the literature, which had predicted some age-related attenuation of physiological reactivity, the expectation was that the amplitude of change on physiological parameters may be somewhat reduced for older participants, but that the pattern of responses would remain intact. Piloting of older participants' skin conductance response to video-based material was conducted prior to the main study, and the findings suggested that the measure could be feasibly used in the trial. Furthermore, some oversampling for older participants had been arranged to retain a sufficiently large sample of "good" data sets for analysis. However, the proportion of older drivers for whom the physiology recordings were bad, turned out to be higher than expected and significantly reduced the available data sample for analysis. Unfortunately, and for the reasons already outlined, the data acquisition period could not be extended and the physiological recording equipment was not available to the experimenter beyond the period initially agreed. This meant that the analysis was limited to the exploration of age-effects on physiological reactions to risk, based on a small participant sample, particularly for the young and older driver group. The considerable inter-individual variability in the data further exacerbated the difficulty of low statistical power as a result of the small sample size. This means that the question whether the physiological component of an affective reaction to risk changes with age, similar to the subjective component, cannot be answered by the current study. Further research with a larger participant sample will be necessary. However, the current study has demonstrated the feasibility of an experimental approach to the exploration of age effects in affective reactions, including their subjective and physiological components. Further empirical research in the field needs to oversample older participants considerably to allow for a considerable proportion of non-responders.

Because of the limitations of the available physiology data the findings from the current study rely on subjective rating data. Therefore, the same limitations as outlined in Section 4.7.7 apply.

As in the previous simulator study, the analyses found no significant age differences on self-reported measures of capability, i.e. rated difficulty of driving situations that the literature shows to typically elicit reports of greater difficulty from older drivers and self-assessments of confidence, skill and caution. According to the literature, young drivers would typically arte their skills and confidence levels as high, whereas older drivers would rate the perceived difficulty of challenging driving situations as high. The fact that no significant differences were found could suggest that the study sample was subject to a self-selection bias of participants who were not fully representative of the overall driver population. Whilst participants in the TRL participant pool receive a small financial compensation for their time spent on trials, it is likely that particularly drivers with an interest in research will put themselves forward as volunteers. Indeed, a conversation with a TRL member of staff previously involved in participant recruitment suggests that many of the drivers registered in the TRL database participate in research on a regular basis. It is possible that particularly older volunteer drivers will be more confident in their driving skills than the average, as drivers who have concerns over their skill would probably avoid situations that could be construed as testing their skill. This may limit the generalizability of the findings to the general driving population who may be less confident or capable to drive. However, if it is the case that the simulator study and the video study used a particularly confident and capable older driver group, then this should all the more support the findings of age effects that point towards a greater general sensitisation towards task demand and risk in traffic with age that is independent of perceived reductions of capability.

7 Summary and conclusion

7.1 Summary overview of this thesis

This thesis explored from a psychological perspective how older drivers' perception of risk differs from that of younger age groups. The ultimate aim of the research was to enhance knowledge and understanding that can inform the development of appropriate measures to maintain the driving safety of older drivers for as long as possible.

Chapter one provided an introduction to current trends and risk factors in connection with older driving. It pointed towards the importance of mobility for wellbeing and quality of life (Whelan et al., 2006) and described demographic trends in the UK and many countries of the Western world, including rising numbers and growing proportions of older drivers (Lanzieri, 2011), coupled with the sustained importance of the car as a relatively safe mode of transport for older people (OECD, 2001; Staplin et al., 2003). Public concern about age-related cognitive, sensory and physical decline associated with "healthy" aging and its impact on older drivers' collision rates (Li, Braver & Chen, 2003) has resulted in a considerable body of research which indicates that older drivers up to the age of 80 have collision rates that are comparable to those of middle-aged drivers, when all severity collision rates are compared on a per licensed driver basis (OECD, 2001; Baldock & McLean, 2005; Lyman et al., 2002). Older drivers' comparatively safe driving performance has been repeatedly attributed to 'self-regulation', which describes the voluntary adaptation or cessation of driving to match changing cognitive, sensory and motor capacities adequately to the requirements of the driving task (Charlton et al., 2006; Oxley et al., 2003; Charlton & Molnar, 2011). However, a considerable body of international research also suggests that older drivers are over-represented in particular types of collisions (e.g. Baldock & McLean, 2005; OECD, 2001; Langford & Koppel, 2006). These include collisions at intersections and in give-way situations during daylight hours in dry conditions. Age-specific patterns should arguably also emerge in the circumstances and contributing factors to these collisions.

The first study of the thesis, described in Chapter two, therefore explored collision involvement rates of different driver age groups and patterns of 62 individual contributory factors in collisions from STATS19, Great Britain's police recorded injury collision database. Contributory factors have only been collected as part of STATS19 since 2005; thus, this study had unique access to a large dataset, which enabled analyses that had never been carried out before. Whilst in-depth collision studies have looked at the biomechanics of injuries for different collision configuration, there had not been studies on detailed collision causation mechanisms to date. The current analysis was based on two years of data and included 472,451 cases. It identified increased collision rates for older drivers, compared to middle-aged drivers, when rates were based on person miles travelled and higher collision rates for older females compared to older males. For example, older male drivers (71+ years) had a fatality risk of 2.48 per 1,000,000 vehicle miles travelled, older females one of 4.85 per 1,000,000 vehicle miles travelled and as a group were closest to the fatality rates of 21-29 year old drivers, where males had a fatality rate of 6.30 per 1,000,000 vehicle miles travelled and females one of 1.99 per 1,000,000 vehicle miles travelled. Collision rate increases occurred in the study's sample with the beginning of the 7th life decade.

The analysis of contributory factor data showed that similar to the middle-aged (31-60 years) driver group, older drivers aged 60-71 years were less likely to have any contributory factors recorded against them. Drivers older than 71 years were similar to young drivers (17-30 years) in that they were more likely to have at least one contributory factor recorded against them. Compared to young and middle-aged drivers the number of contributory factors recorded against older drivers was subject to considerably more variability. The analysis of contributory factor patterns showed that contributory factors, that were recorded particularly frequently against older drivers, but also played a role for young and middle-aged driver groups, included those that pointed to failures in manoeuvring, failures in judgement and failures in attending properly to the traffic situation: the six top ranking factors for drivers aged 71 years and older were also among the top twenty ranking factor for all other driver age groups, even if their relative contribution was smaller, as illustrated in the brackets:

- Failing to look properly (24.3% for 71+ year olds versus 12.4% for 17-30 year olds);
- Failing to judge another person's path or speed (12.8% versus 6.6%);
- Poor turns or manoeuvres (10.5% versus 5.8%);
- Careless, reckless or in a hurry (7.3% versus 11.1%);
- Loss of control (5.3% versus 10.2%);
- Disobeyed 'give way' or 'stop' sign (3.9% versus 1.8%);

A number of contributory factors were almost exclusive to older drivers, i.e. had very low prevalences in younger driver groups. These comprised factors that pointed towards deteriorations of the visual system, general health problems and heightened feelings of anxiety in traffic, including:

- Illness or disability, mental or physical (3.3% for 71+ year olds versus 0.1% for 17-30 year olds);
- Junction overshoot (2.2% for 71+ year olds versus 0.5% for 17-30 year olds);

- Dazzling sun (2.2% for 71+ year olds versus 0.5% for 17-30 year olds);
- Nervous, uncertain or panic (1.8% for 71+ year olds versus 0.5% for 17-30 year olds);
- Passing too close to cyclist, horse rider or pedestrian (1.1% for 71+ year olds versus 0.3% for 17-30 year olds).

Whilst some collisions may be caused by situational factors, rather than driver-dependant factors, the interest of the current thesis is on the aging driver, and thus particularly seeks to explore driver-dependent factors. If collisions are interpreted as unsuccessful driving events, the exploration of their contributory factors can inform us about the circumstances which most likely accompany or cause breakdowns in driving performance. However, they do not deliver a comprehensive model of driving behaviour, of drivers' perception of risk and related decision making. Understanding drivers and their decision-making has considerable potential for the development of assistance technologies or training interventions that can aid older drivers through difficult situations.

In Chapter three the thesis therefore progressed with the exploration of different theoretical conceptualisations of driver behaviour and how they may account for age related differences between younger, middle aged and older drivers that had emerged in the observed patterns of collision circumstances, including older drivers' greater difficulties with manoeuvring, making correct judgements and attending properly to the traffic situation as well as their greater levels of anxiety, vision deterioration and health problems. Several psychological models of driver behaviour that feature the perception of risk as a central component were reviewed, including Wilde's Theory of Risk Homoeostasis (1982; 1988; 1989), Näätänen and Summala's Zero Risk Theory (1974, 1976), Fuller's Threat Avoidance Model (1984) and Fuller's Task Capability Interface Model with its associated Risk Allostasis Theory (2000; 2005; 2009). The comparison of the models showed similarities, in that all models assumed a process of comparison where actual driving is compared to a target and which initiates a process of behaviour adaptation if a discrepancy between the two values is observed. All models proposed that feelings of risk are associated with intolerable discrepancies. However, models varied considerably with regards to the variables that are assumed to determine driving behaviour and the process by which these variables trigger feelings of risk.

Whilst Wilde assumed that perceived risk of a collision modified driving behaviour, Fuller (1984) initially suggested that drivers monitored the occurrence of potentially aversive threats; in his later model of Risk Allostasis he expanded that feelings of risk associated with increases in task difficulty are monitored by the driver. Such feelings can, according to Fuller, be unconscious, and learned avoidance responses ensure that people most of the time drive in such a way that feelings of risk are not manifest consciously. Summala contradicted the tenet of a continuous monitoring process and suggested that only if critical safety margins were violated, did feelings of risk become salient and trigger driver actions. The Zero Risk Theory and the Task Capability Model have attracted the most empirical research in recent years. Whilst both models mention age and experience as factors, they do not make explicit predictions about how higher age and experience will affect the perception of risk and thus driving decisions. A review of the literature on drivers' awareness and compensation of age-related changes, and systematic biases in risk perception and driving skills was therefore undertaken in the second part of Chapter three to bring together empirical findings and theoretical frameworks and to inform the development of testable hypotheses for the second study of the thesis.

Using the Task Capability Interface model as the conceptual framework, the second study in Chapter four investigated the psychological processes through which thirty young, middle-aged and older drivers (ten participants per age group) appraised risk and explored how this shaped their decisions and behaviour in a driving simulator. The synopsis of age-effects identified in the study suggested that on urban roads, older drivers rate task difficulty and feelings of risk significantly higher in all speed conditions (approximately one scale point difference to young drivers) and also estimate collision likelihoods significantly higher (between 10-20% compared to young drivers) in average and high speed conditions. The findings are compatible with the assumption of age-related deteriorations of driving capability and consequently higher levels of task difficulty for older drivers. However, the findings from a post-drive self-assessment that comprised questions typically used in research on older driver self-regulation suggested, that if such age-related decreases in capability were prevalent in the sample, the older driver participant sample did not perceive and report them. At the same time, the older drivers did adopt lower preferred and maximum driving speeds on urban roads in a free drive condition (approximately 10 mph less than the young driver group), which in Fuller's terminology would point to a lower preferred task difficulty range of older drivers compared to young drivers (see also Charlton et al., 2006).

In free driving conditions, young drivers preferred significantly higher speeds than middle-aged drivers on urban roads and dual carriageways, but were also more accurate than older drivers in judging speed. Age-related differences in the perception of speed appeared to mediate task difficulty and risk assessments of older drivers. The results pointed towards overestimations of speed by middle-aged and older drivers in environments that are busy and cluttered (urban roads) and underestimations of speed, on dual carriageways, where such clutter is absent. This would suggest that older drivers are more sensitive to contextual information than young drivers, whose assessment of speed seems to be less reliant on visual cues, and are on the whole more correct in their estimates than older drivers. This would support the notion of older drivers becoming more sensitised to task difficulty changes arising from other sources than just speed, a finding that sits well with Ball et al.'s (1998) notion that older drivers avoid driving in situations where rapid or unexpected events occur in a visually cluttered environment and the adoption of slower speeds as a typical strategy of the older driver population in general. A general sensitisation towards risk also resonates with the finding of increased feelings of anxiety in older drivers, which emerged in the analysis of contributory factor patterns in the first study, and points towards the role of affect in driver decision making.

The study's findings and support for the importance of "feeling of risk" as the parameter that determines driving decisions, led to a review of the literature on affect and decision making in Chapter five to inform the third and last study. Research in this field suggests that emotion-related signals assist and improve cognitive processes, even when they are non-conscious (Bechara & Damasio, 2005; Kahnemann, 2011). Most of the experimentation to date on affect and decision making has taken place under controlled laboratory conditions. However, driving as an activity that requires constant monitoring and fast decision making provides a fruitful field for applied research for the role of affect in decision making and some research in relation to Damasio's Somatic Marker Thesis (Damasio, 2003) has already been carried out. For example, Kinnear (2009) identified significant differences between experienced drivers and novice drivers in reaction to developing hazards, which indicated that whilst the cognitive assessment of risk of both groups was comparable, experienced drivers elicited more skin conductance responses than novice drivers, which suggested anticipatory processing. Whilst there is a debate to which degree physiological responses precede and thus, inform behaviour, or are merely concomitant with behaviour, there is evidence to suggest that the quality of decision making benefits from the physiological response. In their review of the field, Finucance and Holup (2006) conclude that converging evidence is needed for the hypothesised effects of affect and analysis on risk perception and that multiple dependent variables and methodological approaches should be used to provide conclusive evidence and to enable testing of alternative explanations of results. For older drivers, the question of the role of the physiological component of feelings of risk on driver decision making is of particular interest, as studies on emotional reactivity (e.g. Kunzmann et al., 2005) suggest that the three different response systems of an emotion show different age trajectories: autonomic reactivity in older adults have reliably been found to be diminished, due to the decrease of sympathic and parasympathic innervation, whereas subjective and behavioural reactions to emotion-arousing stimuli seem to be undiminished in old age (including amongst others, anxiety, fear, stress and engagement). If physiological responses to risk attenuate with older age and skin conductance is the physiological correlate of feelings of risk, how do older drivers arrive at correct assessments of task difficulty and risk, if drivers are hypothesised to target an optimal range of arousal and thus, feeling of risk? And does the physiological component of risk perception continue to play a role beyond the initial process of acquisition?

Whilst emerging research to date has been concerned with the process of acquisition of somatic markers in learner and novice drivers, the interest of the current thesis was to explore the interplay between non-conscious signals and overt knowledge in older drivers. Research indicates that EDA as a measure is sensitive to a wide variety of stimuli and is not a clearly interpretable measure of any particular psychological process (Figner & Murphy, 2011); it has been used as an unspecific indicator of heightened autonomic activation and arousal in a number of driving studies, but has also been discussed in the context of resource allocation and effortful processing (Helander, 1978) as well as decision making (Bechara, Damasio, Damasio, & Anderson, 1994). Dawson et al. (2000) suggest that the psychological meaning of EDA can be derived from the experimental paradigm in which it occurs and the stimulus conditions used. Measures of cardiac activity on the other hand, including heart rate and heart rate variability, are well-established as indicators of arousal and situational demand and have been employed in empirical work on risk taking over several years (e.g. Trimpop, 1994; Pribam & McGuiness, 1975; Rabbitt, 1979; Van der Molen, et al., 1987; Mulder, 1979). As the posited correlate of subjective feelings of risk in the Risk Allostasis Theory, the expectation for the last study was that physiological responses would track participants' feeling of risk ratings and that increases in subjective ratings would be associated with stronger physiological responses. Additionally, older drivers' physiological response to high difficulty situations were predicted to be stronger than those of young and middle-aged drivers (despite of age attenuation), reflecting the comparatively higher experienced task difficulty resulting from age-related deteriorations in driver capability in this age group and the suppression of positivity effects in high arousal (high difficulty) conditions.

The last study with 34 current drivers therefore explored differences in the affective appraisal of eight video-recorded pairs of high and low difficulty driving situations between young, middle-aged and older drivers through physiological skin conductance and heart rate variability, in addition to the subjective ratings of risk. Four of these situations depicted situations that the literature and collision statistics suggest to present a particular difficulty to older drivers, the other four depicted non-age-relevant situations. Results showed that older drivers rated the perceived difficulty and feelings of risk significantly higher than middle-aged and young drivers for both high and low difficulty versions of the driving situations (for specific situations, the differences in ratings between young and old drivers mostly ranged between 0.5-1 scale points). However, their ratings (and those of middle-aged and young drivers) did not significantly differentiate between age-relevant and non-age-relevant situations, that is, situations that research shows to be particularly risky for older drivers. Only the middle-aged driver group differentiated between the situations in the expected direction, however, without these differences reaching significance.

The analysis of age effects for skin conductance and heart rate variability was hampered by the fact that almost a third of the original sample had to be excluded from analysis, and this affected in particular the group of older drivers. Based on the literature (e.g. Boucsein, 1992), which suggests age-related attenuation of physiological signal, some oversampling of older drivers had been undertaken to compensate for non-responder drop outs; however, the remaining sample was small, particularly since it is known that physiological signals are subject to considerable inter-individual variability. For the biggest participant group, the middle-aged drivers, the pattern of results for SCL and Heart Rate Variability across the eight situation pairs was in the expected direction and in accordance with the direction of the rating data: high difficulty versions were associated with greater skin conductance changes and greater Heart Rate Variability. However, none of the observed differences reached significance for either heart rate or skin conductance, most likely due to the combination of inter-individual variability of physiological signals, coupled with low statistical power. As a result it is suggested that further studies with larger participant samples should be carried out to test, whether physiological signals correspond with subjective measures or may dissociate from them in different age groups. Given that the study relied on a small grant from TRL, rather than being embedded and funded through a Research Council programme or a similar funding source, an extension of the research and additional data acquisition was not possible.

Whilst inconclusive results are, of course, a frustration, the third study has developed an experimental approach that:

- significantly improves on the limitations of conventional, single screen video presentation
- included task demand factors additional to speed
- developed video-material that enables reliable discrimination of high and low task difficulty versions of the same driving situation
- developed stimulus material that is capable of teasing our significant age-differences in the cognitive appraisal component of risk perception

- recommends middle-aged drivers as a reference group against which young and older drivers can be usefully compared
- suggests that older drivers do not rate driving situations that present a particular challenge to older drivers (according to collision statistics and research evidence) as more difficult or risky.

The theoretical and practical implications from this thesis, along with its limitations, are discussed in the following.

7.2 Theoretical implications

The motivational models of driver behaviour reviewed in this thesis, including Wilde's Theory of Risk Homoeostasis (1982; 1988; 1989), Näätänen and Summala's Zero Risk Theory (1974, 1976), Fuller's Threat Avoidance Model (1984) and Fuller's Task Capability Interface Model (2000; 2005; 2009) propose different determinants of driver behaviour, including risk of a collision (Wilde, 1982), occurrence of an aversive threat (Fuller, 1984), violation of learned safety margins (Näätänen and Summala, 1974) and feeling of risk (Fuller, 2005). In line with the assertions from both, the Zero Risk Model and Task Capability Interface Model, experimental findings from this thesis suggest that collision likelihood estimates are inappropriate as a parameter capable of guiding driver decisions.

The Risk Allostasis Theory posits that drivers continuously monitor their feelings of risk, which are associated with the difficulty of the driving task, but not with the probability of a collision; therefore Fuller posited a threshold relationship only for drivers' subjective likelihood of a collision, but linear increases for task difficulty and feelings of risk. Both experimental studies in this thesis used the Task Capability Interface Model as the theoretical framework to the research. The close association between task difficulty and feeling of risk, as posited by the Risk Allostasis Theory, was confirmed in both experimental studies. Coefficients ranged between r=0.74-0.87 in the simulator study and between r=0.79-0.87 in the video-study. Contrary to Fuller's assumption of a threshold relationship for collision likelihood, however, a considerable proportion (approx. 30 percent) of participants in the simulator study and the video study, rated the likelihood of a collision as greater than zero, even in low difficulty situations, whilst at the same time rating task difficulty and risk as low. Similar results have been reported by Kinnear et al. (2008). Based on the growing body of evidence, it is suggested that whilst collision estimates are readily produced by participants, their ability to assess statistical risk is poor, leading to considerable variation in collision estimates. This conclusion echoes other researchers' notion of people as poor intuitive statisticians (Kahneman, 2011; Slovic, Finucane, Peters & MacGregor, 2004) who do not have sensitivity to low probability events (McKenna, 1988; Rothman, Klein & Weinstein, 1996).

None of the motivational models of driver behaviour and the research relating to them has explored age-effects. Whilst demographic factors, including age, are mentioned in all models reviewed, only the Task Capability Interface Model spells out, how age as a variable influences the posited relations, i.e. through its influence on driver capability. The model, however does not make predictions, how age-related deteriorations in cognitive, perceptual and motor components on the one hand and the accumulation of driving experience on the other hand, may interact with each other in their impact on feelings of risk, perceptions of task difficulty and perceptions of collision likelihood. Both experimental studies in this thesis used participant samples of young, middle-aged and older drivers who had a minimum of three years of driving experience and whose current driving exposure was comparable (i.e. no significant differences in weekly mileage). This provided a minimum level of comparability in driving experience between participants. The research hypothesis for both experimental studies predicted that age effects should only become apparent in high task demand situations, where age-related reductions in capability would result in higher perception of task difficulty and thus, feelings of risk. However, observed age effects in both studies indicate that task difficulty and feelings of risk were rated as significantly higher in both, low and high demand situations. This would suggest that age-related reductions in capability lead to a general lowering of the preferred range of task difficulty and thus, an age-related adjustment of the task difficulty system, rather than a differential assessment of its components, task demand and driver capability. This age-related adjustment of the preferred task difficulty range found its expression not only in subjective ratings, but also in behavioural measures, in that older drivers adopted significantly lower preferred and maximum driving speeds in the simulator study than their younger counterparts. Whilst the first experimental study had focussed on demand manipulations through speed, in line with Fuller's assertion of speed as the main determinant of task demand, the second study furthermore demonstrated that a multi-dimensional approach to demand manipulation was also able to tease out age-related differences in subjective ratings.

According to Fuller's model, it is the perception of capability and task difficulty that enter the comparator as shown in Figure 7-1. Accordingly, both experimental studies in this thesis focussed on the collection of participants' perceptions, rather than measurements of actual capability and difficulty.

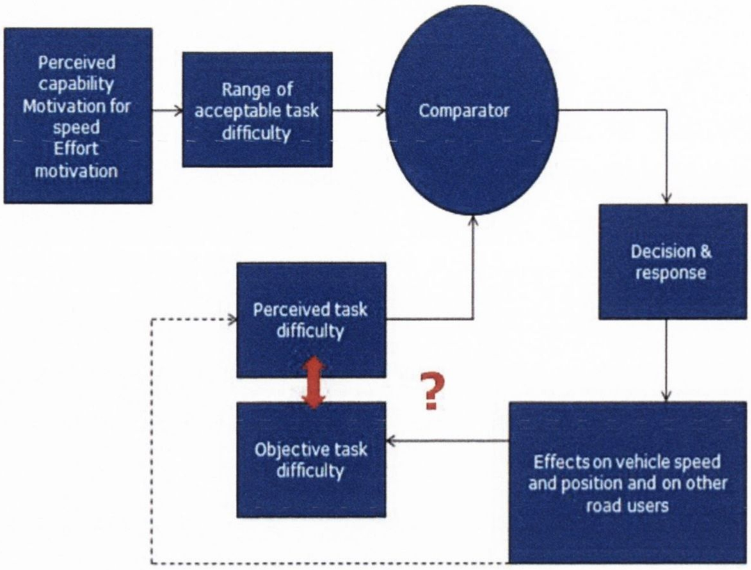

Figure 7-1: Variables entering the comparator according to Fuller's Task Difficulty Interface Model (adapted from Fuller (2005), p. 467.

Contrary to expectation, participants' self-assessments in both studies showed no systematic age differences in reported driver capability, suggesting that the older participant group was not aware of any age-related deterioration in capability. Whilst the possibility of an unrepresentative older driver sample was discussed in Section 4.7.7, the findings also resonate with the review of the literature on self-awareness of age-related deteriorations presented in Section 3.9.1. This found that confidence levels of older drivers were generally high in the studies under scrutiny, suggesting that in most driving situations older drivers did not display any lack of confidence in their driving abilities. Holland and Rabbitt (1992) who undertook a direct comparison between self-rated and objectively assessed visual and aural capacities suggested that the discrepancy between subjectively perceived and objective levels of functioning may be due to the gradual nature of the changes in sensory capacities as well as age-related changes in the drivers' reference system, which meant that older people may compare their capability to a narrower reference group (their peers) with the result of an overall more favourable outcome. These findings support Fuller's assertion that driving decision –naturally- are led by drivers' perceptions. However, this also raises the question of how accurately driver's perceptions of capacity and task difficulty map the true capability and objective difficulty of the task. The correct perception of one's capacity in relation to task demand is typically discussed in the context of young driver who are often reported to suffer from a mismatch between perceived and actual capability in the direction of an overestimation of capability, which is referred to as a lack of calibration (Kuiken & Twisk, 2001). The concept of correct calibration, however, also has obvious applicability for older drivers, whereby a lack of calibration in older drivers may lead to two undesirable outcomes: the overestimation of capability may lead older drivers to expose themselves to driving situations where their capability may be pushed to the limit; alternatively, the overestimation of task difficulty may lead to the unnecessary curtailment of driving.

Further research could help to inform our knowledge about the links between perceived and actual task difficulty (as indicated by the red arrow and question mark in Figure 7-1) and its constituents, driver capability and task demand. Whilst Study Two of this thesis suggested systematic age differences in the assessment of speed, a finding also reported by Sivak et al. (1989) in Section 3.9.2, further systematic variation of task demand, as attempted by Study Three, would be useful to further investigate the factors that impact and or bias older drivers' task difficulty perceptions. If these factors and their impact on risk perception by older drivers can be isolated, interventions can be developed that facilitate their correct assessment by the older driver. An illustration of this mechanism comes from the finding in Study Two, where older drivers' assessment of speed on dual carriageway (and associated perception of risk) was significantly improved by the presence of other road users in the road environment.

Similarly, the exploration of the relationship between actual and perceived driver capability, for example, by conducting research with sub-groups of older drivers suffering from specific, condition-related reductions of capability could enhance our understanding of whether there are particular conditions that are particularly dangerous to the correct calibration of the driver. Whilst the literature reviewed in Section 3.9.1 for example suggests that there is good support for an association between deteriorations of the visual system and avoidance of certain driving situations, such as driving at night, in or in the rain; situations that require complex decision making and thus cognitive capability (for example, turns at uncontrolled junctions and roundabouts) do not seem to attract similarly high avoidance ratings. This finding resonates with Holland (1993) who suggests that whilst older drivers are generally aware of their elevated risk as road users, they may be unaware of the actual sources of the risk. In one of her studies, driving situations that driving instructors described as particularly problematic for older drivers were not perceived to be challenging by the older drivers themselves. Holland (1993) therefore proposed that the inaccuracy of risk perception in specific situations may be an important factor in elderly driving safety and may limit the potential benefit of compensatory adjustments. Study Two of the current thesis produced similar findings: older drivers' ratings of risk and task difficulty did not differentiate between videos that depicted driving situations that collision statistics show older drivers to be over-represented in versus those where they are not over-represented.

Further research to explore the relationship between perceived and actual capability and task difficulty is required to inform interventions to improve older drivers' calibration.

7.3 Limitations of the research

The main limitation of the research is the low participant numbers in Study Two and Three, and with that, the low statistical power. Despite of the small sample, significant age effects still emerged on the dependent variables in the second, simulator-based study and thus permitted the exploration of the research questions. However, in the third, video-based study, problems with the recording of physiology data, led to a considerable loss of participant data, particularly in the oldest participant group. This curtailed the exploration of the research question on the role of the physiological components of risk perception and limited the research's ability to further develop theory: Whilst most of the motivational models of driver behaviour posit a role of negative affect such as tension or anxiety in driver decision making and mention skin conductance as the physiological correlative of feelings of risk, comparatively little research has been carried out to date to systematically investigate the role of the physiological response component in drivers' perception of risk and subsequent decision making. The third study of this thesis aimed to close that gap, particularly, since emerging research in affect and decision-making, points towards the importance of physiological reactions for fast and automatic decision heuristics and provides fascinating inputs for the driver behaviour research agenda. The well-established attenuation of physiological responses with age thereby raises the important question of how feelings of risk are affected, if their physiological base weakens over time. This is particularly interesting, given that the analysis of contributory factors to older driver collisions pointed to a comparatively greater proportion of older drivers, compared to other age groups, who were reported to be "nervous, anxious or panicked". Following the cognitive and behavioural investigation of risk perception and age in the first experimental study of this thesis, the intention was to explore cognitive appraisal and physiological response in the second experimental study. Given the limitations of the data, conclusions on the comparable strength of physiological responses in older drivers and their relationship with cognitive risk appraisals in the different age groups, cannot be drawn. Because of this loss of physiological data, some influence of the common method bias therefore has to be expected in this second experimental study.

7.4 Wider context and practical implications of the findings

Aging populations in most Western countries, the importance of mobility for the well-being of the individual, the relative safety and flexibility of the car compared to other modes of transport mean and increasing licensure rates amongst older drivers mean that the number of older drivers on our roads will increase in future. At the same time collision statistics suggest that older drivers' are no less safe than middle-aged drivers.

The analysis of collision involvement rates carried out in the first study of this thesis, suggested that collision involvement rates only started to increase in the 7th life decade. The relative safety of older drivers regarding their collision risk has been attributed to the process of self-regulation, a term that describes older drivers' compensatory adjustments to their driving to match their changing cognitive, sensory and motor capabilities. Whilst the process of self-regulation is not yet fully understood, there is evidence to indicate that age-associated changes in driving patterns help to maintain safe driving in the majority of older drivers.

The need to consider the transport policy implications of the growing number of older drivers on our roads has stimulated an encouraging and wide range of research activities on the international and national level, including several European projects, covering:

- the development of standardised screening and assessment procedures for fitness to drive assessments of elderly drivers, as undertaken by the 2001 EU project AGILE (AGed people Integration, Mobility, Safety and Quality of Life Enhancement through driving);
- the examination of age-attuned design of public spaces and road environments, exploration of improvements to the accessibility of alternative transport modes and consideration of training and awareness for elderly road users as completed in the 2010 EU project SaMERU (Safer Mobility for Elderly Road Users);
- the exploration of transport needs of elderly road users, based on the review of societal developments, change in mobility needs and available transport alternatives, as conducted by the 2011 EU project Goal (Growing Older, stAying mobiLe);
- the assessment of the potential of ITS to improve the safety and mobility of elderly drivers and provision of recommendations to industry and policy makers regarding Intelligent Transport Systems (ITS) applications, as completed by the 2013 EU project VRUITS (Improving the Safety and Mobility of Vulnerable Road Users Through ITS Applications)

At the national level, the UK Government has recently pledged support for the creation of a task force that should develop a National Older Driver Strategy for the UK for the first time (EuroRap, 2014, November 3rd).

Against the backdrop of these developments, how can the findings from this thesis be translated into applied solutions? Emerging evidence from international and national research suggests that age-related controls, i.e. mandatory driving assessments from a certain age, are neither cost-effective nor beneficial to road safety (see Lang et al., 2013 for a discussion) and may actually put older people at an increased risk of injury by pushing them towards using less safe forms of transport such as walking. Consequently, there appears to be an increasing shift towards and support from policy makers, NGOs and representative groups for the development and introduction of non-mandatory self-help tools for older drivers that promote the calibration of older drivers through the combination of self-assessment and provision of performance feedback and advice (see Lang, Parkes & Fernandez-Median (2013) for a review). Such voluntary self-help tools have the benefit that they can be completed by the older driver at home and provide an opportunity for feedback and increased awareness in a non-threatening, confidential environment, where they may help to identify driving-related problems at an early stage. Whilst fraught with the difficulty of all voluntary measures, self-selection, self-help tools provide a possible mid-way between legislation and "do-nothing". It is in this context that the findings from this thesis could be beneficially applied. The thesis provided a systematic comparison of older drivers' performance (in relation to collision patterns, subjective ratings, behavioural responses with an attempt of the inclusion of physiological measures of risk perception) against middle-aged and younger drivers. Whilst younger drivers' over-representation in collisions does not recommend them as a reference group, the findings from this thesis indicated that middle-aged drivers provide a useful norm group against which older drivers could compare themselves. Whilst currently available self-assessment tools for older drivers focus either on the assessment of upper performance levels or encourage the older driver to reflect on recent experiences of difficulties with driving, a useful way forward could be to develop materials that allow the older driver to contrast their perceptions and performance with those of a middle-aged driver norm group.

8 References

AA Foundation for Safety Research (1988). *Motoring and the older driver.* Automobile Association Report.

Abdel-Aty, M., Radwan, A. (2000). Modelling traffic accident occurrence and involvement. *Accident Analysis and Prevention, 32*(5), 633-642.

Adams, J. G. U. (1988). Risk homeostasis and the purpose of safety regulation. *Ergonomics, 31*(4), 407 - 428. American Elsevier

Adelman, P.K. (1994). Multiple roles and psychological well-being in a national sample of older adults. *Journal of Gerontology, 49*, 277-S285.

Alhakami, A. S. & Slovic, P. (1994). A psychological study of the inverse relationship between perceived risk and perceived benefits. *Risk Analysis, 14*, 1085-1096.

Andrews, E.C., & Westerman, S.J. (2012). Age differences in simulated driving performance: Compensatory processes. *Accident Analysis and Prevention, 45*, 660-668.

Annett, J. (1991). Skill acquisition. In J. E. Morrison (Ed.), *Training for performance* (pp. 13-45). New York: Wiley and Sons.

Anstey, K.J., Horswill, M.S., Wood, J.M. & Hatherly, C. (2012). The role of cognitive and visual abilities as predictors in the Multifactorial Model of Driving Safety. *Accident Analysis & Prevention, 45*, 766-774.

Austin, R. A. & Faigin, B. (2003). Effect of vehicle and crash factors on older occupants. *Journal of Safety Research, 34,* 441-452.

Ayis, S., Gooberman-Hill, R., Ebrahim, S., MRC Health Services Research Collaboration (2004). Long-standing and limiting long-standing illness in older people: associations with chronic diseases, psychosocial and environmental factors. *Age and Aging, 32*, 265-272.

Baba, M., Watahiki, Y., Matsunaga, M. & Takebe, K. (1988). Sympathetic skin response in healthy man. *Electromyography and Clinical Neurophysiology*, 28, 277- 283.

Baldock, M. J., & McLean, A. (2005). *Older drivers- crash involvement rates and causes.* South Australia: The University of Adelaide, Centre for Automotive Safety Research.

Baldock, M. R. J., Mathias, J. L., McLean, A. J., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident Analysis & Prevention, 38*(5), 1038-1045.

Ball, K., Owsley, C., Sloane, M.E., Roenker, D.L., & Bruni, J.R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34,* 3110-3123.

Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis & Prevention, 30*(3), 313-322.

Baster, N. (2012). *It's my choice.* London: Parliamentary Advisory Council for Transport Safety.

Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior. Special Issue on Neuroeconomics, 52*(2), 336-372.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (2005). The Iowa gambling task and the somatic marker hypothesis: Some questions and answers. *Trends in Cognitive Sciences, 9*(4), 159-162.

Bechara, A., Damásio, A. R., Damásio, H., Anderson, S. W. (1994). "Insensitivity to future consequences following damage to human prefrontal cortex". *Cognition 50*(1–3): 7–15

Bechara, A., Damasio, H., Tranel, D., Damasio, A.R. (1997). Deciding Advantageously Before Knowing the Advantageous Strategy. *Science, 275,* 1293-1294.

Benekohal, R., Michaels, R. Shim, E & Resende, P. (1994). Effects of aging on older drivers' travel characteristics. *Transportation Research Record, 1438,* 91-98.

Boucsein, W. (1992). *Electrodermal Activity*. New York and London: Plenum Press.

Box, E., Gandolfi, J. And Mitchell, K. (2010). *Maintaining safe mobility for the aging population. The role of the private car*. London: RAC Foundation.

Braithwaite, J. J., Watson, D. J., Jones, R. (2013). *A Guide for Analysing Electrodermal Activity (EDA) & Skin Conductance Responses (SCRs) for Psychological Experiments (via the Biopac MP36 &AqKnowledge Software)*. Technical Report: Selective Attention & Awareness Laboratory (SAAL) Behaviour Brain Sciences Centre. Birmingham, UK: University of Birmingham.

Braitman, K. A., Kirley, B. B., Ferguson, S., & Chaudhary, N. K. (2007). Factors leading to older drivers' intersection crashes. *Traffic Injury Prevention, 8*(3), 267-274.

Braune, H. J., Korchounov, A.M., Schipper, H. I. (1997). Autonomic dysfunction in Parkinson's Disease assessed by sympathetic skin response: a prospective clinical and neurophysiological trial on 50 patients. *Acta Neurologica Scandinavia, 95*, 293-297.

Broughton, J., Keigan, M., Knowles, J., & Smith, L. (2010a). *Guidance for the analysis of STATS18 Contributory Factors (No. RPN &18)*. Crowthorne: TRL.

Broughton, J., Keigan, M., Knowles, J., & Smith, L. (2010b). *How to analyse STATS19 Contributory Factors (No. RNP 1050)*. Crowthorne: TRL.

Broughton, J., Markey, K. A., & Rowe, D. (1998). *A new system for recording contributory factors in accidents (No. 323)*. Crowthorne: TRL.

Broughton, P. (2008). Flow, task capacity and powered two-wheeler (PTW) rider training. In L. Dorn (Ed.), *Driver behaviour and training volume III.* Aldershot: Ashgate.

Brown, I. D., & Groeger, J. A. (1988). Risk perception and decision taking during the transition between novice and experienced driver status. *Ergonomics, 31*(4), 585 - 597.

Burns, A., Levy, R. (1994). *Dementia*. London: Chapman & Hall.

Burns, P. C., Parkes, A. M., Burton, S., Smith, R. K., & Burch, D. (2002). *How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol (No. 547)*. Crowthorne: Transport Research Laboratory.

Campbell, M.K., Bush, T.L., & Hale, W.E. (1993). Medical Conditions Associated with Driving Cessation in Community-Dwelling, Ambulatory Elders. *Journal Gerontology, 48*(4), 230-234.

Carsten, O. (2007). From Driver Models to Modelling the Driver: What do we really need to know about the driver. In P. Cacciabue (Ed.), *Modelling driver behaviour in automotive environments: Critical issues in driver interactions with intelligent transport systems (pp. 105-121)*. London: Springer-Verlag.

Carty, T., Horesh, N., Apter, A. & Gross, J. J. (2010). Patterns of Emotional Reactivity and Regulation in Children with Anxiety Disorders. *Journal of Psychopathology and Behavioral Assessment, 32*, 23-36.

Centre for Urban Transportation Research (2005). *Transit use viability among older drivers losing their driving privileges – Technical Memorandum One*. Tampa, Florida, National Center for Transit Research.

Charlton, J., Oxley, J., Fildes, B., Oxley, P., Newstead, S., O'Hare, M. & Koppel, S. (2003). *Self-regulatory driving practices of older drivers.* (Report No: 208) Melbourne, Australia: Monash University Accident Research Center.

Charlton, J. L., Oxley, J., Fildes, B., Oxley, P., Newstead, S. & Koppel, S. (2006). Characteristics of older drivers who adopt self-regulatory driving behaviours. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(5), 363-373.

Charlton, J. L. & Molnar, L. (2011, January). *Self-Regulation, Self-Screening instruments and Safe Driving Practices.* Paper presented at the TRB Human Factors Workshop „Managing And Improving Safe Mobility Of Seniors: Identifying Interventions That Work", Washington D.C., USA.

Chipman, M.L., MacGregor, C.G., Smiley, A.M. and Lee-Gossling, M. (1993). The role of Exposure in Comparisons of Crash Risk among Different Drivers and Driving Environments. *Accident Analysis and Prevention, 25*(2), 207-211.

Christie, M. J. (1981). Electrodermal activity in the 1980s: a review. *Journal of the Royal Society of Medicine, 74*, 616-622.

Claret, P., del Castillo, J., Moleón, J., Cavanillas, A., Martín, M. & Vargas, R. (2003). Behavioural factors in accidents at road junctions: The use of e genetic algorithm to extract descriptive rules from police case files. *Accident Analysis and Prevention, 30*(2), 223-234.

Clarke, D. D., Ward, P., Bartle, C., & Truman, W. (2010). Older drivers' road traffic crashes in the UK. *Accident Analysis & Prevention, 42*(4), 1018-1024.

Clarke, D., Forsyth, R., & Wright, R. (1998). Junction accidents during cross-flow turns: a sequence analysis of police case files. *Accident Analysis and Prevention, 31*(1-2), 31-41.

Cnossen, F., Rothengatter, T., & Meijman, T. (2000). Strategic changes in task performance in simulated car driving as an adaptive response to task demands. *Transportation Research Part F: Traffic Psychology and Behaviour, 3*(3), 123-140.

Cobb, R.W. and Coughlin, J.F. (2004). Transportation Policy for an Aging Society – Keeping Older Americans on the Move. *Transportation in an Aging Society: A Decade of Experience, Proceedings 27, 3-21.* Washington DC: Transportation Research Board.

Coke, M. M. (1992). Correlates of life satisfaction among elderly African Americans. *Journal of Gerontology, 47*, 316-320.

Collia, D., Sharp, J. & Giesbrecht, L. (2003). The 2001 national household travel survey: A look into the travel patterns of older Americans. *Journal of Safety Research, 34*, 461-470.

Cooper, P. (1990). Elderly drivers' views of self- and driving in relation to the evidence of accident data. *Journal of Safety Research, 21*, 103-113.

Coughlin, J. F. (2001). Beyond Health and Retirement: Placing Transportation on the Aging Policy Agenda. MIT AgeLab. Retrieved on 3rd October 2007 at: http://www.subnet.nga.org/ci/assets/BeyondHealthRetirement.pdf.

Coughlin, J.F., Mohyde, M., D'Ambrosio, L.A. and Gilbert, J. (2004). Who drives older driver decisions? MIT AgeLab. Retrived on 11th January 2011 at: http://stuff.mit.edu/afs/athena/dept/agelab/news_events/pdfs/AgeLab_driver_decision.pdf.

Cox, D.J., Merkel, R.L., Kovatchev, B., Seward, R. (2000). Effect of stimulant medication on driving performance of young adults with attention-deficit hyperactivity disorder - A preliminary double-blind placebo controlled trial. *Journal of Nervous and Mental Disease, 188,* 230-234.

Daigneault, G., Joly, P., Frigon, J.Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical Experimental Neuropsychology, 24* (2), 221–238.

Daigneault, G., Joly, P., Frigon, J.Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical Experimental Neuropsychology 24*(2), 221–238.

Damasio, A. R. (1994). *Descartes' Error: Emotion, Reason, and the Human Brain*. New York: Grosset/Putnam.

Damasio, A. R. (2003). *Looking for Spinoza: Joy, Sorrow and the Feeling Brain*. London: Heinemann.

Davidson, R. J. (1998). Affective Style and Affective Disorders: Perspectives from Affective Neuroscience. *Emotion and Cognition, 12*(3), 307-330.

Dawson, M. E., Schell, A. M., Filion, D. L. (2000). The Electrodermal System. In J. T. Caccioppo, L. G. Tassinary, C. G. Berntson (Eds.). *Handbook of Psychophysiology*, 2nd edition. United States of America: Cambridge University Press.

Dawson, J.D., Uc, E.Y., Anderson, S.W., Johnson, A.M., & Rizzo, M. (2010). Neuropsychological predictors of driving errors in older adults. *Journal of the American Geriatric Society, 58*, 1090-1096.

Deary, I. J., Johnson, W., & Starr, J. M. (2010). Are processing speed tasks biomarkers of cognitive aging? *Psychology and Aging, 25,* 219–228.

Dejeammes, M. & Ramet, M. (1996). *Aging process and safety enhancement of car occupants*. Proceedings of the 15th International Technical Conference on the Enhances Safety of Vehicles, Volume 2, 1189-1196, Melbourne, Australia.

DeJoy, D. M. (1989). The optimism bias and traffic accident risk perception. *Accident Analysis & Prevention, 21*(4), 333-340.

Dellinger, A. M., Kresnow, M.-j., White, D. D., & Sehgal, M. (2004). Risk to self versus risk to others: How do older drivers compare to others on the road? *American Journal of Preventive Medicine, 26*(3), 217-221.

Denburg, N. L., Tranel, D. & Bechara, A. (2005). The ability to decide advantageously declines prematurely in some normal older persons. *Neuropsychologica, 43*, 1099-1106.

Department for Transport (2004). *Instructions for the completion of road accident reports*- with effect from 1st January 2005. Available online at http://www.dft.gov.uk/pgr/statistics/datatablespublications/accidents/casualtiesgbar/stats20instructionsforthecom5094. Retrieved on 26th July 2007.

Dennis, N.A., & Cabeza, R. (2008) Neuroimaging of healthy cognitive aging. In: Craik, F.I.M, Salthouse TA (eds). *The handbook of aging and cognition*, 3rd ed. (pp 1-54). New York: Psychology.

Department for Transport. (2001). *Older Drivers: A Literature Review (No. No 25)*. London: Department of Transport.

Department for Transport. (2004). *Instructions for the Completion of Road Accident Reports.* London: Department for Transport.

Department for Transport. (2005). *National Travel Survey: 2005.* London: Department for Transport.

Department for Transport. (2008). *Road Statistics 2007: Traffic, Speeds and Congestion.* London: Department for Transport.

Diels, C., & Parkes, A. M. (2010). Geometric Field of View Manipulations Affect Perceived Speed in Driving Simulators. *Advances in Transportation Studies – an International Journal, 12*(Section B), 53-64.

Dobbs, A. R. (1997). Evaluating the Driving Competence of Dementia Patients. *Alzheimer Disease and Associated Disorders*, 11 (Suppl. 1), 8-12.

Dobbs, A.R., Heller, R.B., Schopflocher, D. (1998). A comparative approach to identifying unsafe older drivers. *Accident Analysis and Prevention, 30* (3), 363–370.

Dobbs, B. M., Carr, D. B., Morris, J.C. (2002). Evaluation and Management of the Driver with Dementia. *Neurologist, 8*(2), 61-70.

Dobbs, B. M. (2005). *Medical Conditions and Driving: A review of the literature 1960-2000*. Washington, DC: National Highway Traffic Safety Administration.

Dolan, R. J. (2002). Emotion, Cognition and Behaviour. *Science, 298*, 1191-1194.

Drory, V. E., Korczyn, A.D. (1993). Sympathetic skin response: Age effect. *Neurology, 43*, 1818- 1820.

Dulisse, B. (1997). Older drivers and risk to other road users. *Accident Analysis and Prevention, 29*(5), 573-582.

DVLA (2013). *At a glance – Guide to the current standards of fitness to drive*. Drivers Medical Group, DVLA, Swansea. Available online at http://www.dft.gov.uk/dvla/medical/ataglance.aspx Retrieved on 11th January 2011.

Eberhard, J. (1996). Safe mobility for senior citizens. *Public Policy and Aging Report, 15*(2), 18-20.

Eliot, R. S. & DeCoster, J. (1999). Associative and Rule-Based Processing – A Connectionist Interpretation of Dual- Process Models. In S. Chaiken & Y. Trope (Eds.). *Dual-Process Theories in Social Psychology*. New York: The Guilford Press.

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American Psychologist, 49*, 709–724.

EuroRap (2014, November 3rd). Making Road Safety Pay. Retrieved from http://www.eurorap.org/knowledge-base/news-homepage/2014/making-road-safety-pay/

Ernst, R. & O'Connor, P. (1988). *Report on accident countermeasures focusing on elderly drivers*. South Australia: Road Safety Division, South Australian Department of Road Transport.

Evans, L. (1988). Older driver involvement in fatal and severe traffic crashes. *Journal of Gerontology, Social Sciences, 43*(6), 5186-5193.

Evans, L. (2000). Risks older drivers face themselves and threats they pose to other road users. *International Journal of Epidemiology, 29*(2), 315-322.

Figner, B., & Murphy, R. O. (2011). Using skin conductance in judgment and decision making research. In M. Schulte-Mecklenbeck, A. Kuehberger, & R. Ranyard (Eds.), *A handbook of process tracing methods for decision research (pp. 163-184)*. New York, NY: Psychology Press.

Fildes, B.N. Pronk, N., Langford, J., Hull, M., Frith, B. & Anderson, R. (2000). *Model Licence Re-Assessment Procedure For Older And Disables Drivers*. Sydney: Austroads Incorporated.

Fildes, B. N., Charlton, J., Pronk, N., Langford, J., Oxley, J., Koppel, S. (2008). An Australasian Model Licence Reassessment Procedures for Identifying Potentially Unsafe Drivers. *Traffic Injury Prevention, 9*, 350-359.

Fildes, B., Corben, B., Kent, S., Oxley, J., Le, T. & Ryan, P. (1994). *Older road user crashes.* (Report No. 61). Melbourne, Australia, Monash University Accident Research Center.

Finn, P., & Bragg, B. W. E. (1986). Perception of the risk of an accident by young and older drivers. *Accident Analysis & Prevention, 18*(4), 289-298.

Finucane, M. L. & Holup, J. L. (2006). Risk as Value: Combining Affect and Analysis in Risk Judgements. *Journal of Risk Research, 9*(2), 141-164.

Finucane, M. L., Alhakami, A., Slovic, P. & Johnson, S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making, 13*, 1–17.

Fonda, S., Wallace, R. & Herzog, A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *Journal of Gerontology, Series B: Psychological Science & Social Sciences, 56*(6), 343-51.

Fontaine, H. (2003). Age des conducteurs de voiture et accidents de la route: Quel risqué pour les seniors. *Recherché- Transports-Securite, 79-80*, 107-120.

Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W.W., Lykken, D. T., Venables, P.H. (1981). Publication Recommendations for Electrodermal Measurements. *Psychophysiology, 18*(3).

Fox, G. K., Bowden, S. C., Smith, D. S. (1998). On-road Assessment of Driving Competence After Brain Impairment: Review of Current Practice and Recommendations for a Standardised Examination. *Archives of Physical Medicine and Rehabilitation, 79*, 1288-1296.

Franklin, W .C. & Cleveland, D. E. (1964). *Intersection Illumination Research Report Number 5-6.* Texas: Texas Transportation Institute, Texas A&M University, College Station.

Franz, P. (1984). *Soziologie der räumlichen Mobilität. Eine Einführung*. Frankfurt: Campus - Verlag.

Freund, B., Colgrove, L.A., Petrakos, D., & McLeod, R. (2008). In my car the brake is on the right: Pedal errors among older drivers. *Accident Analysis & Prevention, 40*, 403-409.

Fuller, R. (1984). A conceptualization of driving behaviour as threat avoidance. *Ergonomics, 27*(11), 1139 - 1155.

Fuller, R. (1988). On learning to make risky decisions. *Ergonomics, 31*(4), 519 - 526.

Fuller, R. (1988). Predicting what a driver will do: Implications of the threat-avoidance model of driver behaviour. In J. A. Rothengatter & R. A. deBruin (Eds.), *Road User Behaviour (pp. 93-118).* Assen/Maastricht: Van Gorcum.

Fuller, R. (1991). Behaviour analysis and unsafe driving: warning – learning trap ahead! *Journal of Applied Behaviour Analysis, 24*, 73-75.

Fuller, R. (2000). The Task-Capability Interface model of the driving process. *Recherche - Transports* - Sécurité, 66, 47-59

Fuller, R. (2005a). *Driving by the seat of your pants. A new agenda for research*. Paper presented at the Behavioural Research in Road Safety: Fourteenth Seminar, London: Department for Transport.

Fuller, R. (2005b). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*, 461-472.

Fuller, R. (2009). *Recent developments in driver control theory: from task difficulty homeostasis to risk allostasis.* Dublin: School of Psychology, Trinity College Dublin.

Fuller, R., Bates, H., Gormley, M., Hannigan, B., Stradling, S., Kinnear. N., et al. (2008). *The Conditions for Inappropriate High Speed: A Review of the Research Literature from 1995 to 2006.* London: Department for Transport.

Fuller, R., McHugh, C., & Pender, S. (2008). Task difficulty and risk in the determination of driver behaviour. *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology,* 58(1), 13-21.

Gilley, D.W., Wilson, R.S., Bennett, D.A., Stebbins, G.T., Bernard, B.A., Whalen, M.E., & Fox, J.H. (1991). Cessation of Driving and Unsafe Motor Vehicle Operation by Dementia Patients. *Archives of Internal Medicine, 151*(5).

Grayson, G. B. & Sexton, B. F. (2002). *The development of hazard perception testing. TRL Report TRL 558*. Crowthorne: Transport Research Laboratory.

Grayson, G. B., Maycock, G., Groeger, J. A., Hammond, S. M., & Field, D. T. (2003). *Risk, hazard perception and perceived control (No. 560)*. Crowthorne: TRL.

Groeger, J. A. (2000). *Understanding driving - Applying cognitive psychology to a complex everyday task.* Hove: Psychology Press Ltd.

Groeger, J. A., & Brown, I. D. (1989). Assessing one's own and others' driving ability: Influences of sex, age, and experience. *Accident Analysis & Prevention, 21*(2), 155-168.

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis and Prevention, 45,* 19–28.

Haight, F. A. (1986). Risk, especially risk of traffic accident. *Accident Analysis & Prevention, 18*(5), 359-366.

Haigney, D. E., Taylor, R. G., & Westerman, S. J. (2000). Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. *Transportation Research Part F: Traffic Psychology and Behaviour, 3*(3), 113-121.

Hakamies-Blomqvist, L. & Wahlström, B. (1998). Why do older drivers give up driving? *Accident Analysis & Prevention, 30*, 305-312.

Hakamies-Blomqvist, L. (2004). Safety of Older Persons in Traffic. *Transportation in an Aging Society: A Decade of Experience, Proceedings 27, 3-21.* Washington DC, Transportation Research Board.

Hakamies-Blomqvist, L. and Sirén, A. (2003). Deconstructing a gender difference: Driving cessation and personal driving history of older women. *Journal of Safety Research, 34*, 383-388.

Hakamies-Blomqvist, L., (1993). Fatal accidents of older drivers. *Accident Analysis and Prevention, 25*, 19-27.

Hakamies-Blomqvist, L., Reitanen, T. & O'Neill, D. (2002). Driver aging does not cause higher accident rates per km. *Transportation Research Part F, 5*, 271-274.

Hakamies-Blomqvist, L., Sirén, A. and Davidse, R. (2003). *Older drivers-a review.* Report for Swedish National Road Safety Administration, Sweden.

Hakamies-Blomqvist, L. (2003). *Fifth European Transport Safety Lecture: Ageing Europe, the challenges and opportunities for transport safety.* Brussels, Belgium: European Transport Safety Council.

Hall, J., & West, R. (1996). The role of informal instruction and informal practice in learning to drive. Ergonomics, 39(4), 639-706.

Harré, N., & Sibley, C. G. (2007). Explicit and implicit self-enhancement biases in drivers and their relationship to driving violations and crash-risk optimism. *Accident Analysis & Prevention, 39*(6), 1155-1161.

Harris, A. (2000). *Transport and mobility in rural Victoria.* (Report No. PP/02). Melbourne, Australia, Royal Automobile Club of Victoria.

Harrison, A., & Ragland, D. (2003). Consequences of driving reduction or cessation for older adults. *Transportation Research Record, 1843*, 94-104.

Hasher, L., & Zacks, R.T. (1988). Working memory, comprehension, and aging: A reviewand a new view. In: Bower, G.H. (Ed.). *The Psychology of Learning and Motivation, 22.* Academic Press, New York, NY, pp. 193–225.

Hattakka, M., Keskinen, E., Gregersen, N. P., Glad, A., & Hernetkosi, K. (1999). *Results of the EU-project GADGET, Work Package 3*. Bern: Schweizerische Beratungsstelle für Unfallverhütung.

Hawley, C. (2011, October 13th). *The Role of the GP in Giving Advice on Fitness to Drive*. Presentation at PACTS conference Older, Wiser, Safer: the challenge of an ageing population. London: PACTS.

Heikkila, V.M., Korpelainen, J., Turkka, J., Kallanranta, T., Summala, H.(1999) Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica*, *99*, 349-355.

Helander, M. (1978). Applicability of Drivers' Electrodermal Response to the Design of the Traffic Environment. *Journal of Applied Psychology, 63* (4), 481-488.

Higgins, K.E., & Wood, J.M. (2005). Predicting components of closed road driving performance from vision tests. *Opthalmology and Visual Science 82* (8), 647–656.

Holland (2001). *Older Drivers: A Review.* Road Safety Research Report No. 25, London: DfT. Available online at http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_504602.hcsp. Retrieved on 8th September 2006.

Holland, C. A. (1993). Self-bias in older drivers' judgments of accident likelihood. *Accident Analysis & Prevention, 25*(4), 431-441.

Holland, C. A., & Rabbitt, P. M. A. (1992). People's awareness of their age-related sensory and cognitive deficits and the implications for road safety. *Applied Cognitive Psychology, 6*(3), 217-231.

Holland, C.A. & Rabbitt, P.M.A. (1994). The problems of being an older driver: Comparing the perceptions of an expert group and older drivers. *Applied Ergonomics, 35*(1), 17-27

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 107-129.

Horswill, M. S., Marrington, S.A., Wood, J., Pachana, N.A., McWilliam, J. and Reikos, M.K. (2008). The hazard perception ability of older drivers. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 63*, 212-218.

Hoyes, T. W., & Glendon, A. I. (1993). Risk homeostasis: issues for future research. *Safety Science, 16*(1), 19-33.

Hoyes, T. W., Dorn, L., Desmond, P. A., & Taylor, R. G. (1996). Risk homeostasis theory, utility and accident loss in a simulated driving task. *Safety Science, 22*(1-3), 49-62.

Jackson, J. S. H., & Blackman, R. (1994). A Driving-Simulator Test of Wilde's Risk Homeostasis Theory. *Journal of Applied Psychology, 79*(6), 950-958.

Jamie K. Wardman (2006). Toward a Critical Discourse on Affect and Risk Perception, *Journal of Risk Research, 9*(2), 109-124.

Janke, M. (1991). Accidents, Mileage and the Exaggeration of risk. *Accident Analysis and Prevention, 30*(3), 347-361.

Janke, M. (1994). *Age-related disabilities that may impair driving and their assessment: A literature review.* Sacramento: Department of Motor Vehicles.

Johannson, G., & Rumar, K. (1966). Drivers and road signs: A preliminary investigation of the capacity of car drivers to get information from road signs. *Ergonomics, 9*, 57-62.

Johansson, G., & Backlund, F. (1972). Drivers and road signs. *Applied Ergonomics, 3*(1), 53-53.

Kahnemann, D. (2011). *Thinking, Fast and Slow*. New York: Farrar, Strauss & Giroux.

Kington, R., Reuben, D., Rogowski, J., & Lillard, L. (1994). Sociodemographic and Health Factors in Driving Patterns After 50 Years of Age. *American Journal of Public Health, 84*(8), 1327-1329.

Kinnear, N. (2009). *Driving as you feel: A psychological investigation of the young driver problem* (Unpublished Doctoral Dissertation). Napier University, Edinburgh.

Kinnear, N., & Stradling, S. G. (2011). Young Novice Drivers and the Development of Somatic Markers for Risk on the Road. In D. Hennessy (Ed.), *Traffic psychology: An International Perspective* (pp. 69-85). New York: Nova Science Publishers Inc.

Kinnear, N., Stradling, S. G., & McVey, C. J. (2008). Do we really drive by the seat of our pants? In L. Dorn (Ed.), *Driver Behaviour and Training: Volume III.* Aldershot: Ashgate.

Koppel, S.N., Charlton, J.L. & Fildes, B.N. (2009). Distraction and the older driver. In: M. A. Regan, J. D. Lee, K. L. Young (Eds.), *Driver distraction: Theory, Effects and Mitigation (353-382).* Florida, USA: CRC Press.

Kostyniuk, L.P. & Shope, J.T. (2003). Driving and Alternatives: Older Drivers in Michigan. *Journal of Safety Research*, *34* (4), 407-414.

Kucera, P, Goldenberg, Z & Kurca, E. (2004). Sympathetic skin response: review of method and its clinical use. *Bratislavske Lekarske Listy, 105*(3), 108-116.

Kuiken, M., & Twisk, D. (2001). *Safe driving and the training of calibration.* Leidschendam: SWOV Institute for Road Safety Research.

Lang, B., Parkes, A. M., Fernandez-Medina (2013). *Driving choices for the older motorist: the role of self-assessment tools*. London: RAC Foundation.

Langford, J. (2002). *For many older drivers, mobility may be more important than safety*. Paper presented at the Road Safety Research, Policing and Education Conference, 2001, Melbourne, Victoria, Australia.

Langford, J., & Koppel, S. (2006). The case for and against mandatory age-based assessment of older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(5), 353-362.

Langford, J., Koppel, S., McCarthy, D., Srinivasan, S. (2008). In defence of the low mileage bias. *Accident Analysis and Prevention, 40*, 1996-1999.

Langford, J., Methorst, R. & Hakamies-Blomqvist, L. (2006). Older drivers do not have a high crash risk – a replication of low mileage bias. *Accident Analysis and Prevention, 38*(3), 574-578.

Larsen, L. & Kines, P. (2002). Multidisciplinary in-depth investigations of head-on and left-turn road collisions. *Accident Analysis and Prevention, 34*(3), 367-380.

Lewis-Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention, 38*(3), 610-617.

Lewis-Evans, B., & Rothengatter, T. (2009). Task difficulty, risk, effort and comfort in a simulated driving task--Implications for Risk Allostasis Theory. *Accident Analysis & Prevention, 41*(5), 1053-1063.

Li, G., Braver, E. & Chen, L. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis and Prevention, 35*(2), 227-235.

Loewenstein, G. F., Weber, E. U., Hsee, C. K. & Welch, E. S. (2001). Risk as feelings. *Psychological Bulletin, 127*(2), 267–286.

Lopez-Ramon, M. F., Castro, C., Roca, J., Ledesma, R., & Lupiañez, J. (2011). Attentional networks functioning, age, and attentional lapses while driving. *Traffic Injury Prevention, 12*, 518-528.

Lyman, J. M., McGwin, G., & Sims, R. V. (2001). Factors related to driving difficulty and habits in older drivers. *Accident Analysis & Prevention, 33*, 413-421.

Lynne, P. (2006). *The relationship between driver experience and driver decision making in an Irish population* (Unpublished Doctoral Dissertation). Glasgow: Strathclyde University.

MacPherson, S.E., Phillips, L.H., & Della Sala, S. (2002). Age, Executive Function, and social decision making: A dorsolateral prefrontal theory of cognitive aging. *Psychology and Aging, 17*, 598-609.

Maia, T. V., & McClelland, J. L. (2004). A re-examination of the evidence for the somatic marker hypothesis: What participants really know in the Iowa gambling task. *Proceedings of the National Academy of Sciences, 101*(45), 16075-16080.

Marattoli, R.A., & Richardson, E.D. (1998). Confidence in, and self-rating of, driving ability among older drivers. *Accident Analysis and Prevention*, *30*(3), 331-336.

Marottoli ,R.A., Ostfeld, A.M., Merrill, S.S., Perlman, G.D., Foley, D.J., & Cooney, L.M Jr. (1993). Driving Cessation and Changes in Mileage Driven among Elderly Individuals. *Journal of Gerontology, 48*(5), 255-260.

Marottoli, R. A., & Richardson, E. D. (1998). Confidence in, and self-rating of, driving ability among older drivers. *Accident Analysis & Prevention, 30*(3), 331-336.

Mather, M. & Carstensen, L. L. (2005). Aging and motivated cognition: the positivity effect in attention and memory. *TRENDS in Cognitive Science, 9*(10), 496-502.

Mathey, F.J. (1984). Verkehrsbezogene Mobilitaet aelterer Menschen. *Zeitschrift fuer Gerontologie, 16*, 284-289.

Matthews, M. L., & Moran, A. R. (1986). Age differences in male drivers' perception of accident risk: The role of perceived driving ability. *Accident Analysis & Prevention, 18*(4), 299-313.

Matthews, F. E., Arthur, A., Barnes, L. E., Bond, J., Jagger, C., Robinson, L., Brayne, C. & Medical Research Council Cognitive Function and Aging Collaboration (2013). A two-decade comparison of prevalence of dementia in individuals aged 65 years or older from three geographical areas of England: results of the Cognitive Function and Aging Study I and II. *Lancet, 382*(9902), 1405-1412.

Mathias, J.L., & Lucas, L.K. (2009). Cognitive predictors of unsafe driving in older drivers: a meta-analysis. *International Psychogeriatrics, 21,* 637-653.

Maycock, G. (1997). *The Safety of Older Car Drivers in the European Union*. Basingstoke, United Kingdom: AA Foundation for Road Safety Research.

Maycock, G. (2002). *Novice driver accidents and the driving test (No. 527)*. Crowthorne: TRL.

McGwin, G. & Brown, D. (1999). Characteristics of traffic crashes among young, middle-aged and older drivers. *Accident Analysis & Prevention, 31*, 181-198.

McGwin, G., Owsley, C., & Ball, K. (1998). Identifying crash involvement among older drivers: Agreement between self-report and state records. *Accident Analysis and Prevention*, *30*(6), 781-791.

McGwin, G., Sims, R.V., Pulley, L., Roseman, J.M. (1999). Diabetes and automobile crashes in the elderly - A population-based case-control study. *Diabetes Care, 22,* 220-227.

McGwin, J. G., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention, 31*(3), 181-198.

McKenna, F. P. (1988). What role should the concept of risk play in theories of accident involvement? *Ergonomics, 31*(4), 469 - 484.

McKenna, F. P. (1990). In defence of conventional safety measures: A reply to G.J.S. Wilde. *Journal of Occupational Accidents, 11*(3), 171-181.

McKnight, A. J. & McKnight, A. S. (1999). Multivariate analysis of age-related driver ability and performance deficits. *Accident Analysis and Prevention, 31,* 445-454.

Meng, A. and Siren, A. (2012) Cognitive problems, self-rated changes in driving skills, driving-related discomfort and self-regulation of driving in old drivers. *Accident Analysis and Prevention, 49*, 322-329

Michaels, R. M. (1960). *Tension responses of drivers generated in urban streets*. Highway Research Board, 39th Annual Meeting, Washington, D.C.

Mollenkopf, H., Marcellini, F., Ruoppila, L., Flaschentraeger, P., Gagliardi, C., Spazzafumo, L. (1997). Outdoor mobility and social relationships for elderly people. *Archives of Gerontology and Geriatrics, 24*(3), 295-310.

Moták, L., Gabaude, C., Bougeant, J.-C. and Huet, N. (2014). Comparison of driving avoidance and self-regulatory patterns in younger and older drivers. *Transportation Research Part F, 26*, 18-27.

Mowrer, O. H. (1960) *Learning Theory and Behaviour*. New York: Wiley.

Musselwhite, C. (2006). Attitudes towards vehicle driving behaviour: Categorising and contextualising risk. *Accident Analysis & Prevention, 38*(2), 324-334.

Musselwhite, C., (2011, October 13th). *We need to talk: the role of family, friends and social networks in helping older people give up driving.* Presentation at the PACTS conference Older, Wiser, Safer: the challenge of an ageing population, London, UK.

Näätänen, R., & Summala, H. (1974). A model for the role of motivational factors in drivers' decision-making. *Accident Analysis & Prevention, 6*(3-4), 243-261.

Näätänen, R., & Summala, H. (1976). *Road User Behaviour and Traffic Accidents*. Amsterdam and New York: North Holland.

Naumann, R. B., Dellinger, A. M., & Kresnow, M.-J. (2011). Driving self-restriction in high-risk conditions: How do older drivers compare to others? *Journal of Safety Research, 42*, 67–71.

NHTSA (2008). *Older Driver Screening based on Health Concerns.* Volume II: Appendices. Report No. DOT HS 811 046B. Springfield, Virginia: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Nobis, C & Lenz, B. (2004, November). *Gender differences in Travel Patterns. Role of Employment Status and Household Structure*. Transport Research Board Conference Proceedings 35. Research on Women's Issues in Transportation - Volume 2: Technical Papers, November 18-20, 2004, Chicago: Illinois, 114- 123.

Noble, B. 2000. *Travel Characteristics of Older People*. *Transport Trends.* London: DTLR.

O'Neill, D., Bruce, I., Kirby, M. & Lawlor, B. (2000). Older drivers, driving practices and health issues. *Clinical Gerontologist, 22*(1), 47-54.

OECD. (2001). *Aging and Transport - Mobility Needs and Transport Issues*. Paris: Organisation for Economic Co-operation and Development.

OECD. (2006). *Young Drivers: The Road To Safety.* Paris: Organisation for Economic Co-operation and Development.

Office for National Statistics. (2010). *Population Estimates for UK, England and Wales, Scotland and Northern Ireland, mid 2005*. London: ONS, Population Estimates Unit.

Office of National Statistics (2011). *UK Snapshot – Population – Ageing.* London: ONS. Available online at http://www.statistics.gov.uk/cci/nugget.asp?id=949. Retrieved on 5th January 2011.

Office of Population Censuses and Surveys (1991). *Person's aged 60 and over Great Britain*. London: Official Publications.

Organisation for Economic Co-operation and Development (2001). *Aging and Transport: Mobility needs and safety issues.* Paris: OECD.

Owens, D.A., Wood, J.M., Owens, J.M. (2007). Effects of age and illumination on night driving: a road test. *Human Factors 49* (6), 1115–1131.

Owsley, C. (2004). Driver Capabilities. *Transportation in an Aging Society: A Decade of Experience, Proceedings 27, 3-21.* Washington DC, Transportation Research Board.

Owsley, C., Ball, K., McGwin, G., Sloane, M.E., Roenker, D.L., White, M.F., & Overley, T. (1998). Visual Processing Impairment and Risk of Motor Vehicle Crash Among Older Adults. *Journal of the American Medical Association, 279* (14).

Parasuraman, R., & Nestor, P.G. (1991). Attention and driving skills in aging and Alzheimer's disease. *Human Factors, 33,* 539-557.

Peltzman, S. (1976). The effects of automobile safety regulation: Reply. *Accident Analysis & Prevention, 8*(2), 139-142.

Persson, D. (1993). The elderly driver: Deciding when to stop. *Gerontologist, 33* (1), 88-91.

Preusser, D., Williams, A., Ferguson, S., Ulmer, R., & Weinstein., H. (1998). Fatal crash risk for older drivers at intersections. *Accident Analysis and Prevention, 30*, 151-159.

Quimby, A. R., & Watts, G. R. (1981). *Human factors and driving performance (Laboratory Report 1004).* Crowthorne, England: Transport and Road Research Laboratory.

Rabbitt, P., Carmichael, A., Shilling, W., & Sutcliff, P. (2002). Age, health and driving: *Longitudinally observed changes in reported general health, in mileage, self-rated competence and in attitudes of older drivers.* Manchester, UK: AA Foundation for Road Safety Research.

Ragland, D., Satariano, W & Macleod, K., (2005). Driving cessation and increased depressive symptoms. *The Gerontological Society of America, 60A*(3), 399-403.

Raitanen, T., Törmäkangas, T., Mollenkopf, H., & Marcellini, F. (2003). Why do older drivers reduce driving? Findings form three European countries. *Transportation Research Part F, 6,* 81-95.

Ranney, T. A. (1994). Models of driving behavior: A review of their evolution. *Accident Analysis & Prevention, 26*(6), 733-750.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., Dahle, C., Gerstorf, D. & Acker, J. D. (2005). Regional Brain Changes in Aging Healthy Adults: General Trends, Individual Differences and Modifiers. *Cerebral Cortex, 15*(11), 1676-1689.

Redelmeier, D. A., Yarnell, C. J., Thiruchelvam, D., Tibshirani, R. J. (2012). Physician's Warnings of Unfit Drivers and the Risk of Trauma from Road Crashes. *The New England Journal of Medicine, 367*(13), 1228-1236.

Reed, N., & Robbins, R. (2008). *The Effect Of Text Messaging On Driver Behaviour - A Simulator Study (No. 367).* Crowthorne: TRL.

Reeves, C., Lang, B., Parkes, A.M., Bernhoft, I-M., Senk, P. & Gabaude, C (2013). Traffic accident patterns in an ageing population. - CONSOL Report D3.1., available at: http://consolproject.eu/index.php/deliverables.

Reed, N., & Kinnear, N. & Weaver, L. (2012). *Why do older drivers have more 'fail to look crashes' – a simulator-based study (No. 635).* Crowthorne: TRL.

Reger, M. A., Welsh R. K., Watson G. S., Cholerton B. , Baker L. D., Craft, S. (2004). The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. *Neuropsychology 18*, 85-93.

Reimer, B. et al (2013). Impact of age and cognitive demand on lane choice and changing under actual highway conditions. *Accident Analysis and Prevention, 52*, 125–132.

Richter, D. (2009). *Empathie: Gewinne und Verluste im Erwachsenenalter* (Doctoral Dissertation). Retrieved on 15th October 2013 from http://www.jacobs-university.de/phd/files/1241709243.pdf.

Rimmo, P. A., & Hakamies-Blomqvist, L. (2002). Older drivers' aberrant driving behaviour, impaired activity, and health as reasons for self-imposed driving limitations. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*(1), 345-360.

Rosenbloom, S. (1995). *Travel by the elderly. In 1990 nationwide personal transportation survey: Demographic special reports.* Washington DC: US Department of Transportation, Federal Highway Administration.

Rosenbloom, S. (2001). Driving cessation among older people: When does it happen and what impact does it have? *Transportation Research Records, 1779,* 93-99.

Rosenbloom, S. (2004). Mobility of the Elderly: Good News and Bad News. *Transportation in an Aging Society: A Decade of Experience, Proceedings 27, 3-21.* Washington DC: Transportation Research Board.

Rothengatter, T. (2002). Drivers' illusions--no more risk. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*(4), 249-258.

Rothman, A. J., Klein, W. M., & Weinstein, N. D. (1996). Absolute and Relative Biases in Estimations of Personal Risk. *Journal of Applied Social Psychology, 26*(14), 1213-1236.

Rumar, K. (1988). Collective risk but individual safety. *Ergonomics, 31*(4), 507-518.

Ryan, G. A., Legge, M., & Rosman, D. (1998). Age related changes in drivers' crash risk and crash type. *Accident Analysis & Prevention, 30*(3), 379-387.

Sammer G. (1991): Zukünftige Mobilitätsentwicklung – Einflußfaktoren und Spielraum der Steuerung der Mobilitätsnachfrage. *VDI Berichte 915*. Duesseldorf: VDI.

Satariano, W.A., MacLeod, K.E., Cohn, T.E., & Ragland, D.R. (2004). Problems With Vision Associated Limitations or Avoidance of Driving in Older Populations. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 59*, 281-286.

Salthouse, T.A. (1991). *Theoretical Perspective on Cognitive Aging*. Lawrence Erlbaum: Hillsdale, NJ.

Salthouse, T.A. (2010). Selective review of cognitive aging. Journal of International *Neuropsychological Society, 16,* 754-760.

Scheibe, S. & Carstensen, L. L. (2010). Emotional Aging: Recent Findings and Future Trends. *Journal of Gerontology: Psychological Sciences, 65B*(2), 135-144.

Schlag, B. (1993). Elderly drivers in Germany – fitness and driving behaviour. *Accident Analysis and Prevention, 25*(1), 47-55.

Selander, H., Lee, H. C., Johansson, K. & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis and Prevention, 43*, 1348-1354.

Sexton, B. F. (1997). *Validation trial for testing impairment of driving due to alcohol (No. TRL Report 226)*. Crowthorne: Transport Research Laboratory.

Silverman, A. J., Cohen, S. I., Shmavonian, B. M. (1958). Psychophysiologic response specifity in the elderly. *Journal of Gerontology*, 5, 443

Simon, H. A. (1967). Motivational and emotional controls of cognition. *Psychological Review, 57*, 386-420.

Siren, A., & Hakamies-Blomqvist, L. (2004). Private car as the grand equaliser? Demographic factors and mobility in Finnish men and women aged 65+. *Transportation Research Part F: Traffic Psychology and Behaviour, 7*(2), 107-118.

Siren, A., & Kjær, M. R. (2011). How is the older road users' perception of risk constructed? *Transportation Research Part F: Traffic Psychology and Behaviour, 14*(3), 222-228.

Sirén, A., Heikkinen, S. & Hakamies-Blomqvist, L. (2001). *Older female road users: A review*. (Rapport 467A). Sweden: VTI.

Sivak, M., Soler, J., & Tränkle, U. (1989a). Cross-cultural differences in driver risk-taking. *Accident Analysis & Prevention, 21*(4), 363-369.

Sivak, M., Soler, J., & Tränkle, U. (1989b). Cross-cultural differences in driver self-assessment. *Accident Analysis & Prevention, 21*(4), 371-375.

Sivak, M., Soler, J., Tränkle, U., & Spagnhol, J. M. (1989). Cross-cultural differences in driver risk-perception. *Accident Analysis & Prevention, 21*(4), 355-362.

Sjöberg, L. (2000). The methodology of risk perception research. *Quality and Quantity, 34*, 407-418.

Sjöberg, L. (2006). Will the Real meaning of Affect Please Stand Up? *Journal of Risk Research, 9*(2), 101-108.

Slovic, Finucane, Peters & MacGregor (2003, February 13-14). *Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality.* Paper presented at the National Cancer Institute workshop on Conceptualizing and Measuring Risk Perceptions, Washington D.C.

Slovic, P., Finucane, M. L., Peters, E. & MacGregor, D. G. (2004). Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk and Rationality. *Risk Analysis, 24*(2), 311-322.

Smiley, A. (2004). Adaptive strategies of older drivers. *Transportation in an Aging Society: A Decade of Experience, Proceedings 27, 3-21.* Washington DC: Transportation Research Board.

Stalvey, B.T. & Owlsley, C. (2000). Self-perceptions and Current Practices of High-risk Older Drivers: Implications for Older Driver Interventions, *Journal of Health Psychology, 5*(4), 441-456.

Staplin, L., Gish, K. & Joyce, J. (2008). 'Low mileage bias' and related policy implications - a cautionary note. *Accident Analysis and Prevention, 40*, 1249-1252.

Streubel, B. & Kunzmann, U. (2011). Age Differences in Emotional Reactions: Arousal and Age-Relevance Count. *Psychology and Aging, 26*(4), 966-978.

Stutts, J.C. & Wilkins, J.W. (2003). On-road driving evaluations: a potential tool for helping older adults drive safely longer. *Journal of Safety Research, 34*(4), 431-439.

Stutts, J.C. (1998). Do older drivers with visual and cognitive impairments drive less? *Journal of the American Geriatric Society*, *46* (7), 854-861.

Stutts, J.C., Wilkins, J. & Schatz, S. (1999). *The decision to stop driving: results of focus groups with seniors and family members*. Proceedings of the 78th Annual Meeting of the Transportation Research Board, Washington DC.

Stutts, J.C., Wilkins, J.W., Reinfurt, D.W., Rodgman, E.A., & Van Heusen-Causey, S. (2001). *The Premature Reduction and Cessation of Driving by Older Men and Women*. Project G.7 Final Project Report University of North Carolina Highway Safety Research Center Chapel Hill, NC, available online at www.Hsrc.Unc.Edu/Pdf/2001/G7Report.Pdf.

Suen, S. L. & Sen, L. (2004). *The value of intelligent transport systems to elderly and disabled travellers.* Paper presented to the 8th International Conference on Mobility and Transport for Elderly and Disabled People, TRANSED, Perth, Australia.

Summala, H. (1988). Risk control is not risk adjustment: the zero-risk theory of driver behaviour and its implications. *Ergonomics, 31*(4), 491 - 506.

Summala, H. (1996). Accident risk and driver behaviour. *Safety Science, 22*(1-3), 103-117.

Summala, H. (2000). Automatization, automation, and modeling of driver's behavior. *Recherche - Transports - Sécurité, 66*(3), 35-45.

Summala, H., & Näätänen, R. (1988). The Zero Risk Theory and overtaking decisions. In J. A. Rothengatter & R. A. deBruin (Eds.), *Road User Behaviour* (pp. 82-92). Assen/Maastricht: Van Gorcum.

Svenson, O. (1981). Are we all less risky and more skillful than our fellow drivers? *Acta Psychologica, 47*(2), 143-148.

Taylor, D. H. (1964). Driver' galvanic skin response and the risk of accident. *Ergonomics, 7*(4), 439 - 451.

Thomae, H. (1991). Lebenszufriedenheit. In W.D. Oswald, W.M. Herrmann, S. Kanowski, U.M. Lehr & H. Thomae (Hrsg.), *Gerontologie. Medizinische, psychologische und sozialwissenschaftliche Grundbegriffe* (2. Auflage) (S. 323-328). Stuttgart: Kohlhammer.

Trimpop, R. M. (1994). *The Psychology of Risk Taking Behaviour.* Advances in Psychology. Amsterdam/The Netherlands: North-Holland.

Trimpop, R. M. (1996). Risk homeostasis theory: Problems of the past and promises for the future. *Safety Science, 22*(1-3), 119-130.

Venables, P. H. & Christie, M. J. (1980). In: Techniques in Psychophysiology. I. Martin & P. H. Venable (ed.). Wiley, Chichester, 3-67.

Wagner, J.T., Müri, R.M., Neft, T., & Mosimann, U.P. (2011). Cognition and driving in older persons. *Swiss Medical Weekly, 140*, 131-136.

Warnes, A.M. and D.A. Fraser, 1992. Car driving as a social skill. *Gerontology and Geriatrics Education, 13* (1/2), 103-28.

Welsh, R., Morris, A., Hassan, A. & Charlton (2006). Crash characteristics and injury outcomes for older passenger car occupants. *Transportation Research Part F, 9*, 322-334. Wells, P., Tong, S., Sexton, B. F., Grayson, G. B., & Jones, E. (2008). *Cohort II: A study of Learner and New Drivers, Volume 1 - Main Report (Road Safety Research Report No. 81)*. London: Department for Transport.

Whelan, M., Langford, J., Oxley, J., Koppel, S. and Charlton, J. (2006). *The Elderly and Mobility: Review of the Literature.* Report Number 255, Monash University Accident Research Centre, Victoria, Australia.

Wickens, C.M., Toplak, M.E. and Wiesenthal, D.L. (2008). Cognitive failures as predictors of driving errors, lapses, and violations. *Accident Analysis and Prevention, 40*, 1223-1233.

Wilde, G. J. S. (1982). The Theory of Risk Homeostasis: Implications for Safety and Health. *Risk Analysis 2*(4), 209-225.

Wilde, G. J. S. (1988). Risk homeostasis theory applied to a fictitious instance of an individual driver's decision making. In J. A. Rothengatter & R. A. DeBruin (Eds.), *Road User Behaviour* (pp. 66-76). Assum/Maastricht: Van Gorcum.

Wilde, G. J. S. (1989). Accident countermeasures and behavioural compensation: The position of risk homeostasis theory. *Journal of Occupational Accidents, 10*(4), 267-292.

Williams, A., & Shabanova, V. (2003). Responsibility of drivers, by age and gender, for motor-vehicle crash deaths. *Journal of Safety Research, 34*(5), 527-531.

Wood, J.M., Mcgwin, G., Elgin, J., Vaphiades, M.S., Braswell, R.A., Decarlo, D.K., Kline, L.B., Meek, G.C., Searcey, K., Owsley, C. (2009). On-road driving performance by persons with hemianopia and quadrantanopia. *Investigative Opthalmology and Visual Science 50* (2), 577–585.

Yanik, A., & Monfootron, R. (1991). At fault crash patterns of older drivers. *Journal of Traffic Medicine, 10*(2), 87-92.

Yassunda, M.S., Wilson, J.J. & von Mering, O. (1997): Driving cessation: The perspective of senior drivers. *Educational Gerontology, 23* (6), 525-536.

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences, *American Psychologist, 35*, 151–175.

Zhang, J., Lindsay, J., Clarke, K., Robbins, G., & Mao, Y. (2000). Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. *Accident Analysis and Prevention, 32*(1), 117-125.

Appendix A

Sept. 2004

MG NSRF/A

ACCIDENT STATISTICS

*FATAL / SERIOUS / SLIGHT

Incident URN

Other ref.

1.3 ACCIDENT REFERENCE

1.9 TIME H H M M DAY* Su M T W Th F S 1.7 DATE D D M M 2 0 Y Y

1st Road Class & No. or (Unclassified - UC) (Not Known - NK) — 1st Road Name

Outside House No. or Name or Marker Post No. — at junction with / or — metres N S E W * of

2nd Road Class & No. or (Unclassified - UC) (Not Known - NK) — 2nd Road Name

Town — Sector /Beat No.

County or Borough

Parish No. or Name — 1.10 Local Auth No. (if known)

1.11 Grid Reference E→ N↑

REPORTING OFFICER Name — Number

BCU/Stn — 1.2 Force — Tel Number

1.5 Number of vehicles	
1.6 Number of casualties	

1.14 ROAD TYPE		✗
Roundabout	1	
One way street	2	
Dual carriageway	3	
Single carriageway	6	
Slip road	7	
Unknown	9	

1.15 Speed Limit (Permanent)	

1.16 JUNCTION DETAIL		✗
Not at or within 20 metres of junction	00	
Roundabout	01	
Mini roundabout	02	
T or staggered junction	03	
Slip road	05	
Crossroads	06	
Multiple junction	07	
Using private drive or entrance	08	
Other junction	09	

JUNCTION ACCIDENTS ONLY

1.17 JUNCTION CONTROL		✗
Authorised person	1	
Automatic traffic signal	2	
Stop sign	3	
Give way or uncontrolled	4	

1.20a PEDESTRIAN CROSSING - HUMAN CONTROL		✗
None within 50 metres	0	
Control by school crossing patrol	1	
Control by other authorised person	2	

1.20b PEDESTRIAN CROSSING - PHYSICAL FACILITIES		✗
No physical crossing facility within 50m	0	
Zebra crossing	1	
Pelican, puffin, toucan or similar non-junction pedestrian light crossing	4	
Pedestrian phase at traffic signal junction	5	
Footbridge or subway	7	
Central refuge — no other controls	8	

1.22 WEATHER		✗
Fine without high winds	1	
Raining without high winds	2	
Snowing without high winds	3	
Fine with high winds	4	
Raining with high winds	5	
Snowing with high winds	6	
Fog or mist — if hazard	7	
Other	8	
Unknown	9	

1.23 ROAD SURFACE CONDITION		✗
Dry	1	
Wet / Damp	2	
Snow	3	
Frost / Ice	4	
Flood (surface water over 3cm deep)	5	

1.21 LIGHT CONDITIONS		✗
Daylight: street lights present	1	
Daylight: no street lighting	2	
Daylight: street lighting unknown	3	
Darkness: street lights present and lit	4	
Darkness: street lights present but unlit	5	
Darkness: no street lighting	6	
Darkness: street lighting unknown	7	

1.24 SPECIAL CONDITIONS AT SITE		✗
None	0	
Auto traffic signal out	1	
Auto traffic signal partially defective	2	
Permanent road signing or marking defective or obscured	3	
Roadworks	4	
Road surface defective	5	
Oil or diesel	6	
Mud	7	

1.25 CARRIAGEWAY HAZARDS		✗
None	0	
Dislodged vehicle load in carriageway	1	
Other object in carriageway	2	
Involvement with previous accident	3	
Pedestrian in carriageway - not injured	6	
Any animal in carriageway (except ridden horse)	7	

1.26 Did a police officer attend the scene and obtain the details for this report?		✗
Yes	1	
No	2	

Subject to local directions, boxes with a grey background need not be completed if already recorded

* Circle as appropriate

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VEHICLE RECORD

Sept. 2004

2.26 VEHICLE REGISTRATION MARK	
Vehicle 001	
Vehicle 002	
Vehicle 003	
Vehicle 004	

2.28 FOREIGN REGISTERED VEHICLE ✗		VEHICLE 1	2	3	4
Not foreign registered vehicle	0				
Foreign registered vehicle LHD	1				
Foreign registered vehicle RHD	2				
Foreign reg' vehicle-two wheeler	3				

2.5 TYPE OF VEHICLE ✗					
Pedal cycle	01				
M/cycle 50cc and under	02				
M/cycle over 50cc and up to 125cc	03				
M/cycle over 125cc and up to 500cc	04				
Motorcycle over 500cc	05				
Taxi / Private hire car	08				
Car	09				
Minibus (8-16 passenger seats)	10				
Bus or coach (17 or more passenger seats)	11				
Other motor vehicle	14				
Other non-motor vehicle	15				
Ridden horse	16				
Agricultural vehicle (include diggers etc)	17				
Tram / Light rail	18				
Goods vehicle 3.5 tonnes mgw and under	19				
Goods vehicle over 3.5 tonnes mgw and under 7.5 tonnes mgw	20				
Goods vehicle 7.5 tonnes mgw and over	21				

2.6 TOWING AND ARTICULATION ✗					
No tow or articulation	0				
Articulated vehicle	1				
Double or multiple trailer	2				
Caravan	3				
Single trailer	4				
Other tow	5				

2.21 SEX OF DRIVER ✗					
Male	1				
Female	2				
Driver not traced	3				

2.22 AGE OF DRIVER (Estimate if necessary)			
Vehicle 001		Vehicle 002	
Vehicle 003		Vehicle 004	

2.27 DRIVER HOME POSTCODE or Code: 1- Unknown 2- Non UK Resident 3 - Parked & unattended

Vehicle 001		
Vehicle 002		
Vehicle 003		
Vehicle 004		

2.23 BREATH TEST ✗		VEHICLE 1	2	3	4
Not applicable	0				
Positive	1				
Negative	2				
Not requested	3				
Refused to provide	4				
Driver not contacted at time of acc'	5				
Not provided (medical reasons)	6				

2.24 HIT AND RUN ✗					
Not hit and run	0				
Hit and run	1				
Non-stop vehicle, not hit	2				

2.29 JOURNEY PURPOSE OF DRIVER/RIDER ✗					
Journey as part of work	1				
Commuting to / from work	2				
Taking school pupil to/from school	3				
Pupil riding to / from school	4				
Other/Not known	5				

2.9 VEHICLE LOCATION AT TIME OF ACCIDENT RESTRICTED LANE/AWAY FROM MAIN C'WAY ✗					
On main carriageway not in restricted lane	00				
Tram / Light rail track	01				
Bus lane	02				
Busway (inc. guided busway)	03				
Cycle lane (on main carriageway)	04				
Cycleway or shared use footway (not part of main carriageway)	05				
On lay-by / hard shoulder	06				
Entering lay-by / hard shoulder	07				
Leaving lay-by / hard shoulder	08				
Footway (pavement)	09				

2.10 JUNCTION LOCATION OF VEHICLE ✗					
Not at or within 20m of junction	0				
Approaching junction or waiting /parked at junction approach	1				
Cleared junction or waiting/ parked at junction exit	2				
Leaving roundabout	3				
Entering roundabout	4				
Leaving main road	5				
Entering main road	6				
Entering from slip road	7				
Mid junction– on roundabout or on main road	8				

2.7 MANOEUVRES ✗					
Reversing	01				
Parked	02				
Waiting to go ahead but held up	03				
Slowing or stopping	04				
Moving off	05				
U turn	06				
Turning left	07				
Waiting to turn left	08				
Turning right	09				
Waiting to turn right	10				
Changing lane to left	11				
Changing lane to right	12				
O'taking moving veh on its offside	13				
O'taking stationary veh on its offside	14				
Overtaking on nearside	15				
Going ahead left hand bend	16				
Going ahead right hand bend	17				
Going ahead other	18				

2.11 SKIDDING AND OVERTURNING ✗		VEHICLE 1	2	3	4
No skidding, jack-knifing or overturning	0				
Skidded	1				
Skidded and overturned	2				
Jack-knifed	3				
Jack-knifed and overturned	4				
Overturned	5				

2.12 HIT OBJECT IN CARRIAGEWAY ✗					
None	00				
Previous accident	01				
Roadworks	02				
Parked vehicle	04				
Bridge-roof	05				
Bridge-side	06				
Bollard / Refuge	07				
Open door of vehicle	08				
Central island of roundabout	09				
Kerb	10				
Other object	11				
Any animal (except ridden horse)	12				

2.13 VEHICLE LEAVING CARRIAGEWAY ✗					
Did not leave carriageway	0				
Left carriageway nearside	1				
Left carriageway nearside and rebounded	2				
Left carriageway straight ahead at junction	3				
Left carriageway offside onto central reservation	4				
Left carriageway offside onto central reserve and rebounded	5				
Left carriageway offside and crossed central reservation	6				
Left carriageway offside	7				
Left carriageway offside and rebounded	8				

2.14 FIRST OBJECT HIT OFF CARRIAGEWAY ✗					
None	00				
Road sign / Traffic signal	01				
Lamp post	02				
Telegraph pole / Electricity pole	03				
Tree	04				
Bus stop / Bus shelter	05				
Central crash barrier	06				
Nearside or offside crash barrier	07				
Submerged in water (completely)	08				
Entered ditch	09				
Other permanent object	10				

2.16 FIRST POINT OF IMPACT ✗					
Did not impact	0				
Front	1				
Back	2				
Offside	3				
Nearside	4				

2.17 FIRST CONTACT BETWEEN EACH VEHICLE
Example: In a 3 car collision vehicle 1 collides with the rear of vehicle 2 pushing it into vehicle 3.

Example Code:			
Vehicle 001 first collides with vehicle 002	0	0	2
Vehicle 002 first collides with vehicle 001	0	0	1
Vehicle 003 first collides with vehicle 002	0	0	2

Vehicle 001	0			Vehicle 002	0		
Vehicle 003	0			Vehicle 004	0		

Subject to local directions, boxes with a grey background need not be completed if already recorded

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MG NSRF/D **CONTRIBUTORY FACTORS** Sept. 2004

1. Select up to six factors from the grid, relevant to the accident.
2. Factors may be shown in any order, but an indication must be given of whether each factor is **very likely (A)** or **possible (B).**
3. Only include factors that you consider contributed to the accident. (i.e. do NOT include "Poor road surface" unless relevant).
4. More than one factor may, if appropriate, be related to the same road user.
5. The same factor may be related to more than one road user.
6. The participant should be identified by the relevant vehicle or casualty ref no. (e.g. 001, 002 etc.), preceded by "V" if the factor applies to a vehicle, driver/rider or the road environment (e.g. V002), or "C" if the factor relates to a pedestrian or passenger casualty (e.g. C001).
7. Enter U000 if the factor relates to an uninjured pedestrian.

	Road Environment Contributed	101	102	103	104	105	106	107	108	109	
		Poor or defective road surface	Deposit on road (e.g. oil, mud, chippings)	Slippery road (due to weather)	Inadequate or masked signs or road markings	Defective traffic signals	Traffic calming (e.g. speed cushions, road humps, chicanes)	Temporary road layout (e.g. contraflow)	Road layout (e.g. bend, hill, narrow carriageway)	Animal or object in carriageway	
	Vehicle Defects	201	202	203	204	205	206				
		Tyres illegal, defective or under-inflated	Defective lights or indicators	Defective brakes	Defective steering or suspension	Defective or missing mirrors	Overloaded or poorly loaded vehicle or trailer				
Driver/Rider Only (Includes Pedal Cycles and Horse Riders)	Injudicious Action	301	302	303	304	305	306	307	308	309	310
		Disobeyed automatic traffic signal	Disobeyed 'Give Way' or 'Stop' sign or markings	Disobeyed double white lines	Disobeyed pedestrian crossing facility	Illegal turn or direction of travel	Exceeding speed limit	Travelling too fast for conditions	Following too close	Vehicle travelling along pavement	Cyclist entering road from pavement
	Driver/ Rider Error or Reaction	401	402	403	404	405	406	407	408	409	410
		Junction overshoot	Junction restart (moving off at junction)	Poor turn or manoeuvre	Failed to signal or misleading signal	Failed to look properly	Failed to judge other person's path or speed	Passing too close to cyclist, horse rider or pedestrian	Sudden braking	Swerved	Loss of control
	Impairment or Distraction	501	502	503	504	505	506	507	508	509	510
		Impaired by alcohol	Impaired by drugs (illicit or medicinal)	Fatigue	Uncorrected, defective eyesight	Illness or disability, mental or physical	Not displaying lights at night or in poor visibility	Cyclist wearing dark clothing at night	Driver using mobile phone	Distraction in vehicle	Distraction outside vehicle
	Behaviour or Inexperience	601	602	603	604	605	606	607			
		Aggressive driving	Careless, reckless or in a hurry	Nervous, uncertain or panic	Driving too slow for conditions or slow vehicle (e.g. tractor)	Learner or inexperienced driver/rider	Inexperience of driving on the left	Unfamiliar with model of vehicle			
	Vision Affected by	701	702	703	704	705	706	707	708	709	710
		Stationary or parked vehicle(s)	Vegetation	Road layout (e.g. bend, winding road, hill crest)	Buildings, road signs, street furniture	Dazzling headlights	Dazzling sun	Rain, sleet, snow or fog	Spray from other vehicles	Visor or windscreen dirty or scratched	Vehicle blind spot
	Pedestrian Only (Casualty or Uninjured)	801	802	803	804	805	806	807	808	809	810
		Crossing road masked by stationary or parked vehicle	Failed to look properly	Failed to judge vehicle's path or speed	Wrong use of pedestrian crossing facility	Dangerous action in carriageway (e.g. playing)	Impaired by alcohol	Impaired by drugs (illicit or medicinal)	Careless, reckless or in a hurry	Pedestrian wearing dark clothing at night	Disability or illness, mental or physical
	Special Codes	901	902	903	904						*999
		Stolen vehicle	Vehicle in course of crime	Emergency vehicle on a call	Vehicle door opened or closed negligently						Other – Please specify below

	1st	2nd	3rd	4th	5th	6th
Factor in the accident						
Which participant? (e.g. V001, C001, U000)						
Very likely (A) or Possible (B)						

* If 999 Other, give brief details ....

(Note: Only use if another factor contributed to the accident **and include it in the text description of how the accident occurred)**

These factors reflect the reporting officer's opinion at the time of reporting and may not be the result of extensive investigation

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Figure A-1: STATS 19 collision reporting form.

Risk perception as a function of age

Table A-1 displays the percentage distributions for OTS accident investigators and Police officers, differentiated by driver age. Contributory factors that were recorded at least 1% more frequently by police officers compared to OTS investigators were marked in yellow (comparison across all age groups). Those factors, which were at least 1% more frequently recorded by OTS investigators, were marked in green (all age groups). Instances where the percentage differences between OTS investigators and police officers exceeded 5% were marked in red.

Table A-1: Percentage distribution of contributory factors as recorded by OTS accident investigators and the police for n=495 collisions in 2005 and 2006.

	Database	Data recorders: OTS investigators				Data recorders: police officers			
		Age				Age			
CF class	Contributory factor	17-34	35-59	60+	All	17-34	35-59	60+	All
1	Poor or defective road surface	0.0	0.0	0.2	0.2	0.1	0.0	0.1	0.3
	Deposit on road	0.1	0.0	0.0	0.1	0.6	0.0	0.0	0.6
	Slippery road	0.5	0.0	0.2	0.7	3.6	1.4	0.1	5.2
	Inadequate or masked signs or road markings	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3
	Defective traffic signals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Traffic calming	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
	Temporary road layout	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.6
	Road layout	0.3	0.0	0.0	0.3	1.1	0.0	0.1	1.3
	Animal or object in carriageway	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4
2	Tyres illegal, defective or under-inflated	0.5	0.3	0.0	0.8	1.1	0.1	0.0	1.3
	Defective lights or indicators	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	Defective brakes	0.0	0.1	0.0	0.1	0.3	0.0	0.0	0.3
	Defective steering or suspension	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.1
	Defective or missing mirrors	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Overloaded or poorly loaded vehicle or trailer	0.1	0.1	0.0	0.2	0.1	0.1	0.0	0.3

	Table cont.	Data recorders: OTS investigators				Data recorders: police officers			
CF class	Contributory factor	17-34	35-59	60+	All	17-34	35-59	60+	All
3	Disobeyed automatic traffic signal	0.5	0.5	0.0	1.1	0.6	0.4	0.1	1.1
	Disobeyed "Give way" or "stop" sign or markings	2.0	1.1	1.0	4.1	0.7	0.9	0.7	2.3
	Disobeyed double white lines	0.2	0.0	0.0	0.2	0.1	0.0	0.0	0.1
	Disobeyed pedestrian crossing facility	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
	Illegal turn or direction of travel	0.4	0.3	0.0	0.6	0.6	0.0	0.0	0.6
	Exceeding speed limit	4.0	0.9	0.3	5.1	2.6	0.4	0.0	3.0
	Travelling too fast for conditions	5.5	1.4	0.5	7.5	3.6	1.1	0.3	5.0
	Following too close	2.6	1.2	0.3	4.1	1.9	0.9	0.3	3.0
	Vehicle travelling along pavement	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
	Cyclist entering road from pavement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	Junction overshoot	0.2	0.2	0.1	0.5	0.6	0.6	0.3	1.4
	Junction restart	1.1	0.8	0.3	2.2	0.4	0.6	0.6	1.6
	Poor turn or manoeuvre	3.3	2.0	0.3	5.6	3.0	2.3	0.3	5.6
	Failed to signal or misleading signal	0.7	0.2	0.2	1.1	0.3	0.3	0.0	0.6
	Failed to look properly	5.0	3.7	1.4	10.1	7.3	4.7	1.7	13.7
	Failed to judge other person's path or speed	2.9	2.0	0.5	5.4	3.7	2.6	1.0	7.3
	Passing too close to cyclist, horse rider or pedestrian	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
	Sudden braking	1.9	0.9	0.6	3.4	2.6	1.1	0.3	4.0
	Swerved	1.0	1.0	0.4	2.3	0.9	1.1	0.3	2.3
	Loss of control	6.1	2.0	1.2	9.3	6.3	2.1	1.1	9.6

	Table cont.	Data recorders: OTS investigators				Data recorders: police officers			
CF class	Contributory factor	17-34	35-59	60+	All	17-34	35-59	60+	All
5	Impaired by alcohol	1.0	0.3	0.3	1.5	1.9	0.4	0.4	2.7
	Impaired by drugs (illicit or medicinal)	0.2	0.0	0.0	0.2	0.1	0.0	0.0	0.1
	Fatigue	0.3	0.9	0.1	1.3	0.4	0.4	0.1	1.0
	Uncorrected, defective eyesight	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0
	Illness or disability, mental or physical	0.2	0.7	0.7	1.6	0.1	0.9	0.9	1.9
	Not displaying lights at night or in poor visibility	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cyclist wearing dark clothing at night	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Driver using mobile phone	0.3	0.0	0.0	0.3	0.1	0.1	0.0	0.3
	Distraction in vehicle	1.2	0.5	0.0	1.7	1.1	0.4	0.0	1.6
	Distraction outside vehicle	0.1	0.3	0.2	0.5	0.0	0.1	0.0	0.1
6	Aggressive driving	1.5	0.2	0.0	1.7	1.4	0.1	0.0	1.6
	Careless, reckless or in a hurry	8.7	3.9	1.0	13.6	4.9	2.1	0.1	7.2
	Nervous, uncertain or panic	1.5	0.9	0.2	2.6	0.4	0.6	0.3	1.3
	Driving too slow for conditions, or slow vehicle	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1
	Learner or inexperienced driver/rider	2.4	0.0	0.0	2.4	2.9	0.3	0.0	3.1
	Inexperience of driving on the left	0.3	0.0	0.0	0.3	0.3	0.0	0.0	0.3
	Unfamiliar with model of vehicle	1.0	0.1	0.0	1.1	0.4	0.0	0.0	0.4

	Table cont.	Data recorders: OTS investigators				Data recorders: police officers			
CF class	Contributory factor	17-34	35-59	60+	All	17-34	35-59	60+	All
7	Stationary or parked vehicle	0.5	0.6	0.3	1.4	0.6	0.6	0.3	1.4
	Vegetation	0.2	0.2	0.0	0.4	0.0	0.0	0.0	0.0
	Road layout	0.5	0.5	0.1	1.1	0.6	0.3	0.3	1.1
	Buildings, road signs, street furniture	0.0	0.2	0.1	0.3	0.1	0.0	0.1	0.3
	Dazzling headlights	0.1	0.0	0.0	0.1	0.1	0.3	0.0	0.4
	Dazzling sun	0.6	0.2	0.1	0.9	0.6	0.3	0.0	0.9
	Rain, sleet, snow or fog	0.1	0.1	0.1	0.3	0.3	0.7	0.3	1.3
	Spray from other vehicles	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.1
	Visor or windscreen dirty or scratched	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
	Vehicle blind spot	0.5	0.5	0.3	1.3	0.1	0.1	0.0	0.3
	Total	60.0	28.9	11.2	100.0	60.1	29.3	10.6	100.0

- Yellow marking: CF recorded at least 1% more frequently by police officer than OTS investigator
- Green marking: CF recorded at least 1% more frequently by OTS investigator than police officer
- Red marking: Differences between the police's and the OTS investigators' CF recordings exceed 5%

Table A-2 shows the absolute frequencies and the percentage distributions of very likely contributory factors associated with different age groups for female drivers.

Table A-2: Frequencies and percentage distribution of "very likely" contributory factors for female drivers differentiated by age.

	Frequencies					Percentages				
	17-30	31-50	51-60	61-70	70+	17-30	31-50	51-60	61-70	70+
Poor or defective road surface	94	47	4	12	2	0.4	0.3	0.1	0.5	0.1
Deposit on road	239	111	21	16	8	1.0	0.7	0.5	0.7	0.3
Slippery road (due to weather)	1624	748	184	92	55	6.9	4.9	4.8	4.2	2.4
Inadequate or masked signs or road markings	59	38	19	14	8	0.3	0.2	0.5	0.6	0.3
Defective traffic signs	16	13	4	0	4	0.1	0.1	0.1	0.0	0.2
Traffic calming	8	16	2	2	5	0.0	0.1	0.1	0.1	0.2
Temporary road lay-out	29	26	8	6	3	0.1	0.2	0.2	0.3	0.1
Road lay-out (e.g. bend, hill or narrow carriageway	346	188	54	31	34	1.5	1.2	1.4	1.4	1.5
Animal or object in carriageway	172	96	19	5	8	0.7	0.6	0.5	0.2	0.3
Tyres illegal, defective or underinflated	98	49	2	6	3	0.4	0.3	0.1	0.3	0.1
Defective lights or indicators	3	3	0	1	1	0.0	0.0	0.0	0.0	0.0
Defective brakes	30	24	3	2	2	0.1	0.2	0.1	0.1	0.1
Defective steering or suspension	26	7	1	2	1	0.1	0.0	0.0	0.1	0.0
Overloaded or poorly loaded vehicle or trailer	3	5	1	1	0	0.0	0.0	0.0	0.0	0.0
Disobeyed automatic traffic signal	218	150	37	24	20	0.9	1.0	1.0	1.1	0.9

Table cont.	Frequencies					Percentages				
	17-30	31-50	51-60	61-70	70+	17-30	31-50	51-60	61-70	70+
Disobeyed "give way" or "stop" sign or marking	631	516	134	95	128	2.7	3.4	3.5	4.3	5.6
Disobeyed double white lines	37	23	4	4	3	0.2	0.2	0.1	0.2	0.1
Disobeyed pedestrian crossing facility	39	43	10	3	15	0.2	0.3	0.3	0.1	0.7
Illegal turn or direction of traffic	96	90	25	8	14	0.4	0.6	0.7	0.4	0.6
Exceeding speed limit	1139	292	31	8	3	4.9	1.9	0.8	0.4	0.1
Travelling too fast for conditions	1746	860	157	65	54	7.5	5.6	4.1	3.0	2.3
Following too close	694	530	132	65	52	3.0	3.5	3.4	3.0	2.3
Vehicle travelling along pavement	16	10	5	2	3	0.1	0.1	0.1	0.1	0.1
Cyclist entering road from pavement	7	7	2	1	0	0.0	0.0	0.1	0.0	0.0
Junction overshoot	306	165	55	28	58	1.3	1.1	1.4	1.3	2.5
Junction restart (moving off at junction)	181	202	75	53	47	0.8	1.3	2.0	2.4	2.0
Poor turn or manoeuvre	1823	1677	443	272	311	7.8	11.0	11.6	12.4	13.5
Failed to signal or misleading signal	97	110	23	19	10	0.4	0.7	0.6	0.9	0.4
Failed to look properly	3331	3053	861	526	576	14.2	20.0	22.5	24.0	25.0
Failed to judge other person's path or speed	1547	1194	328	183	215	6.6	7.8	8.6	8.4	9.3
Passing too close to cyclist, horse rider or pedestrian	46	79	16	14	24	0.2	0.5	0.4	0.6	1.0
Sudden braking	587	341	74	41	22	2.5	2.2	1.9	1.9	1.0
Swerved	479	252	59	32	22	2.0	1.6	1.5	1.5	1.0
Loss of control	1842	874	192	105	130	7.9	5.7	5.0	4.8	5.6
Impaired by alcohol	915	560	88	23	8	3.9	3.7	2.3	1.1	0.3

Table cont.	Frequencies					Percentages				
	17-30	31-50	51-60	61-70	70+	17-30	31-50	51-60	61-70	70+
Impaired by drugs (illicit or medicinal)	51	27	5	2	0	0.2	0.2	0.1	0.1	0.0
Fatigue	96	69	26	18	11	0.4	0.5	0.7	0.8	0.5
Uncorrected, defective eye-sight	7	4	6	7	23	0.0	0.0	0.2	0.3	1.0
Illness or disability, mental or physical	21	55	29	24	58	0.1	0.4	0.8	1.1	2.5
Not displaying lights at night or in poor visibility	5	11	1	0	2	0.0	0.1	0.0	0.0	0.1
Cyclist wearing dark clothing at night	3	4	0	0	1	0.0	0.0	0.0	0.0	0.0
Driver using mobile phone	38	21	1	0	0	0.2	0.1	0.0	0.0	0.0
Distraction in vehicle	231	169	22	17	16	1.0	1.1	0.6	0.8	0.7
Distraction outside vehicle	132	87	30	20	15	0.6	0.6	0.8	0.9	0.7
Aggressive driving	480	180	29	17	7	2.1	1.2	0.8	0.8	0.3
Careless, reckless, or in a hurry	1748	1207	279	131	118	7.5	7.9	7.3	6.0	5.1
Nervous, uncertain or panic	177	97	39	28	56	0.8	0.6	1.0	1.3	2.4
Driving too slow for conditions, or slow vehicle (e.g. tractor)	9	1	4	2	2	0.0	0.0	0.1	0.1	0.1
Learner or inexperienced driver/rider	942	70	7	5	3	4.0	0.5	0.2	0.2	0.1
Inexperience of driving on the left	45	30	13	2	3	0.2	0.2	0.3	0.1	0.1
Unfamiliar with model of vehicle	64	49	6	8	3	0.3	0.3	0.2	0.4	0.1
Stationary or parked vehicle	237	255	85	50	39	1.0	1.7	2.2	2.3	1.7
Vegetation	29	24	10	7	3	0.1	0.2	0.3	0.3	0.1
Road layout (e.g. bend, winding road, hill crest)	125	108	32	14	11	0.5	0.7	0.8	0.6	0.5

Table cont.	Frequencies					Percentages				
	17-30	31-50	51-60	61-70	70+	17-30	31-50	51-60	61-70	70+
Buildings, road signs, street furniture	15	20	10	3	0	0.1	0.1	0.3	0.1	0.0
Dazzling headlights	26	16	10	6	6	0.1	0.1	0.3	0.3	0.3
Dazzling sun	145	132	45	39	51	0.6	0.9	1.2	1.8	2.2
Rain, sleet, snow or fog	183	151	39	19	20	0.8	1.0	1.0	0.9	0.9
Spray from other vehicles	20	15	9	1	4	0.1	0.1	0.2	0.0	0.2
Visor or windscreen dirty or scratched	15	17	4	2	1	0.1	0.1	0.1	0.1	0.0
Vehicle blind spot	29	57	20	7	2	0.1	0.4	0.5	0.3	0.1
	23397	15275	3834	2190	2304	100	100	100	100	100

Table A-3 shows the absolute frequencies and the percentage distributions of very likely contributory factors associated with different age groups for male drivers.

Table A-3: Frequencies and percentage distribution of "very likely" contributory factors for male drivers differentiated by age.

	Frequencies					Percentage distribution				
	17-30	31-50	51-60	61-70	71+	17-30	31-50	51-60	61-70	71+
Poor or defective road surface	112	63	10	7	3	0.3	0.3	0.2	0.2	0.1
Deposit on road	290	135	27	20	9	0.7	0.6	0.5	0.6	0.2
Slippery road (due to weather)	2195	961	223	123	69	5.1	3.9	3.8	3.5	1.7
Inadequate or masked signs or road markings	79	59	21	16	13	0.2	0.2	0.4	0.5	0.3
Defective traffic signs	14	23	4	0	6	0.0	0.1	0.1	0.0	0.2
Traffic calming	15	20	3	3	5	0.0	0.1	0.1	0.1	0.1

Table cont.	Frequencies					Percentage distribution				
	17-30	31-50	51-60	61-70	71+	17-30	31-50	51-60	61-70	71+
Temporary road lay-out	46	33	16	7	6	0.1	0.1	0.3	0.2	0.2
Road lay-out (e.g. bend, hill or narrow carriageway	523	273	62	46	48	1.2	1.1	1.1	1.3	1.2
Animal or object in carriageway	233	109	24	11	9	0.5	0.4	0.4	0.3	0.2
Tyres illegal, defective or underinflated	188	85	5	9	5	0.4	0.3	0.1	0.3	0.1
Defective lights or indicators	5	5	1	1	4	0.0	0.0	0.0	0.0	0.1
Defective brakes	68	36	3	2	0	0.2	0.1	0.1	0.1	0.0
Defective steering or suspension	32	12	0	3	1	0.1	0.0	0.0	0.1	0.0
Defective or missing mirrors	0	2	0	0	0	0.0	0.0	0.0	0.0	0.0
Overloaded or poorly loaded vehicle or trailer	10	11	3	1	0	0.0	0.0	0.1	0.0	0.0
Disobeyed automatic traffic signal	297	193	52	26	26	0.7	0.8	0.9	0.7	0.7
Disobeyed "give way" or "stop" sign or marking	779	624	173	117	156	1.8	2.6	2.9	3.3	3.9
Disobeyed double white lines	64	33	7	3	4	0.1	0.1	0.1	0.1	0.1
Disobeyed pedestrian crossing facility	53	58	10	11	21	0.1	0.2	0.2	0.3	0.5
Illegal turn or direction of traffic	161	125	30	11	21	0.4	0.5	0.5	0.3	0.5
Exceeding speed limit	2068	538	51	20	9	4.8	2.2	0.9	0.6	0.2
Travelling too fast for conditions	3505	1449	253	88	80	8.1	5.9	4.3	2.5	2.0
Following too close	1069	843	199	98	90	2.5	3.5	3.4	2.8	2.3
Vehicle travelling along pavement	23	18	3	2	5	0.1	0.1	0.1	0.1	0.1
Cyclist entering road from pavement	10	8	6	2	0	0.0	0.0	0.1	0.1	0.0
Junction overshoot	468	285	75	43	87	1.1	1.2	1.3	1.2	2.2

Table cont.	Frequencies					Percentage distribution				
	17-30	31-50	51-60	61-70	71+	17-30	31-50	51-60	61-70	71+
Junction restart (moving off at junction)	241	240	87	59	71	0.6	1.0	1.5	1.7	1.8
Poor turn or manoeuvre	2509	2053	574	352	415	5.8	8.4	9.7	9.9	10.5
Failed to signal or misleading signal	179	163	48	30	17	0.4	0.7	0.8	0.8	0.4
Failed to look properly	5368	4637	1301	836	961	12.4	19.0	22.0	23.6	24.3
Failed to judge other person's path or speed	2863	2171	638	414	504	6.6	8.9	10.8	11.7	12.8
Passing too close to cyclist, horse rider or pedestrian	112	118	33	32	43	0.3	0.5	0.6	0.9	1.1
Sudden braking	1214	583	115	58	48	2.8	2.4	1.9	1.6	1.2
Swerved	1014	486	95	56	57	2.3	2.0	1.6	1.6	1.4
Loss of control	4442	1607	276	181	211	10.2	6.6	4.7	5.1	5.3
Impaired by alcohol	1730	892	128	37	17	4.0	3.7	2.2	1.0	0.4
Impaired by drugs (illicit or medicinal)	154	68	10	4	2	0.4	0.3	0.2	0.1	0.1
Fatigue	182	146	30	25	26	0.4	0.6	0.5	0.7	0.7
Uncorrected, defective eye-sight	13	3	6	3	46	0.0	0.0	0.1	0.1	1.2
Illness or disability, mental or physical	37	73	45	44	131	0.1	0.3	0.8	1.2	3.3
Not displaying lights at night or in poor visibility	19	10	1	1	2	0.0	0.0	0.0	0.0	0.1
Cyclist wearing dark clothing at night	4	4	3	2	0	0.0	0.0	0.1	0.1	0.0
Driver using mobile phone	44	42	7	4	0	0.1	0.2	0.1	0.1	0.0
Distraction in vehicle	386	243	44	38	22	0.9	1.0	0.7	1.1	0.6
Distraction outside vehicle	238	162	61	32	36	0.5	0.7	1.0	0.9	0.9
Aggressive driving	1511	492	78	21	9	3.5	2.0	1.3	0.6	0.2

Table cont.	Frequencies					Percentage distribution				
	17-30	31-50	51-60	61-70	71+	17-30	31-50	51-60	61-70	71+
Careless, reckless, or in a hurry	4804	2710	611	329	288	11.1	11.1	10.4	9.3	7.3
Nervous, uncertain or panic	215	80	26	25	73	0.5	0.3	0.4	0.7	1.8
Driving too slow for conditions, or slow vehicle (e.g. tractor)	10	4	0	0	5	0.0	0.0	0.0	0.0	0.1
Learner or inexperienced driver/rider	2054	87	11	4	4	4.7	0.4	0.2	0.1	0.1
Inexperience of driving on the left	129	61	16	7	5	0.3	0.2	0.3	0.2	0.1
Unfamiliar with model of vehicle	199	83	14	11	17	0.5	0.3	0.2	0.3	0.4
Stationary or parked vehicle	420	379	123	69	64	1.0	1.6	2.1	1.9	1.6
Vegetation	36	42	20	11	5	0.1	0.2	0.3	0.3	0.1
Road layout (e.g. bend, winding road, hill crest)	249	144	49	34	28	0.6	0.6	0.8	1.0	0.7
Buildings, road signs, street furniture	27	25	5	7	7	0.1	0.1	0.1	0.2	0.2
Dazzling headlights	50	27	13	6	12	0.1	0.1	0.2	0.2	0.3
Dazzling sun	202	198	59	58	86	0.5	0.8	1.0	1.6	2.2
Rain, sleet, snow or fog	336	248	73	56	43	0.8	1.0	1.2	1.6	1.1
Spray from other vehicles	39	25	15	3	2	0.1	0.1	0.3	0.1	0.1
Visor or windscreen dirty or scratched	31	14	4	4	3	0.1	0.1	0.1	0.1	0.1
Vehicle blind spot	82	107	21	19	15	0.2	0.4	0.4	0.5	0.4
	43450	24428	5901	3542	3952	100	100	100	100	100

Appendix B

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F.A.O. Michael Gormley

School of Psychology Research Ethics Committee

24 April 2009

Dear Michael,

I am pleased to inform you that your application entitled "Driving stimulator study on risk perception" has been approved by the School of Psychology Research Ethics Committee.

Yours sincerely,

K Thomas

Kevin Thomas, PhD
Chair,
School of Psychology Ethics Committee

Figure B-1: Ethics approval for Study 2 from Trinity College Dublin.

Table B-1: Driver experience questionnaire used in Study 2 and 3.

Risk Perception Simulator Study

To be completed by TRL

Participant Number: ________________	Date: ___/___/_____

SECTION A

Note:

- All information on this form is confidential.
- It will be stored securely at TRL.
- The data gathered will not be used for any other projects at TRL.
- No individuals will be identifiable in subsequent reporting on the data.

A1. Name:

A2. Please state your age in years:

A3. Please state your sex (tick):

☐1 Male	☐2 Female

A4. Please state the year when you obtained your full car driving licence:

A5.	Do you hold any other licence (tick)?
	☐1 No ☐2 Yes.
	If yes, please state: ______________________
A6.	**Since taking your test, have you participated in any driver training interventions (e.g. provided by Rospa or IAM)?**
	☐1 No ☐2 Yes.
	If yes, please state: ______________________
A7.	**Please state your estimated weekly mileage in miles (including commuting and driving for work):**
A8.	**Do you have regular access to a car?**
	☐1 No ☐2 Yes
A9.	**What percentage (%) of your annual mileage do you drive on each of the following? (The 3 numbers should add up to 100%)**
	Motorways ______________ %
	Roads in built-up areas ______________ %
	Roads in non-built-up areas ______________ %
	Total **100%**

A10. Please select your four most frequent journey purposes from the following options (insert number 1 (most frequent) to 4 (least frequent))	
___	Commuting to and from work
___	Driving at work
___	Visiting friends/ family
___	Shopping
___	Medical appointments
___	Leisure activities
___	Other (please state):________________________

A11. Over the last 12 months have you been prosecuted for speeding?
☐1 No ☐2 Yes.
If yes, please state how many times: ________________________

A12. How many points do you currently carry on your driving licence?

A13. How many accidents have you been involved in over the last 12 months? Please write the numbers in the appropriate boxes. If none, enter "0".		
	Active crashes (i.e. you hit another road user or obstacle)	Passive crashes (i.e. you were hit by another road user)
Damage only		

Minor injury (e.g. cuts and bruises)		
Serious or fatal injury (e.g. fractures, internal bleeding)		

A14. On a scale of 1 to 7 where 1 is "Not at all difficult" and 7 is "Very difficult", compared to driving in good weather with clear traffic how difficult do you find driving the following? (Circle)

Driving in the dark

1 2 3 4 5 6 7

Not at all difficult Neither nor Very difficult

Driving in bad weather

1 2 3 4 5 6 7

Not at all difficult Neither nor Very difficult

Driving in heavy traffic

1 2 3 4 5 6 7

Not at all difficult Neither nor Very difficult

Driving long distances

1 2 3 4 5 6 7

Not at all difficult Neither nor Very difficult

A15. On a scale from 1 to 7, where 1 is "Not at all skilful" and 7 is "very skilful" how skilful a driver do you think you are? (Circle)	
1 2 3 4 5 6 7 Not at all skilful Neither nor Very skilful	
A16. On a scale from 1 to 10, where 1 is "not at all cautious" and 10 is "very cautious" how cautious a driver do you think you are? (Circle)	
1 2 3 4 5 6 7 Not at all cautious Neither nor Very cautious	
A17. On a scale from 1 to 7, where 1 is "not at all confident" and 10 is "very confident" how confident a driver do you think you are? (Circle)	
1 2 3 4 5 6 7 Not at all confident Neither nor Very confident	
A18. Do you wear glasses?	
☐1 No	☐2 Yes

Table B-2: Rating sheet with questions asked at the end of each drive in the first part of the simulator study.

Post-drive rating sheet for the simulator study on risk perception						
At what speed do you think you have just been driving?						
How difficult did you find it to drive on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all difficult						Extremely difficult
How nervous were you driving on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all nervous						Extremely nervous
How stressful did you find it to drive on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all stressful						Extremely stressful
How risky did it feel to drive on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all risky						Extremely risky

How enjoyable did you find driving on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all enjoyable						Extremely enjoyable
How dangerous did you find driving on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all dangerous						Extremely dangerous
How much effort did you have to expend to drive on this section of the road at this speed?						
1	2	3	4	5	6	7
Not at all effortful						Extremely effortful
If you drove on this section of the road at this speed a hundred times, how often do you think you would have a crash?						

Table B-3: Means and standard deviations for risk ratings, difficulty ratings and collision likelihood ratings on urban roads and the dual carriageway.

		Urban			Dual carriageway		
Feeling of risk	**age category**	***M***	***SD***	***N***	***M***	***SD***	***N***
slow speed, no ambient risk	18-25	1.25	0.71	8	1.50	0.53	8
	35-45	1.82	0.87	11	1.18	0.40	11
	65+	2.18	2.40	11	1.64	1.57	11
slow speed, ambient risk	18-25	1.50	0.76	8	2.25	1.16	8
	35-45	1.73	1.01	11	1.27	0.47	11
	65+	2.09	2.43	11	1.55	1.29	11
average speed, no ambient risk	18-25	2.38	0.52	8	2.00	1.07	8
	35-45	2.36	1.57	11	1.55	0.82	11
	65+	3.73	1.90	11	1.64	1.21	11
average speed, ambient risk	18-25	2.00	0.93	8	2.75	1.28	8
	35-45	2.91	1.64	11	2.55	1.21	11
	65+	4.00	2.00	11	2.55	1.51	11
high speed, no ambient risk	18-25	4.38	1.51	8	3.75	1.28	8
	35-45	4.82	1.25	11	3.09	1.30	11
	65+	5.64	1.80	11	2.73	1.95	11
high speed, ambient risk	18-25	4.88	1.13	8	4.63	2.07	8
	35-45	4.73	1.42	11	3.27	1.56	11
	65+	6.18	1.25	11	4.09	2.21	11

Table cont.		**Urban**			**Dual carriageway**		
Task difficulty	**age category**	***M***	***SD***	***N***	***M***	***SD***	***N***
slow speed, no ambient risk	18-25	1.00	0.00	8	1.63	0.74	8
	35-45	1.27	0.65	11	1.18	0.40	11
	65+	1.91	1.64	11	1.27	0.65	11
slow speed, ambient risk	18-25	1.00	0.00	8	1.75	0.89	8
	35-45	1.36	0.67	11	1.27	0.47	11
	65+	2.09	1.97	11	1.73	1.19	11
average speed, no ambient risk	18-25	1.75	0.46	8	1.75	0.89	8
	35-45	2.00	1.26	11	1.36	0.67	11
	65+	2.91	2.07	11	1.18	0.60	11
average speed, ambient risk	18-25	2.13	1.13	8	2.25	1.28	8
	35-45	2.64	1.69	11	1.82	1.08	11
	65+	3.09	1.92	11	2.36	1.29	11
high speed, no ambient risk	18-25	3.38	1.85	8	3.38	1.69	8
	35-45	4.00	1.67	11	2.00	0.77	11
	65+	4.91	2.02	11	2.55	1.51	11
high speed, ambient risk	18-25	4.00	1.31	8	3.75	1.91	8
	35-45	4.09	1.38	11	2.64	1.12	11
	65+	5.36	1.80	11	3.45	1.92	11

Table cont.		**Urban**			**Dual carriageway**		
Collision likelihood	**age category**	***M***	***SD***	***N***	***M***	***SD***	***N***
slow speed, no ambient risk	18-25	0.63	1.06	8	0.88	1.73	8
	35-45	1.82	3.25	11	0.55	1.81	11
	65+	1.00	3.00	11	0.09	0.30	11
slow speed, ambient risk	18-25	0.75	1.04	8	2.38	5.15	8
	35-45	1.09	2.02	11	0.73	1.85	11
	65+	1.00	3.00	11	0.36	0.92	11
average speed, no ambient risk	18-25	1.63	3.42	8	1.63	3.46	8
	35-45	1.27	2.41	11	1.45	4.18	11
	65+	13.64	19.97	11	0.00	0.00	11
average speed, ambient risk	18-25	2.13	3.27	8	2.75	5.06	8
	35-45	2.64	5.89	11	2.00	4.38	11
	65+	11.45	18.22	11	0.73	1.56	11
high speed, no ambient risk	18-25	7.50	8.47	8	2.63	4.31	8
	35-45	7.00	8.31	11	3.27	8.25	11
	65+	20.73	25.91	11	2.45	3.83	11
high speed, ambient risk	18-25	6.38	6.70	8	5.50	8.40	8
	35-45	8.00	9.62	11	4.00	8.79	11
	65+	28.45	33.93	11	2.55	3.27	11

Appendix C

COLÁISTE NA TRÍONÓIDE, BAILE ÁTHA CLIATH | TRINITY COLLEGE DUBLIN
Ollscoil Átha Cliath | The University of Dublin

24th July 2012

F.A.O. Britta Lang

School of Psychology Research Ethics Committee

Dear Britta,

I am pleased to inform you that your application entitled "Risk perception – differences in its subjective and physiological correlates as a function of age" has been approved by the School of Psychology Research Ethics Committee.

It is not routine policy of the Committee to issue duplicate or replacement letters confirming ethical approval. It is therefore the responsibility of the applicant to keep the approval letter safe.

Yours sincerely,

Dr. Tim Trimble
Chair
School of Psychology Research Ethics Committee

SCHOOL OF PSYCHOLOGY
Aras an Phairsaigh
Trinity College
Dublin 2

Scoil na Síceolaíochta,
Dámh na nEolaíochtaí Sóisialta agus Daonna,
Áras an Phiarsaigh, Coláiste na Tríonóide,
Baile Átha Cliath 2, Éire

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Figure C-1: Ethics approval for Study 3 from Trinity College Dublin.

Table C-1: Situation pair ratings by two independent observers (S=speed, C=static clutter, ORU+ other road users).

		Observer 1				Observer 2			
	Situation	S	C	ORU	Total score	S	C	ORU	Total score
1a	Turn left onto a major road at a junction high	2	3	3	8	2	3	3	8
1b	Turn left onto a major road at a junction low	2	2	1	5	2	1	1	4
2a	Turn right at roundabout high	1	3	3	7	2	2	3	7
2b	Turn right at roundabout low	2	2	2	6	2	1	1	4
3a	Turn right at junction high	2	3	3	8	1	3	3	7
3b	Turn right at junction low	2	2	2	6	2	1	2	5
4a	Drive straight across roundabout high	2	3	2	7	1	3	3	7
4b	Drive straight across roundabout low	2	2	3	7	2	3	3	8
5a	Follow a vehicle high	2	3	3	8	3	2	2	7
5b	Follow a vehicle low	2	1	1	4	2	1	1	4
6a	Overtake high	3	2	2	7	3	1	2	6
6b	Overtake low	2	1	2	5	2	2	1	5
7a	Pedestrians crossing the road high	2	3	3	8	2	3	3	8
7b	Pedestrians crossing the road low	1	1	1	3	1	2	1	4
8a	Negotiate a bend in the road high	2	2	2	6	2	2	2	6
8b	Negotiate a bend in the road low	1	2	1	4	1	2	1	4

Table C-1: Example of completed rating recording spreadsheet.

Participant Number: ED-02 Participants name: ____ Date: 11/5/12 Time: 11:20

		Marker on	Marker off	Time			
	Baseline at rest	11:21:55	11:22:25				
	Baseline during loud noise	11:22:50	11:23:26				
	Video clip name			**Difficulty**	**Riskiness**	**Crash risk**	**Comments**
1	120323_MRAB_Turn_right_HW	11:25:09	11:25:41	1	3	0	
2	120426_Straight_across_RAB_with_road_works_middle.mp4	26:22	27:02	3	2	1	
3	120319_Turn_left_tjunction_High_Workload_test.mp4	27:42	28:09	2	2	1	
4	120426_Turn_right_at_a_tjunction_middle.mp4	28:39	29:05	1	1	0	
5	120323_TJ_turn_right_HW	29:35	29:59	4	5	1	
6	120426_Negotiating_a_left_bend (HW)	30:29	30:51	2	2	0	
7	120426_Vehicle_in_front_braking_to_turn_right	31:21	31:42	2	2	1	
8	120320_Haz_turn_car	32:12	32:35	4	4	2	
9	120320_Car_Follow_LW_2	33:04	33:19	2	3	1	
10	120427_Turn_right_RAB_LW.mp4	33:49	34:10	3	4	2	
11	120323_Overtake_cyc_LW.mp4	34:40	34:55	4	5	4	
12	120323_RAB_striaght_HW.mp4	35:24	35:45	3	4	2	
13	120426_Ped_crossing (LW)	36:14	36:36	2	3	1	
14	120416_Driving_past_bus	37:06	37:29	3	4	3	
15	120426_Overtaking (HW)	37:58	38:14	3	5	3	
16	120426_Turn_left_onto_a_major_road	38:43	38:56	1	2	0	
17	120320_Follow_Car_HW	39:26	39:46	2	3	1	
18	120323_Past_school_HW3.mp4 (pedestrians crossing road)	40:16	40:36	3	6	4	
19	120320_Turn_right_RAB_HW.mp4	41:06	41:27	5	4	3	
20	120320_Bend (LW)	41:57	42:16	2	3	1	
21	120426_Turn_right_at_mini_RAB_middle.mp4	42:46	43:16	2	4	2	
22	120323_MC_overtake_Haz	43:46	44:02	1	1	0	

Table C-2: Means and standard deviations for ratings of difficulty, feeling of risk and collision likelihood for all 34 participants.

Difficulty ratings								
			n	*m*	*SD*	*t*	*Df*	*p*
A	Turn left at junction	H	34	1.91	0.97	2.23	33	0.03
		L	34	1.41	0.89			
B	Turn right at roundabout	H	34	2.38	1.35	2.69	33	0.01
		L	34	1.56	1.13			
C	Turn right at junction	H	34	1.79	1.04	3.03	33	0.005
		L	34	1.21	0.54			
D	Straight across roundabout	H	34	2.94	1.71	4.71	33	>0.001
		L	34	1.74	1.12			
E	Follow car	H	34	1.88	1.09	1.43	33	0.16
		L	34	1.56	1.19			
F	Overtake	H	34	2.68	1.48	3.56	33	0.001
		L	34	1.71	1.03			
G	Pedestrian crossing	H	34	2.41	1.50	3.83	33	0.001
		L	34	1.47	0.86			
H	Negotiate bend in road	H	34	1.44	0.86	1.09	33	0.28
		L	34	1.29	0.58			
H1	Car turning in front		34	1.79	1.04			
H2	Driving past bus		34	1.87	1.08			
H3	Motorcycle overtaking		34	1.82	1.06			
H4	Vehicle in front braking to turn		31	1.45	0.89			

Table cont.								
Risk ratings			*n*	*m*	*SD*	*t*	*df*	*p*
A	Turn left at junction	H	34	2.63	1.40	3.28	33	0.002
		L	34	1.76	1.23			
B	Turn right at roundabout	H	34	2.57	1.61	1.93	33	0.062
		L	34	1.85	1.33			
C	Turn right at junction	H	34	2.56	1.44	4.93	33	>0.001
		L	34	1.25	0.61			
D	Straight across roundabout	H	34	3.76	1.83	5.26	33	>0.001
		L	34	2.32	1.45			
E	Follow car	H	34	2.26	1.56	1.54	33	0.13
		L	34	1.85	1.67			
F	Overtake	H	34	3.68	1.72	4.66	33	>0.001
		L	34	2.34	1.38			
G	Pedestrian crossing	H	34	2.71	1.45	4.96	33	>0.001
		L	34	1.74	0.90			
H	Negotiate bend in road	H	34	1.76	1.30	1.89	33	0.067
		L	34	1.47	0.71			
H1	Car turning in front		34	2.41	1.56			
H2	Driving past bus		34	2.38	1.44			
H3	Motorcycle overtaking		34	2.50	1.46			
H4	Vehicle in front braking to turn		31	1.84	1.32			

Table cont.								
Collision ratings			*n*	*m*	*SD*			
A	Turn left at junction	H	34	0.88	3.51			
		L	34	0.47	1.21			
B	Turn right at roundabout	H	34	1.47	4.49			
		L	34	1.32	3.90			
C	Turn right at junction	H	34	1.03	2.73			
		L	34	0.12	0.33			
D	Straight across roundabout	H	34	4.75	10.36			
		L	34	1.12	2.90			
E	Follow car	H	34	1.29	4.32			
		L	34	0.44	1.11			
F	Overtake	H	34	2.53	3.74			
		L	34	0.68	1.27			
G	Pedestrian crossing	H	34	1.56	3.50			
		L	34	0.26	0.99			
H	Negotiate bend in road	H	34	0.15	0.44			
		L	34	0.32	1.04			
H1	Car turning in front		34	1.66	4.56			
H2	Driving past bus		34	0.97	2.77			
H3	Motorcycle overtaking		34	1.91	6.84			
H4	Vehicle in front braking to turn		32	0.56	1.63			

Table C-3: Means and standard deviations for ratings of difficulty, feeling of risk and collision likelihood, differentiated by age.

Difficulty ratings											
				21-25			**40-55**			**65+**	
			n	*m*	*SD*	*n*	*m*	*SD*	*n*	*m*	*SD*
A	Turn left at junction	H	7	1.71	0.76	12	1.42	0.67	15	2.40	1.06
		L	7	1.00	0.00	12	1.33	0.65	15	1.67	1.18
B	Turn right at roundabout	H	7	2.29	1.11	12	2.08	1.38	15	2.67	1.45
		L	7	1.00	0.00	12	1.25	0.62	15	2.07	1.49
C	Turn right at junction	H	7	1.71	0.76	12	1.75	1.22	15	1.87	1.06
		L	7	1.00	0.00	12	1.33	0.65	15	1.20	0.56
D	Straight across roundabout	H	7	2.00	1.16	12	3.17	1.70	15	3.20	1.86
		L	7	1.43	0.54	12	1.33	0.65	15	2.20	1.47
E	Follow car	H	7	1.43	0.54	12	1.50	1.00	15	2.40	1.18
		L	7	1.00	0.00	12	1.50	0.80	15	1.87	1.60
F	Overtake	H	7	2.36	1.18	12	2.42	1.38	15	3.03	1.67
		L	7	1.43	0.54	12	1.58	1.17	15	1.93	1.10
G	Pedestrian crossing	H	7	2.43	1.27	12	1.42	0.52	15	3.20	1.70
		L	7	1.29	0.49	12	1.17	0.39	15	1.80	1.15
H	Negotiate bend in road	H	7	1.14	0.38	12	1.50	1.00	15	1.53	0.92
		L	7	1.00	0.00		1.25	0.45	15	1.47	0.74
H1	Car turning in front		7	1.43	0.54	12	1.42	0.67	15	2.27	1.28
H2	Driving past bus		7	1.71	0.76	12	1.33	0.49	15	2.37	1.34
H3	Motorcycle overtaking		7	1.57	0.79	12	2.00	1.13	15	1.80	1.15
H4	Vehicle in front braking to turn		5	1.20	0.45	12	1.18	0.41	15	1.73	1.16

Table cont. Risk ratings											
			21-25			**40-55**			**65+**		
			n	***m***	***SD***	***n***	***m***	***SD***	***n***	***m***	***SD***
A	Turn left at junction	H	7	1.57	0.79	12	2.46	1.34	15	3.27	1.39
		L	7	1.00	0.00	12	1.92	1.08	15	2.00	1.51
B	Turn right at roundabout	H	7	2.86	1.77	12	2.13	1.60	15	2.80	1.57
		L	7	1.43	0.54	12	1.50	0.80	15	2.33	1.76
C	Turn right at junction	H	7	1.71	0.76	12	2.67	1.371	15	2.87	1.64
		L	7	1.00	0.00	12	1.46	0.78	15	1.20	.56
D	Straight across roundabout	H	7	2.57	0.98	12	4.17	1.95	15	4.00	1.89
		L	7	1.86	0.90	12	1.67	0.78	15	3.07	1.75
E	Follow car	H	7	1.14	0.38	12	1.83	1.59	15	3.13	1.46
		L	7	1.00	0.00	12	1.92	1.51	15	2.20	2.08
F	Overtake	H	7	3.29	1.38	12	3.17	1.64	15	4.27	1.83
		L	7	2.29	0.95	12	2.13	0.96	15	2.53	1.81
G	Pedestrian crossing	H	7	2.57	1.13	12	2.08	1.00	15	3.27	1.71
		L	7	1.57	0.79	12	1.67	0.78	15	1.87	1.06
H	Negotiate bend in road	H	7	1.00	0.00	12	1.67	1.16	15	2.20	1.57
		L	7	1.14	0.38	12	1.33	0.49	15	1.73	0.88
H1	Car turning in front		7	1.43	0.79	12	2.33	1.16	15	2.93	1.91
H2	Driving past bus		7	2.00	0.82	12	1.83	0.94	15	3.00	1.77
H3	Motorcycle overtaking		7	2.00	0.58	12	2.58	1.38	15	2.67	1.80
H4	Vehicle in front braking to turn		5	1.40	0.55	12	1.64	0.67	15	2.13	1.767

Table cont. **Collision ratings**											
			21-25			**40-55**			**65+**		
			n	***m***	***SD***	***n***	***m***	***SD***	***n***	***m***	***SD***
A	Turn left at junction	H	7	0.29	0.49	12	0.29	0.49	15	1.80	5.21
		L	7	0.00	0.00	12	0.00	0.00	15	0.40	1.06
B	Turn right at roundabout	H	7	1.29	2.56	12	1.29	2.56	15	0.67	1.80
		L	7	0.43	0.79	12	0.43	0.79	15	2.53	5.69
C	Turn right at junction	H	7	0.00	0.00	12	0.00	0.00	15	1.33	3.81
		L	7	0.00	0.00	12	0.00	0.00	15	0.13	0.35
D	Straight across roundabout	H	7	1.00	0.82	12	1.00	0.82	15	3.83	6.63
		L	7	0.71	1.25	12	0.71	1.25	15	2.00	4.18
E	Follow car	H	7	0.14	0.38	12	0.14	0.38	15	0.93	1.44
		L	7	0.00	0.00	12	0.00	0.00	15	0.47	1.25
F	Overtake	H	7	3.29	5.47	12	3.29	5.47	15	2.40	2.87
		L	7	0.43	1.13	12	0.43	1.13	15	0.87	1.55
G	Pedestrian crossing	H	7	1.29	2.36	12	1.29	2.36	15	2.53	4.78
		L	7	0.00	0.00	12	0.00	0.00	15	0.60	1.45
H	Negotiate bend in road	H	7	0.00	0.00	12	0.00	0.00	15	0.27	0.59
		L	7	0.00	0.00	12	0.00	0.00	15	0.67	1.50
H1	Car turning in front		7	0.43	0.54	12	0.43	0.54	15	3.00	6.68
H2	Driving past bus		7	0.29	0.49	12	0.29	0.49	15	1.67	4.08
H3	Motorcycle overtaking		7	0.29	0.76	12	0.29	0.76	15	0.67	0.90
H4	Vehicle in front braking to turn		5	0.00	0.00	12	0.00	0.00	15	0.80	2.01

Table C-4: Means and standard deviations for SCL change, HR change and HRV, differentiated by age.

SCL change											
				21-25			**40-55**			**65+**	
			n	***m***	***SD***	***n***	***m***	***SD***	***n***	***m***	***SD***
A	Turn left at junction	H	6	0.22	0.26	12	0.18	0.12	5	0.16	0.15
		L	6	0.66	0.58	12	0.29	0.19	5	0.59	0.63
B	Turn right at roundabout	H	6	0.52	0.69	12	0.50	0.36	5	-0.04	0.42
		L	6	0.54	0.43	12	0.16	0.39	5	0.48	0.39
C	Turn right at junction	H	6	0.34	0.33	12	0.23	0.19	5	0.26	0.21
		L	6	0.23	0.38	12	0.20	0.18	5	0.21	0.19
D	Straight across roundabout	H	6	0.35	0.24	12	0.24	0.20	5	0.29	0.46
		L	6	0.63	0.41	12	0.32	0.23	5	0.48	0.38
E	Follow car	H	6	0.59	0.56	12	0.27	0.17	5	0.24	0.43
		L	6	0.57	0.38	12	0.27	0.19	5	0.50	0.48
F	Overtake	H	6	0.48	0.65	12	0.33	0.20	5	0.35	0.30
		L	6	0.60	0.46	12	0.28	0.21	5	0.46	0.39
G	Pedestrian crossing	H	6	0.56	0.61	12	0.23	0.16	5	0.24	0.41
		L	6	0.55	0.48	12	0.29	0.17	5	0.51	0.40
H	Negotiate bend in road	H	6	0.51	0.68	12	0.27	0.19	5	0.31	0.30
		L	6	0.33	0.33	12	0.24	0.18	5	0.29	0.19
H1	Car turning in front		6	0.53	0.44	12	0.25	0.20	5	0.27	0.21
H2	Driving past bus		6	0.40	0.51	12	0.26	0.16	5	0.35	0.27
H3	Motorcycle overtaking		6	0.49	0.50	12	0.30	0.19	5	0.32	0.31
H4	Vehicle in front braking to turn		6	0.50	0.35	12	0.27	0.21	5	0.24	0.23

Table cont. **HR change**											
			n	***m***	***SD***	***n***	***m***	***SD***	***n***	***m***	***SD***
A	Turn left at junction	H	6	2.16	2.22	12	2.39	4.15	6	4.27	5.12
		L	6	3.65	6.16	12	2.51	4.77	6	2.78	8.85
B	Turn right at roundabout	H	6	4.08	4.49	12	4.37	6.54	6	1.44	4.83
		L	6	3.94	4.72	12	3.31	5.50	6	1.68	5.82
C	Turn right at junction	H	6	5.34	4.59	12	2.35	4.19	6	6.24	6.67
		L	6	5.22	5.98	12	3.68	4.88	6	4.71	6.39
D	Straight across roundabout	H	6	4.93	5.58	12	3.59	4.40	6	3.95	9.05
		L	6	4.60	7.81	12	3.45	5.39	6	2.39	6.21
E	Follow car	H	6	4.33	6.52	12	2.68	5.25	6	3.09	6.21
		L	6	4.16	5.27	12	2.58	4.02	6	5.46	8.94
F	Overtake	H	6	3.91	6.13	12	3.32	4.82	6	1.78	5.25
		L	6	4.70	6.32	12	3.45	3.83	6	2.22	7.44
G	Pedestrian crossing	H	6	3.68	6.34	12	2.05	5.55	6	3.57	5.19
		L	6	2.66	5.14	12	2.86	5.53	6	3.71	9.90
H	Negotiate bend in road	H	6	3.91	4.28	12	3.76	3.29	6	5.76	5.55
		L	6	2.55	5.72	12	3.36	4.94	6	2.88	4.69
H1	Car turning in front		6	4.26	5.34	12	3.22	4.73	6	-1.88	14.24
H2	Driving past bus		6	4.31	5.99	12	2.31	11.07	6	0.16	11.09
H3	Motorcycle overtaking		6	3.31	9.17	12	4.80	6.83	6	6.77	8.61
H4	Vehicle in front braking to turn		6	5.85	6.03	12	3.87	4.46	6	-2.79	20.07

Table cont. **HRV change**											
			n	***m***	***SD***	***n***	***m***	***SD***	***n***	***m***	***SD***
A	Turn left at junction	H	6	3.53	2.15	12	2.48	1.23	6	2.12	1.71
		L	6	4.67	4.06	12	2.13	1.40	6	2.77	2.15
B	Turn right at roundabout	H	6	3.29	1.97	12	2.87	2.28	6	2.52	1.50
		L	6	4.79	2.97	12	2.25	1.52	6	2.01	0.91
C	Turn right at junction	H	6	4.89	3.70	12	3.10	2.26	6	2.30	0.88
		L	6	3.47	1.97	12	2.08	0.84	6	2.24	0.94
D	Straight across roundabout	H	6	4.69	3.84	12	2.68	1.27	6	2.28	1.24
		L	6	3.96	3.10	12	2.43	1.52	6	2.10	0.58
E	Follow car	H	6	3.71	2.33	12	3.36	2.63	6	3.95	4.77
		L	6	3.71	2.34	12	2.60	1.48	6	3.85	2.73
F	Overtake	H	6	3.27	2.01	12	2.37	1.23	6	1.48	0.47
		L	6	2.16	0.67	12	2.36	2.42	6	3.64	1.90
G	Pedestrian crossing	H	6	3.46	2.01	12	2.78	2.24	6	2.64	1.56
		L	6	3.12	2.33	12	2.75	1.69	6	3.62	3.00
H	Negotiate bend in road	H	6	3.45	2.88	12	2.80	1.86	6	1.80	0.81
		L	6	3.21	2.30	12	2.97	1.81	6	3.43	2.59
H1	Car turning in front		6	2.86	1.22	12	1.72	0.85	6	2.40	2.05
H2	Driving past bus		6	3.21	2.24	12	2.78	2.40	6	4.45	4.16
H3	Motorcycle overtaking		6	3.43	2.17	12	3.66	2.89	6	2.65	1.86
H4	Vehicle in front braking to turn		6	3.44	1.97	12	3.48	3.15	6	2.53	1.07