



MONASH University
Accident Research Centre

**THE EFFECT OF COGNITIVE
IMPAIRMENT ON OLDER
PEDESTRIAN BEHAVIOUR
AND CRASH RISK**

by

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The effect of cognitive impairment on older pedestrian behaviour and crash risk

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Abstract:

Pedestrians are an extremely vulnerable road user group and make up approximately 15 percent of all road fatalities and 12 percent of all serious injuries. A large proportion of pedestrian deaths and serious injuries involve older adults, who are more vulnerable because of age-related frailty. Given that many crashes involving older road users occur in complex situations, it is suggested that age-associated cognitive and functional limitations may play some role in crash causation. While most research on older road users has focussed on identifying those who may be at increased risk, there is a lack of knowledge with regard to the effect of functional impairment, particularly the types and levels of cognitive impairment, on performance and crash risk of older pedestrians.

This report assesses the current state of knowledge in regard to the key issues affecting older pedestrian safety, particularly the effect of cognitive impairment on behaviour and crash risk. A distinction is made between normal age-related cognitive decline and cognitive impairment associated with medical conditions. The association between normal age-related cognitive decline and pedestrian performance and crash risk seems to be fairly moderate. In contrast, more substantial evidence was found of an effect of medical conditions that result in cognitive impairment on pedestrian performance and crash risk. This was particularly so for impairments associated with moderate to severe dementia, moderate to severe Parkinson's Disease, cerebrovascular disease (particularly stroke), and multiple sclerosis.

The review highlighted the need for better knowledge with regard to the effect and extent of cognitive decline and impairment on pedestrian safety and provides a number of recommendations for research priorities. While there are obvious benefits of walking for health and well-being of individuals and the environment, and pedestrian travel is a major mode of transport, older adults are at increased risk of death and serious injury as pedestrians. Unless there is a good understanding of how cognitive decline and impairment contributes to crash risk of older pedestrians and development of appropriate countermeasures, the problems and risks associated with pedestrian travel will worsen in the coming decades.

Key Words:

Pedestrian, Safety, Older Road Users, Behaviour, Functional Perform, Medical Conditions, Cognitive Impairment, Crash Risk

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EXECUTIVE SUMMARY

Crashes involving pedestrians are serious in nature and are a significant road safety problem world-wide. Many of these crashes involve older adults, who are more vulnerable because of age-related frailty. While there is little doubt that the majority of older pedestrians use the road-transport system without injurious consequences, many still experience many problems using the road-transport system. Given that crashes involving older road users often occur in complex situations, it is suggested that age-associated cognitive functional limitations may play some role in crash causation. While much research on older road users has focussed on identifying those who may be at increased risk, there is a lack of knowledge with regard to the effect of functional impairment, particularly the types and levels of cognitive impairment, on pedestrian performance and crash risk of older adults.

This review assessed the current state of knowledge in regard to the key issues affecting older pedestrian safety, particularly the effect of cognitive impairment on behaviour and crash risk, and provides some recommendations for further work to understand this relationship better.

During the course of the literature search, the distinction between normal age-related cognitive decline and cognitive impairment associated with medical conditions emerged as a key issue and these are discussed separately in the review. It is noted throughout this review that very few studies are directly related to pedestrian performance or crash risk. The conclusions drawn from this review are from a combination of evidence of an effect of cognitive impairment on driving ability, ability to perform activities of daily living, particularly walking (these are intuitively related to crossing roads in a safe manner) and the few studies directly related to pedestrian behaviour.

With regard to the effect of normal age-related cognitive decline on pedestrian performance and crash risk, the association seems to be fairly moderate. The outcome of the review is summarised as follows:

Issue	No. studies	Outcome
Age differences in road-crossing behaviour	6	No direct evidence of the effect of cognitive decline on pedestrian performance
Effect of cognitive decline on road-crossing decisions	5	Some evidence of the effect of multiple cognitive declines on ability to select safe gaps
Effect of cognitive decline on pedestrian crash risk	0	No evidence
Effect of cognitive decline on driving ability and crash risk	5	Moderate associations found
Effect of cognitive decline on walking ability	3	Moderate associations found

The evidence suggests the following:

- Most people experience some level of cognitive and executive function decline as they age, and functional limitations are most prevalent towards the end of normal life.
- Normal age-related declines in single cognitive and executive functions appear to have little effect on performance in less demanding traffic situations.
- Declines in multiple relevant cognitive and executive functions appear to have some effect on performance in demanding traffic situations. The most relevant declines for road-crossing performance include: slowed information processing, declines in attentional processes, memory problems, difficulty in selecting and integrating information, poor decision-making and slowed response initiation.
- Most older adults have the capacity to compensate for declines in cognitive and executive functions, although the ability to compensate may be inadequate where there are multiple declines in several cognitive and executive functions, especially amongst those approaching the end of their lives.
- Adoption of compensation strategies rely on insight or awareness of abilities. This insight may be affected where there are multiple declines in several cognitive and executive functions.

With regard to the effects of medical conditions that result in cognitive impairment, very few studies addressed pedestrian risk and few conclusions can be drawn. More substantial evidence of cognitive impairment associated with medical conditions on driving ability and ability to perform activities of daily living related to walking was found. The outcome of the review is summarised as follows:

Issue	No. studies	Outcome
Effect of cognitive impairment associated with dementia and pedestrian crash risk	1	High proportion of fatally injured pedestrians with neurodegenerative change
Effect of medical conditions on driving ability and crash risk	24	Moderate to strong associations found
Dementia	5	
Parkinson's disease	8	
Cerebrovascular disease	8	
Multiple Sclerosis	3	
Effect medical conditions on walking ability	10	Moderate to strong associations found
Dementia	5	
Parkinson's disease	2	
Cerebro-vascular disease	2	

The evidence suggests that:

- Cognitive and executive function impairment associated with some diseases and medical conditions are more likely to have functional implications for older pedestrian performance.
 - Cognitive and executive impairment associated with moderate to severe dementia may greatly affect pedestrian performance, as it affects attention, memory, accuracy of movement, risk perception, ability to perform novel tasks and awareness of their compromised cognitive condition, skills necessary for safe negotiation of traffic and road-crossing decisions.
 - Cognitive and executive impairment associated with mild, moderate and severe PD may greatly affect the ability to walk and interact safely in traffic, as it affects slowness of movement, gait difficulty, postural instability, planning and executing movement, attention, and memory, skills necessary for safe negotiation of traffic and road-crossing decisions.
 - Cognitive and executive impairment associated with cerebro-vascular disease may affect pedestrian performance, as attention, memory, judgement, decision-making, and gait difficulty are affected in some of these diseases, particularly stroke.
 - Cognitive and executive impairment associated with MS may affect pedestrian performance, as it can affect information processing, attention, recognition of objects, problem-solving, ability to perform novel tasks, and physical skills.

Given that these associations are somewhat speculative and predominantly based on studies that have investigated cognitive and executive functions on walking and driving abilities, related to pedestrian performance, but not focussed on road-crossing performance, recommendations are made for further research. It is essential to first understand the basic problems that older adults face as pedestrians, particularly understanding the relationships between cognitive impairment and pedestrian performance and crash risk. It is only with this knowledge that appropriate countermeasures can be developed. The following research priorities are recommended:

An understanding of the prevalence of cognitive decline and impairment amongst older people who walk. This can be achieved in the following ways:

- i) a longitudinal case/control study of crash-involved and non-crash-involved pedestrians to gain in-depth information on the effect of progressive cognitive impairment on walking and road-crossing ability. Information on changes in pedestrian activity, exposure, behaviour and travel patterns, changes in cognitive and health status and crash involvement amongst pedestrians with cognitive impairment would be collected.
- ii) an in-depth study of crash-involved seriously injured pedestrians to provide important information on road user characteristics, road user behaviour, cognitive status, health status and incidence of medical conditions, information on crashes and contributing factors, crash severity and health outcomes.
- iii) analysis of databases on fatal pedestrian crashes (e.g., analysis of the National Coroner's Information System [NCIS]) to provide information on the proportion of older pedestrians with a medical condition (e.g., a diagnosis of dementia) who have been involved in a fatal crash, the types of crashes they are involved in, and other key characteristics including medications and the presence of co-morbid conditions.

An understanding of the effect and extent of cognitive decline and impairment on pedestrian performance, particularly the specific skills and severity of impairment that affect road-crossing safety. These issues may be examined in an experimental research program designed to investigate the effects of a range of diseases and medical conditions and general impairments on the ability to make safe road-crossing decisions and identify 'high-risk' pedestrians.

An understanding of the effect of road complexity on pedestrian performance. A number of complex manoeuvres and road environments have been identified for older drivers and pedestrians, particularly in the work conducted by Oxley et al., showing that two-way traffic is problematic for older adults, however, much is still to be learned about other types of complex environments and tasks for older pedestrians. An investigation of these issues using an experimental design should be undertaken in order to understand the effect of complexity on road-crossing performance amongst pedestrians with and without cognitive impairment.

Development of countermeasures. Many countermeasures have been suggested to improve the mobility and safety of older pedestrians, however, the functional difficulties experienced by cognitively impaired pedestrians are rarely considered and the majority of countermeasures are not evaluation. There is a clear need to first identify the problems experienced by cognitively impaired pedestrians and to develop and evaluate countermeasures designed with the needs of these pedestrians in mind. In their review of measures to reduce crash and injury risk to older vulnerable road users, Oxley et al. (2004) identified world 'best-practice' solutions and initiatives that may have some effect on older pedestrian safety and suggested a comprehensive strategy that includes educational, training and awareness initiatives, improvements to vehicle design and ensuring a safe and comfortable road environment in which to walk. Improved infrastructure and road design can achieve immediate and cost-effective results and the provision of a safe road environment can markedly improve the mobility and safety of all-aged vulnerable road users. Road design improvements that may particularly benefit older pedestrians include: measures to moderate vehicle speeds in high pedestrian activity areas, measures to separate or restrict vehicular and non-vehicular traffic in high pedestrian activity areas, and measures to reduce the complexity of intersections and road lengths.

In conclusion, there are obvious benefits of walking for health and well-being of individuals and the environment and pedestrian travel is a major mode of transport. Indeed, there are many programs world-wide that actively promote increased walking and cycling. However, older pedestrians are at increased risk of death and serious injury as pedestrians. While there is evidence that functional declines and impairments contribute to increased crash risk amongst older pedestrians, there is still much to be learned, however, about the effect and extent of cognitive decline and impairment on pedestrian safety. Unless there is a good understanding of how cognitive decline and impairment contribute to crash risk of older pedestrians and development of appropriate countermeasures, the problems and risks associated with pedestrian travel will worsen in the coming decades.

THE EFFECT OF COGNITIVE IMPAIRMENT ON OLDER PEDESTRIAN BEHAVIOUR AND CRASH RISK

1 INTRODUCTION

Crashes involving pedestrians represent a major road safety problem world-wide. They are an extremely vulnerable road user group because they are largely unprotected in traffic, compared to vehicle occupants. Furthermore, because of their physical frailty, the elderly are especially vulnerable to injuries and death, compared to younger adult pedestrians.

Much of the research on older road users in the last few decades has focussed on the contributing factors to crashes and, perhaps unfairly, many have speculated that older road users themselves contribute, in part, to their crash involvement. That is, due to their diminished capabilities to cope with traffic, they precipitate their own crashes.

The recent Victorian Parliamentary Inquiry into Road Safety for Older Road Users identified a lack of knowledge with regard to the effect of functional impairment, particularly the types and levels of cognitive impairment, on pedestrian and driving performance and crash risk of older people. This resulted in the formulation of Recommendation 7, that 'VicRoads undertake research to better understand the effect on pedestrian and driving performance and crash risk of older people who have various types and levels of cognitive impairment'. Subsequently, VicRoads invited the Monash University Accident Research Centre (MUARC) to review the current state of knowledge on the effect of cognitive impairment on pedestrian behaviour and crash risk.

This review aims to identify current and emerging issues for older pedestrian safety, to present the evidence of an effect of cognitive impairment on pedestrian performance and crash/injury risk, and to identify policy and research recommendations to address pedestrian safety while meeting their transportation and mobility needs.

1.1 LITERATURE SEARCH STRATEGY

An extensive literature search was undertaken to identify relevant scientific literature on the following databases that contain records of national and international publications on relevant fields:

- PsychInfo,
- PubMed,
- The Cochrane Library,
- Australian Transport Index (ATRI),
- Transport Research Information Services (TRIS) database,
- International Transport Research Documentation (ITRD) database, and
- MUARC publications.

Search terms included cognitive impairment, executive impairment, crash risk, pedestrian, driver, dementia, and physical activity. All abstracts were read and selected for relevance

and research strength. As a general rule, only publications from 1990 onwards were selected for the review. This criterion was waived, however, where articles appeared to have exceptional worth and where the findings and content remain relevant.

The search strategy yielded in excess of 200 references, the majority of which were research papers in scientific journals, review papers, editorials and other brief notes of commentaries in scientific journals, as well as textbooks, reports and websites of reputable organisations.

During the course of the literature search, the role of executive functions (including planning and error monitoring) emerged as an important variable, strongly associated with task performance. Given its importance in the ageing research literature and the strong relationships with cognitive function and performance, the review includes a discussion of executive function impairment as well as impairments in other cognitive abilities and the impact on older pedestrian performance and safety.

The review yielded a large body of literature linking cognitive and executive functions with a range of activities of daily living; however, few were specific to pedestrian safety. For example, there was strong evidence of the effect of cognitive and executive function impairment and the risk of falling. This body of literature provides additional insight into factors that have considerable relevance to pedestrian safety. Walking in traffic can also be considered as a type of activity of daily living. It is possible, then, that pedestrian crashes are linked to a similar subset of functional abilities as those implicated in other daily living activities, particularly those involving walking and interacting in a dynamic and complex environment. Moreover, much of the research on older road users focuses on older driver performance. While driving and walking are two very different tasks, the skills required to interact in traffic may be similar, therefore papers discussing the effect of cognitive and executive function impairment on driving performance and crash risk are presented where appropriate and probable links with pedestrian performance are discussed.

1.2 THE POSITIVES OF WALKING

Prior to a discussion of crash and injury risk and contributing factors, it is important to understand the mobility needs of the elderly and discuss the importance of walking as a travel mode and the positives of physical activity.

Walking is a major mode of transport, is a component of most trips (even if it is walking to and from car-parks and shops), and is vital to the mobility of older people, not only for short trips to carry out essential daily tasks but also an important factor in maintaining social contacts and health-promoting exercise.

There is an increased awareness of the negative aspects of motorised transport and positive aspects of physical activity, and non-motorised modes of transport are becoming increasingly popular, especially for short trips. Increased walking and cycling is now actively promoted by governments and health professionals in Europe and in Australia (the ADONIS, PROMISING and WALCYNG programs supported by the European Union and 'Go For Your Life' campaign, supported by the Victorian Government).

Walking is said to provide health, fitness, exercise and enjoyment, a sense of freedom, well-being and relaxation (Forward, 1998; Hydén, Nilsson & Risser, 1998; van der Heiden & Rooijers, 1994; Wigan, 1995). There is evidence to suggest that physical activity in advancing age has major benefits for physical well-being and decreases the risk for chronic disease (e.g., diabetes and heart disease), mortality from cardiovascular disease and other associated diseases in older persons (Visser, Pluijm, Stel, Bosscher & Deeg, 2002;

Wannamethee, Shaper & Walker, 1998). Moreover, there are some reports that regular daily activities such as walking, sport participation and household activity in older age has positive effects on cognitive functioning, particularly slowing functional and mobility decline (Binder, Schechtman, Ehsani, Steger-May, Brown, Sinacore, Yarasheski & Holloszy, 2002; Clark, 1996; LaCroix, Guralnik & Berkman, 1993; Wang, van Belle, Kukull & Larson, 2002).

1.3 CRASH AND INJURY RISK

While there has been a general downward trend in pedestrian deaths in Australia and internationally, pedestrian trauma remains of great concern to road safety, constituting a substantial proportion of deaths and serious injuries. In Australia, pedestrian fatalities make up about 15 percent of all road fatalities and 12 percent of all serious injuries (ATSB, 2003). In 2004 in Victoria alone, 49 pedestrians were killed, which constituted 14 percent of all road fatalities in this State (TAC, 2005). International figures also show that pedestrian crash and injury risk is a significant road safety problem (Davies, 1999; Öström & Eriksson, 2001; NHTSA, 2001).

A large proportion of pedestrian deaths and serious injuries involve older adults. Australia reports high proportions of older pedestrian deaths and serious injuries but lower proportions of minor injury crashes, as do European countries and the USA. Öström and Eriksson (2001) reported that pedestrians aged 75 to 84 years in Sweden have a risk of death that is 14 times higher than that of younger adult pedestrian aged 35 to 44 years. The ATSB (2003) reported that 36 percent of all pedestrian fatalities in 2004 and 36 percent of all pedestrian serious injuries in 2002 were adults aged 60 years or over. Likewise, in Victoria in 2004, 36 percent of all pedestrian fatalities were adults aged 60 years or over (see Figure 1). This reflects, in part, the frailty of older adults – once involved in a crash older pedestrians are more likely to sustain fatal or serious injuries than younger pedestrians (Mitchell, 2000; Harruff, Avery & Alter-Pandya, 1998; Koepsell, McCloskey, Wolf, Vernez-Moundon, Buchner, Kraus & Patterson, 2002; NHTSA, 2001). It may also reflect an over-involvement in crashes due to other factors.

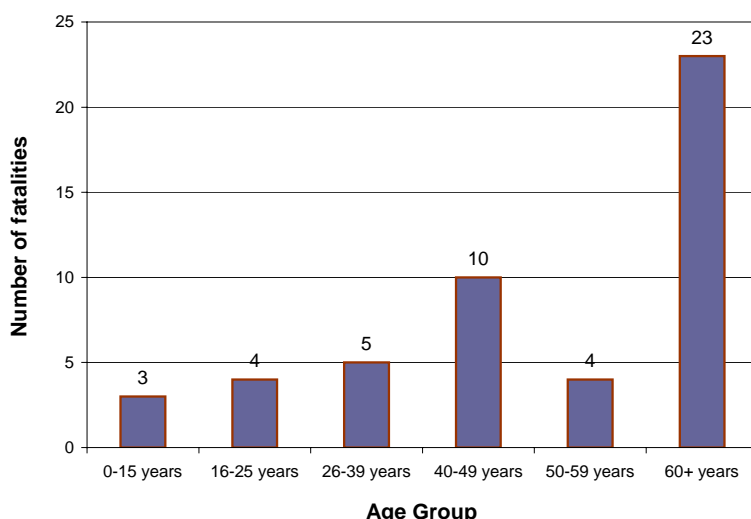


Figure 1: Number of pedestrian fatalities by age group, Victoria 2004 (Source: TAC, 2005)

These figures are raw numbers only and do not take any exposure measures into account such as population structure, number of pedestrians, and level of pedestrian activity

(distances travelled, number of trips, number of roads crossed and type of road travelled on). There are no available pedestrian activity data in Australia, however, international data shows that, using any exposure measure (either on a population or travel pattern basis), risk for older pedestrians is high compared to other age groups (Hagenzieker, 1996; Mesken & Davidse, 2001).

1.4 CRASH TYPES

Older pedestrian crashes tend to occur on a regular trip, during daylight hours, often during autumn and winter, and often close to home or at shopping centres or recreational venues where, no doubt, older people tend to spend much of their time away from home (Koepsell et al., 2002; Toivonen & Niskanen, 1998; Zegeer, Stutts, Huang, Zhou & Rodgman, 1993).

Much of the research on older pedestrian safety draws the conclusion that complex traffic situations play a major role in crash involvement (Carthy, Packham, Salter & Silcock, 1995; Fontaine & Gourlet, 1997; Hunter, Stutts, Pein & Cox, 1995; Oxley, Fildes, Ihsen, Charlton & Day, 1997; Sheppard & Pattinson, 1986). Older pedestrians, like older drivers, are over-represented in crashes at complex locations such as intersections, particularly those without traffic signals, and being struck by a turning vehicle. Harkey (1995) noted that 33 percent of older pedestrian deaths and 51 percent of older pedestrian injuries took place at intersections. No other age group of pedestrians obtained percentages as high as these. Older pedestrians are also over-represented in crashes when they are crossing mid-block sections of roads, particularly on wide multi-lane roads, in busy bi-directional traffic, when boarding or exiting public transport, as well as in crashes with reversing vehicles (Harruff et al., 1998; Jensen, 1999; Koepsell et al., 2002; Oxley et al., 1997; Zegeer et al., 1993). The CEMT (2001) added that older pedestrians are more likely to be involved in crashes within built-up areas compared to outside them and they tend to be at fault in their collisions (however, the CEMT also noted that this claim is based on police reports and may be biased in favour of the driver), and collisions are often due to their inability to handle complex traffic situations.

While pedestrian crashes involving vehicles are the dominant crash type for pedestrians and, not surprisingly, these collisions result in the most severe outcomes, older pedestrians also appear to be over-represented in non-vehicle related pedestrian collisions and sustain injuries severe enough to require emergency department treatment. Many of these occur as a result of a fall on footpaths, stepping off kerbs and falling while crossing the road (without being struck by a vehicle), and collisions in driveways, car parks and on footpaths (FHWA, 1999; Stutts & Hunter, 1999; Eck & Simpson, 1996). Although injuries resulting from pedestrian falls and other non-collision events are not as serious as those where a vehicle is involved, they nevertheless represent a significant cause of trauma for older pedestrians.

2 RISK FACTORS

The causes of older road user crashes are undoubtedly complex and poorly understood, however, it is necessary to attempt an understanding of the potential risk factors in order to develop appropriate measures to decrease risk. Several explanations have been offered to account for the over-representation of older adults in serious injury and fatal pedestrian crashes and include behavioural aspects and road/vehicle design. A detailed discussion of behavioural aspects is provided here with particular emphasis on cognitive/executive function decline and impairment. While road and vehicle design are important factors in pedestrian crash risk, they are not the focus of this review and will not be discussed here (see Oxley, Corben, Fildes, O'Hare & Rothengatter, 2004 for full descriptions of these factors). However, a brief discussion of the complexity of the road-transport system environment is presented, as this has wide implications for pedestrians with cognitive/executive function decline and impairment.

It should be noted at the outset that older road users are generally considered to be safe and cautious, and indeed, the majority of older drivers and pedestrians use the road-transport system without injurious consequences. There is evidence to suggest that older road users self-regulate their driving and walking patterns, adopting cautious behaviours, and may well do this as a result of changing skills (Charlton, Oxley, Fildes & Oxley, 2003; Eberhard, 1996; OECD, 2001; Smiley, 1999; Winter, 1988), particularly 'younger-old' adults aged in their 60's (Oxley, 2000). On the other hand, it appears that some older road users do not compensate adequately, and this may be due to accumulation of age-related losses to a point where they overwhelm the normal attempts at compensation, particularly when demands are significant or complex (Yanik & Monforton, 1991), and a reduced awareness of the impact of ageing on task performance (Elliott, Elliott & Lysaght, 1995; Holland & Rabbitt, 1992; Marottoli & Richardson, 1998).

2.1 PEDESTRIAN BEHAVIOUR AND FUNCTIONAL PERFORMANCE

Much of the literature on older road user safety has pointed to the nature of age-related performance change and has questioned how well older drivers and pedestrians interact with traffic, suggesting that, because of age-related limitations, they may precipitate their own crashes.

2.1.1 The cognitive demands of road-crossing behaviour

Safe walking and making decisions about when it is safe to cross roads in relation to available traffic gaps requires adequate functioning of a range of sensory, perceptual, cognitive, executive and physical abilities, particularly attention, perception of speed and distance, processing of sensory input, judgement, decision-making and memory. In order to cross a road safely without engineering assistance, pedestrians must, while approaching or stopping at the edge of the road, inspect the roadway in both directions and look for approaching vehicles. This part of the task involves detecting objects and motion, ascertaining the direction and velocity of moving objects, the identity of the object and estimating when the vehicle will arrive at the crossing point. This may involve judgements about vehicle distance, velocity, acceleration and deceleration. These operations rely on reasonably intact perceptual, attentional and cognitive skills. Furthermore, in many situations pedestrians must integrate and remember information about traffic in both directions and in multiple lanes as well as combine vehicle arrival times with own walking speed in order to reach a decision to cross safely. This requires focussing and re-focussing attention on the traffic in both directions, switching attention from one source of

information to another, and selecting and integrating the relevant information to arrive at a safe decision. Once a crossing has been initiated, near- and far-sides of the road have to be re-scanned to verify (or update) earlier estimates of arrival time of vehicles and adjustments to walking speed may have to be initiated. These operations require ability to process complex information rapidly. Clearly, walking, crossing roads and negotiating traffic are complex processes requiring good functioning and performance and it is likely that diminished capability in any cognitive or executive function has the potential to compromise pedestrian performance because of poor detection of oncoming vehicles and difficulty in crossing the road quickly enough to evade oncoming vehicles. These factors can lead to increased crash risk.

While there have been many attempts to find relationships between functional and health issues and performance on the road (see Janke, 1994 and Marottoli, Richardson, Stowe, Miller, Brass, Cooney and Tinetti, 1998 for reviews), research has generally failed to find unequivocal relationships between age-related declines in single functions and crash rates. Many researchers now contend that the older road user problem is mainly restricted to certain sub-groups of older people, rather than encompassing all older people. Much of the recent research, therefore, has focussed on identifying which older road users are most at risk, and it seems that simultaneous deterioration of several relevant functions and/or specific functional deficits linked to certain illnesses (especially those that lead to cognitive deterioration such as dementia) increase crash risk considerably (OECD, 2001).

A distinction needs to be made between normal age-related cognitive/executive function decline and cognitive/executive function impairment associated with medical conditions such as dementia. The 'normal' age-related decline of cognitive and executive functions generally refers to a mild deterioration in memory performance, executive functions (particularly divided and selective attention) and speed of cognitive processing, but within normal limits given an individual's age (Schaie, 1996; Salthouse, 2000). Cognitive impairment associated with diseases and/or medical conditions (such as dementia) is likely to be more severe and can be manifested in specific patterns of decline in memory, language, orientation, visuo-spatial and attentional decline.

Cognitive decline and impairment are broad terms given to a wide variety of dysfunctions which may result from a variety of potential causes. Cognitive processes include information processing, memory, decision-making verbal abstraction and intelligence. The term executive function generally refers to a grouping of high-level cognitive processes underlying everyday abilities modulate and use information from the posterior cortical sensory systems to produce behaviour with a unifying purpose of goal, in other words, the structuring of goal-directed behaviour. These include initiation or intention of action, planning, anticipation, attention, mental flexibility, problem solving and regulation and monitoring of behaviour. For people with dementia, there is thought to be a disturbance in both the functionality of the individual processes as well as a decline in overall capacity (Baddeley, 1999).

The majority of studies examining the effect of cognitive function decline and impairment on performance use well-established psychological and neuropsychological tests to assess performance (see Table 1).

Table 1: Summary of tests.

PERFORMANCE ASSESSMENT	DESCRIPTION
Mini Mental Status Examination (MMSE) (Folstein, Folstein & McHugh, 1975)	A short and widely used screening instrument for dementia and examines general levels of cognitive dysfunction. It comprises a set of general memory questions, tests of orientation, immediate and delayed recall, backward spelling, object naming, repetition of a phrase, sentence reading and comprehension, sentence writing and design copying.
Wisconsin Card Sort Test (WCST) (Grant & Berg, 1948)	The WCST assesses perseveration and abstract thinking and is considered a measure of executive function (requiring the ability to develop and maintain an appropriate problem-solving strategy across changing stimulus conditions in order to achieve a future goal). Respondents are required to sort 64 cards according to different principles during the test administration.
Dementia Rating Scale (DRS) (Mattis, 1976).	This test examines five areas of cognitive performance that are particularly sensitive to the behavioural changes that characterise dementia of the Alzheimer's type including attention, initiation and perseveration, construction, conceptualisation and memory. The scale measures severity of dementia on a continuum from normal ageing through to AD. It classifies people with dementia into 'no dementia', 'mild', 'moderate', or 'severe'.
Trail Making Tests (TMT) Parts A and B (Reitan, 1958)	Originally developed for use by the US Army, the test measures visual conceptual and visuomotor tracking, simple and complex sequencing, visual scanning and attentional functions, visuomotor co-ordination, motor speed and short-term memory. This is a well-established test of general cognitive function and has been shown to be highly sensitive to the progressive cognitive declines associated with ageing and dementia.
Verbal fluency	A component of the controlled oral word association test, verbal fluency is measured by asking subjects to name words beginning with a particular consonant or the names of animals. This assesses fluency in naming and speed of processing (thinking), as task considered to be an executive function.
Digit span	This is a test used to measure working memory and attention.
Mattis Organic Mental Syndrome Screening Examination (MOMSSE) (Mattis, 1976).	This is a shortened version of the DRS and measures mental status using 8 sub-tests. It assesses general knowledge, verbal abstraction, digit span, orientation, visual and verbal memory, language, construction and block design.
Useful Field Of View (UFOV) (Ball & Owsley, 1993)	The UFOV measures the visual field extent that is available to a person focussing on a task in the central part of visual field. It comprises 3 sub-tasks that involve perceptual-response time, visual search, and divided and selective attention.
Rey Complex Figure Test (RCFT) (Rey & Osterrieth, 1993)	The RCFT captures five domains of neuropsychological functioning: visuo-spatial recall memory, visuo-spatial recognition memory, response bias, processing speed, and visuo-spatial constructional ability and discriminates mildly brain-injured patients with memory impairment from normal patients. It includes a copy trial, an immediate recall trial, a delayed recall trial and a recognition trial and evaluates the relative contributions of encoding, storage, and retrieval processes to memory performance.
Stroop Colour and Word Test (Stroop, 1935)	This test measures cognitive processing and provides diagnostic information on brain dysfunction, cognition and psychopathology. Cognitive functions include flexibility, resistance to interference and creativity. Respondents read down a list of words naming the words and printed colour as quickly as possible within a time limit.
Wechsler Adult Intelligence Scale (WAIS) (and revisions, WAIS-R, WAIS-III) (Wechsler, 1955)	The WAIS consists of 11 sub-tests including general information, similarities, arithmetic reasoning, vocabulary, comprehension, digit span, picture completion, picture arrangement, block design, object assembly and digit-symbol substitution. It is the most widely used intelligence test, but also provides clues to cognitive strengths.
Clock Drawing Test (Freedman et al. (1994)	Commonly used as part of a screening battery for dementia. It can provide information about visuo-spatial functions, the ability to follow directions, planning and organization.

2.2 NORMAL AGEING AND GENERAL DECLINES IN FUNCTIONAL PERFORMANCE

The degree to which cognitive and executive function decline is a function of normal advancing age compared to the result of disease process is often difficult to evaluate. Older adults vary considerably in their level of maintained cognitive and executive function ability, with some individuals showing high functioning into their ninth and tenth decades with the only detectable changes being cognitive slowing and slight difficulties on the most attention-demanding tasks. Other older adults show severe memory decline at early ages. There are people under the age of 65 with clinically diagnosed dementia and also people over the age of 90 who do not show significant cognitive decline (Green, Kay & Ball, 2000). Moreover, it should be pointed out that positive changes can occur in old age and that some cognitive and executive functions are not age-sensitive. For example, crystallised intelligence (abilities involving the use of knowledge acquired through experience) and verbal fluency are maintained and sometimes can improve with age (Dixon, Kramer & Baltes, 1985; Parkin & Java, 1999; Masunaga & Horn, 2000).

However, most people experience some level of functional decline as they age, particularly in sensory, physical and cognitive areas, and cognitive decline is a slow and often insidious process, with individuals often lacking awareness of the deficits. There is general agreement that normal ageing reduces or slows down sensation, perception, cognition, psychomotor response and physical functioning. Functional limitations (in one or more activities of daily living) have been observed to be more prevalent with increasing age, with rates increasing from 7 percent for those aged 65 to 74 years to 24 percent in those aged 85 and older (Manton, 1988). More recently, it has been estimated that at least 10 percent of people older than 65 years and 50 percent of those older than 85 years have some form of cognitive decline or impairment, ranging from mild deficits to dementia (Jorm & Jolley, 1998; Kukull & Ganguli, 2000).

While few studies have found direct links between simultaneous deterioration of several functions and pedestrian performance and crash risk, there are a number of studies that implicate cognitive decline in road-crossing behaviour, abilities in a range of activities of daily living, and driving and pedestrian ability. In the following sections, the literature is reviewed in four parts: I) road-crossing behaviour specifically investigating age differences and implications for safety, ii) the effect of cognitive decline on road-crossing behaviour, iii) the effect of cognitive decline on driving performance and crash risk, and iv) the effect of cognitive decline on performance of activities of daily living, particularly walking ability and falling.

2.2.1 Road-crossing behaviour

A number of observational studies and surveys have sought to identify age differences in road-crossing behaviours that may account for higher crash risk for older pedestrians. While the majority of studies have examined behaviour at mid-block crossings (without the aid of crossing facilities), a few studies have also observed behaviour at crossing facilities and it seems that, when older adults use facilities, they are more likely to comply with signal phasing than younger adults (Carsten, Hodgson & Tight, 1990). Draskòszy (1990) found substantial differences in proportion of red light violations between older adults (0-43%) and younger adult pedestrians (45-72%).

With regard to mid-block crossings, the majority of studies point to attempted compensation for age-related changes, but risky crossing decisions by older pedestrians, particularly in selecting appropriate gaps to accommodate for their slower walking speed in complex traffic environments (Carthy et al., 1995; Oxley et al., 1997; Oxley, 2000).

Carthy et al. (1995) found that older people (estimated to be aged 65 years and older) were disproportionately represented in potentially unsafe crossings (those necessitating some form of evasive action either by the driver or by the pedestrian) compared to younger pedestrians (estimated to be aged 30-55 years). They argued that older pedestrians experienced problems selecting safe gaps because they lacked appropriate consideration of the speed of approaching vehicles. They also found that when crossing without the aid of formal crossings, older pedestrians often crossed the first half of the road without consideration of the outcome for the second half. They noted some extreme instances of older pedestrians successfully crossing the near-side of the road but being caught in the middle waiting for oncoming far-side traffic and panicking to reach the other side of the road.

This is consistent with findings among a sample of pedestrians in Victoria (Oxley et al., 1997, Oxley, 2000). Road-crossing behaviour of younger (estimated to be aged 30-45 years) and two groups of older adult pedestrians (estimated ages 60-69 years and 75+ years) differed substantially on a number of measures. The oldest pedestrians (those estimated to be over 75 years old) spent more time inspecting traffic while waiting at the kerb, more time leaving the kerb and crossing the road. They also were more likely to interact with the far-side traffic during their cross which required them to wait in the centre of the road. Most importantly, these pedestrians, who were also the slowest walkers, were at increased risk of collision because many of them left dangerously short times between reaching safety and the time that the vehicle they crossed in front of reached the crossing point. This was most apparent in complex two-way traffic. Experimental studies confirmed the difficulties in selecting safe gaps in which to cross, especially when under time pressure. These findings may imply that the over-involvement of the elderly in pedestrian crashes may be critically related to perceptual and cognitive declines.

Sheppard & Pattinson (1988) described some of the difficulties in crossing roads, as reported by 473 older pedestrians (average age 75 years) who had been involved in a pedestrian-vehicle crash. Failure to see, or to see in time to take evasive action, the vehicle that struck them was reported by 63 percent of respondents. About two-thirds of those who saw the vehicle that struck them saw it only when it was within about 9 m of them; for 17 percent it was not more than a car length away, by their estimates, when it was seen.

Of those respondents who saw the vehicle before being hit, 41 percent noted that the vehicle that struck them was doing something unusual. The most frequent replies were: reversed into me (30%), expected driver to stop or alter course (20%), thought the vehicle was not moving (11%), and vehicle came from behind a corner, parked car, etc. (10%). Errors in judgement of the speed or course of vehicles and unwarranted expectancies about the behaviour of drivers are central factors here. When asked about ability to judge speeds of approaching cars, 30% said they could 'not do this well at all'. This reply was much more common among those who had never driven or who had stopped driving. Only 44 percent said they could make this judgement 'fairly well', the most positive response category. The problems are also reflected in the replies of 204 people who said the location of their crash was a difficult place to cross. One-fourth reported that it was hard to see, 14 percent indicated that the intersection was confusing and 25 percent said the traffic comes too quickly. When queried about difficulties in seeing, hearing or walking about one-third of the participants indicated such problems – 33 percent walking, 45 percent eyesight and 51 percent hearing. These findings support suggestions that age-related changes in sensory, perceptual, cognitive and motor functions contribute to difficulties in making appropriate road-crossing decisions and increase the risk of collision.

Data from Sweden also indicate that more than one-third of elderly road users find it difficult to be pedestrians (Ståhl, 1991; Ståhl, Brundell-Freij & Makri, 1993) and these problems can affect road-crossing behaviour. The problems were reportedly caused by the following: they are afraid of being involved in a crash caused by their personal limitations; they are afraid of falling due to poor maintenance of the roads; cyclists present a problem; and they find it difficult to gather information in complicated and changing traffic situations. Ståhl also noted that older people's lower physical ability and related fear and anxiety often result in them trusting traffic regulations which might result in a sense of false feeling of security and increase crash risk.

2.2.2 Cognitive decline and road-crossing ability

There are large gaps in the knowledge about how functional limitations and resulting behaviour specifically affect the safety of older pedestrians. Only three articles were found that addressed these issues.

Experimental studies of age differences in gap selection (Oxley, Ihsen, Fildes, Charlton and Day, 2005) revealed risky crossing decisions by older adults (aged 75+ years) compared to younger adults. In a simulated road-crossing task, participants in all age groups (young, young-old and old-old) based their crossing decision primarily on the distance of the vehicle and less so on time-of-arrival. Despite the apparent ability to process the distance and speed of oncoming traffic when given enough time to do so, many old-old adults selected insufficiently large gaps in which to cross safely. Moreover, when under time constraint, old-old adults experienced difficulty integrating speed and distance information of approaching vehicles which led to dangerous crossing decisions. The authors suggested that losses in cognitive function may have resulted in a reduced ability to integrate perceptual information about oncoming traffic when under time pressure. However, given, that older adults were able to integrate this information given sufficient time, but still made risky decisions, the authors concluded that unsafe crossing decisions were more likely a function of declines in executive processes, which may have led to misperception of risk and/or difficulties with choosing gaps sufficiently large to compensate for the decline in walking speed. Similar findings were reported by Carthy et al. (1995) who measured the ability to make judgements of speed and distance amongst two groups of older adults (60-74 years and 75+ years) using videos of traffic situations in which speed of the vehicle was manipulated. They found that distance gap was the prime variable used to anticipate arrival times by both groups and that the oldest group made significantly more estimation errors and over-estimated arrival times compared to the younger group. Further, they found that the older group was less able to discriminate between relative speeds of approaching vehicles than the younger group.

Oxley, Ihsen, Fildes and Charlton (2001) provided further evidence of the impact of age-related changes in functional performance on crossing decisions. Performance on functional assessments was correlated with crossing decisions in a simulated road-crossing environment. The results of this study showed associations between attentional, cognitive and physical abilities and crossing responses. First, slower walkers made more 'incorrect' (or unsafe) crossing decisions than faster walkers. This finding suggests that slower walkers experience difficulty in adjusting behaviour to suit changing abilities and supports Lee, Young and McLaughlin's (1984) argument that older people need to re-calibrate as they become infirm and slower but this may be a very difficult task to achieve. Second, the finding that participants who performed poorly on tests of visual search, attention and cognitive skill were more likely to make an 'incorrect' (or unsafe) crossing response suggests that the road-crossing task places overwhelming demands on attentional and cognitive resources of the oldest pedestrians. In a complex road environment with

approaching traffic, it seems that inabilities in attending to, integrating and processing many different sources of information could reduce the ability to respond safely to approaching traffic. These findings implicate cognitive and executive function declines in pedestrian performance.

2.2.3 Cognitive decline and driving ability

There is some evidence that simultaneous deterioration of several functions is associated with increased crash risk for older drivers (Valcour, Masaki & Blanchette, 2002; Cooper, Tallman, Tuokko & Beattie, 1993).

Stutts, Stewart and Martell (1998) examined the associations between cognitive function and crash risk amongst a group of older drivers aged 65 years or older applying for licence renewal in North Carolina. They found a significant association between level of cognitive function (especially when based on performance on TMT) and crash risk, even after controlling for the effects of driver age, race, self-reported annual mileage and driving frequency. However, the observed effect was relatively small, such that drivers scoring in the bottom 10 percent of performance on various cognitive tests had less than a two-fold higher crash risk than those scoring in the top 10 percent. Also, the increase in crash risk observed from the lowest to highest levels of test performance was very gradual, so that there was no clear cut point for identifying a particularly high risk subgroup of drivers.

A recent study by Daigneault, Joly and Frignon (2002) examined the relationships between two key areas of attention and executive disorder and driving behaviour and crash involvement using the Wisconsin Card Sort Test (attention), TMT (visual search), Stroop Colour Word (controlled responses) and the Tower of London test (planning). Demographics and self-reports of risky behaviours were also collected. They found that crash-involved drivers showed more cognitive deficits than controls, but no causal relationships were shown.

Lundberg, Hakamies-Blomqvist, Almkvist and Johansson (1998) investigated the extent to which limitations in cognitive functions, regardless of aetiology, contributed to adverse traffic events within the general older population. Cognitive functions of two groups of older drivers who had had their licence suspended on the grounds of 'a violation of an essential traffic safety regulation', (one group included those who were also crash-involved and the other group had not been involved in a crash), were compared to a group of matched older drivers who had no licence suspension. Cognitive functions were assessed using three subtests of the WAIS (similarities, block design and digit symbol), the Rey-Osterreith Complex Figure, the Rey Auditory Verbal learning test, the TMT and computerised tests of reaction time and divided attention. They found that crash-involved drivers with suspended licences performed significantly worse than controls on tests of visuo-spatial memory, verbal, visuoconstructive ability and psychomotor speed. On the other hand, non-crash-involved suspended drivers did not differ negatively from controls on any measure. They argued that their findings are consistent with a view that cognitive functions contributing to an adequate visual processing and to the integration of perception and motor functions are essential to traffic safety.

2.2.4 Cognitive decline and task performance

The literature on ageing clearly documents the effect of task complexity on performance. Older adults appear to be more affected than younger adults when the conditions of a task become more complex and demanding (Salthouse, 1991). Complex situations can provide interference to a person's information-processing system, which may be affected by the ageing process. For older road users, then, some traffic environments cause more difficulty

than others and it is this factor that can explain, in part, the over-representation of older road user crashes at intersections, when merging in to traffic, when changing lanes, and in busy and fast moving traffic. These types of traffic situations are complex, presenting multiple sources of information that must be sampled continuously to decide on a safe course of action.

Salthouse (2000) argues that a single basic construct (a systematic decline in basic neural operations and therefore processing speed) accounts for most, though not all, of normal age-related cognitive decline. He also incorporates the occurrence of an increased error rate by assuming that elderly adults allow insufficient extra time, and hence occasionally respond before adequate processing has occurred. He argues that difficult tasks require more processing and are, hence, more affected by age. In the case of dual task performance, it seems that older adults are significantly disadvantaged compared to younger adults, and this has led some researchers to argue that there appears to be declines of different aspects of attention as well as the slowing of processing speed on multiple tasks (Baddeley, Baddeley, Bucks & Wilcock, 2001; Perry & Hodges, 1999; Rogers, Fisk & Walker, 1996; Birren & Schaie, 1996).

There is also consistent evidence of some degree of cognitive change associated with normal ageing on a variety of other cognitive measures, including tests of visual and verbal memory (Arenberg, 1990; Hultsch, Hertzog, Small, McDonald-Miszczak & Dixon, 1992), abstraction (Albert, Wolfe & Lafleche, 1990), naming and verbal fluency (Albert, Heller & Millberg, 1988; Hultsch et al., 1992), and fluid intelligence (Botwinick & Siegler, 1980; Schaie, 1990).

Neurophysiological and neuroanatomical studies of elderly individuals also report general declines in frontostriatal systems, which implicate planning and executive functions that require inhibitory control of attentional systems (Brody, 1994; Raz, Gunning-Dixon, Head, Dupuis & Acker, 1997; Hasher & Zacks, 1988; Sweeney, Rosano, Berman & Luna, 2001) and in the temporal cortex, hippocampus and limbic system, which are known to be implicated in memory and learning (Eustache, Rioux, Desgranges, Marchal, Petit-Taboue, Dary, Lechavalier & Baron, 1995).

Older adults seem to experience some problems in negotiating visually cluttered environments and some have suggested that visual search problems may be the result of difficulties with inhibiting irrelevant targets, selective attention, divided attention, spatially localising task-relevant information, and slowing of processing speed. Owsley and McGwin (2004) examined the relationship between visual attention and several mobility measures (frequency of performing activities including gardening, household chores, walking and swimming, how much time the person was engaged in the activity, and number of falls in last 12 months) in a large cohort of older community-dwelling adults. Cognitive status was evaluated using the MOMSSE and visual attention was assessed using the UFOV test. Their results showed that declines in visually divided attention/processing speed was associated with deficits in performance mobility, even after the adjustment for other known influences on mobility performance such as age, visual and cognitive status and comorbid medical conditions. These findings are consistent with the literature indicating that dual task conditions, which challenge the attentional system, particularly divided attentional skill, impede older adults' postural stability, ambulation, and other types of movement through the environment more so than they do for younger adults.

Carlson, Fried, Xue, Bandeen-Roche, Zeger and Brandt (1999) examined whether executive attentional abilities were uniquely associated with the performance of complex, instrumental activities of daily living (e.g., looking up and dialling a telephone number)

and mobility-based activities of daily living (e.g. walking 4m), in cognitively intact and physically high-functioning older women. They found that tests of executive attention were associated with performance on instrumental activities of daily living and, to a lesser degree, with mobility-based activities of daily living. They concluded that executive difficulties in flexibly planning and initiating a course of action were selectively associated with slower performance of higher-order instrumental activities of daily living, relative to other domains of cognition and suggested that executive functions may be important in mediating the onset and progression of physical functional declines.

2.2.5 Cognitive decline and walking ability and falling

Physical skills deteriorate with age and pedestrian crashes involving older adults have been linked to reduced agility and motor responses. There is no doubt that motor control and physical agility are of prime importance when crossing the road: older pedestrians with motor impairments have a reduced ability to initiate actions and, respond to threats as quickly as other people. They are less agile and often more dependent on other people for assistance. Good balance is also essential for avoiding tripping or falling when crossing roads or walking on uneven footpaths. Balance control mechanisms and postural reflexes are also susceptible to age-related changes, resulting in impaired mobility and increased risk of falling and injury.

There is a large body of literature providing strong evidence that cognitive and executive function declines are powerful predictors of walking ability and falling. While walking is generally viewed as an automated, over-learned, rhythmic motor task, it seems that this is a simplistic view and that, for many older adults, walking is a more complex task requiring integration of a number of visual, cognitive, and psychomotor skills. Hausdorff, Yogeve, Springer, Simon & Giladi (2005) compared walking performance to performance on the Stroop Test and tests of memory amongst a group of non-demented, ambulatory older adults. Walking was associated with higher-level cognitive resources, specifically, executive function, but not with memory or cognitive function in general, which led them to conclude that cognitive and executive function may play a key role in the regulation of even routine walking

DiFabio, Kurszewski, Jorgenson and Kunz (2004) examined obstacle clearance among community-dwelling older people. They found that high-risk elderly (those who had at least one fall in the previous year and scored poorly on the Timed Up and Go test) showed a marked asymmetry in foot clearance while stepping over an obstacle, with the lag foot clearing the obstacle at a much lower distance than the lead foot. They argued that control of limb movements over an obstacle requires initiation of footlift without visual input and that adults must use memory to plan and execute footlift (presumably involving cognitive/executive functions). They reported that deficits in cognitive and executive cognitive function amongst their participants accounted, at least partially, for asymmetries during obstacle step-over.

A second, related study (DiFabio, Zampieri, Henke, Olson, Rickheim & Russell, 2005) reported on the effects of executive function on attention in the lower visual field during step initiation amongst groups of older adults with and without executive function declines and younger adults. They monitored eye and head angulations as participants fixated on a point at eye-level and while visual stimuli were presented in the peripheral visual field to cue the selection of the right or left foot to lead a step over an obstacle at their feet. Both groups experienced greater stepping errors as a result of stimuli being presented in the lower versus the upper visual field and with increasing eccentricity. However, the obstacle contact rate was greater, cue-saccade latency was prolonged, and fewer down-saccades

were generated in the group with poor executive abilities compared to those with high executive function and younger participants.

Ble, Volpato, Zuliani, Guralnik, Bandinelli, Lauretani, Bartali, Maraldi, Fellin and Ferrucci (2005) examined the association between performance on psychological tests of executive function (TMT) and performance on two walking tasks, one a 4m course at usual walking pace (low attention demand) and one a 7m obstacle course at a fast walking pace (high attention demand) in a large sample of older adults without dementia, stroke, Parkinson's Disease (PD), visual impairment or current treatments with neuroleptics. They found no association between performance on TMT and the low attention demand walking task, a task that uses highly learned motor skills. In contrast, a strong, independent association between performance on TMT and performance on the 7m obstacle course at fast walking pace was found, a task that is considerably more attention demanding. Participants who performed fair or poor on the TMT were more likely than those who performed well to walk more slowly on the 7m obstacle course. The authors argued that executive function may play a significant role in the ability of older adults to manage complex lower extremity motor tasks and is much less important for highly learned tasks such as usual-pace gait. They concluded that, if executive function is important in the performance of complex mobility tasks, then the age-related decline in executive function described by many observational studies is not without consequences for the health, mobility and safety of older individuals. Indeed, this finding would seem to have major implications for older pedestrian safety, particularly with regard to adjusting walking pace while crossing roads in a complex traffic environment where attentional demands are great.

With regard to the association between cognitive decline and falling, a clear link has been established. The incidence of falling by cognitively impaired adults is approximately twice the rate of cognitively normal older people (Bergland & Wyller, 2004; Kenny, Kalaria & Ballard, 2002; Chen, March, Schwarz, Zochling, Makaroff, Sitoh, Lau, Lord, Cameron, Cumming & Sambrook, 2005; DiFabio et al., 2005). In addition, cognitively impaired adults experience significantly more difficulties performing quick postural adjustments (Hauer, Pfisterer, Weber, Wezler, Kliegel & Oster, 2003), and maintaining postural control during quiet stance and walking, compared to unimpaired adults (Hauer et al., 2003; Melzer & Oddsson, 2004; Verghese, Buschke, Viola, Katz, Hall, Kuslansky & Lipton, 2002; Lajoie, Teasdale, Bard & Fleury, 1996; Shumway-Cook & Woollacott, 2000; Camicioli, Howieson, Lehman & Jeffrey, 1997; Lundin-Olsson, Nyberg & Gustafson, 1997; Brown, Shumway-Cook & Woollacott, 1999; Rankin, Woollacott, Shumway-Cook, & Brown, 2000). Rankin et al. (2000) also showed that muscular activity in both the gastrocnemius and tibialis anterior decreased when participants were asked to perform a cognitive task. They suggested that this effect was due to a reduced availability of attention for balance control.

Many of these studies have used divided attention tasks to examine the effect of cognitive and executive function decline on postural control and the evidence points to a clear link between poor postural control and declining attentional functions. Verghese et al. (2002) explored the influence of cognitive processes using a divided attention task on gait amongst non-demented community living older adults aged over 65 years. They found that walking while talking tests, combining cognitive and gait tasks, powerfully predicted falls. Participants who walked slower and performed worst in the walking while talking task were more likely to fall in the year following testing (OR = 13.7). Similarly, Hauer et al. (2003) found that postural control decreased significantly during all dual tasks in patients with impaired attention, with an almost 100 percent increase in postural sway amongst cognitively impaired patients when performing dual tasks.

Melzer and Oddsson (2004) pointed out that the ability to take a quick step or to grasp for external support in the environment are important motor skills that could prevent a fall from occurring and that once a fall is initiated, a rapid step execution is critical for successful balance recovery. This has implications for many everyday life situations, such as crossing roads – the requirement to step to maintain balance while crossing the road would occur under more complicated circumstances with cognitive attention focussed on, for example, watching traffic or reading street signs and not on performing a specific motor task.

Melzer and Oddsson's finding that an attention-demanding cognitive task delayed the initiation and execution of a voluntary step in both younger and older adults, but the effect was more pronounced for the older group supports this argument. They found that during the single-task condition, step initiation times were 42 to 54 percent longer for the elderly than for the younger individuals. Under the dual task condition, the differences were substantially larger, with 190 to 256 percent longer initiation times for the elderly participants. In addition, times to foot contact (determining duration of step execution) were also significantly different between the two groups, ranging from 589ms to 699 ms in the young group and from 853ms to 992ms in the older group in the single-task condition and from 648ms to 793ms for the young group and from 1140ms to 1336ms for the older group under dual-task conditions. They concluded that the increase in duration of the step initiation phase during the dual task was largely due to an increase in central neural processing time. This confirms the results of another study (Beauchet, Dubost, Stierlam, Blanchon, Mourey, Pfitzenmeyer, Gonthier & Kressig, 2002) reporting that, in frail elderly subjects, a dual-task condition provoked a slower gait with an increased number of steps, a reduction in cadence and step length, and a significant increase in the number of lateral deviations and stops.

Yaffe, Barnes, Nevitt, Liu and Covinsky (2001) measured cognitive performance and physical activity amongst community-dwelling women without baseline cognitive decline or physical limitations. They found that women with a greater physical activity at baseline were less likely to experience cognitive decline during a 6-8 years follow-up period. After adjustment for age, educational level, health status, depression score, stroke, diabetes, hypertension, myocardial infarction, smoking status, estrogen use, and functional limitation, women in the highest quartile of physical activity were less likely than women in the lowest quartile to develop cognitive decline.

2.2.6 Summary of the effect of normal age-related cognitive/executive function declines on pedestrian performance and crash risk

The literature clearly shows that normal ageing is associated with changes in sensory, perceptual, physical and cognitive/executive function systems. However, in the absence of disease and associated functional impairment, there is little unequivocal empirical evidence that the subtle or moderate normal age-related changes in cognitive or executive function skills affect the ability of older persons to interact with traffic safely, that they lead to a discernible increase in crash risk, or to undertake activities of daily living (see Tables 2 & 3). Indeed, how these changes manifest in functional performance changes has been debated. What is clear is that there is a sub-group of older adults, those who have more severe and/or simultaneous declines in a number of functions (most often the oldest-old), who experience difficulty performing tasks and are at increased risk of crashing, particularly in complex traffic situations.

Table 2: Cognitive decline in driving and pedestrian risk

Authors	Method	Subject Matter / Key Findings
Carthy et al. (1995)	<p>i) Observations of 166 older (estimated age >65 years), 244 (estimated age 30-55 years) younger and 22 child (estimated age <14 years) pedestrian road crossings.</p> <p>ii) Experimental studies of 89 'young-old' (60-74 years) and 'old-old' (75+ years) adults using videos of traffic and manipulating speed of approaching vehicles</p>	<p>Pedestrian behaviour</p> <p>Older adults made more potentially unsafe crossings (poor choice of place to cross and crossings that necessitated evasive action) than younger adults and children..</p> <p>Distance gap was the prime variable used to anticipate arrival times. The oldest group made significantly more estimation errors and over-estimated arrival times compared to the younger group. The older group was less able to discriminate between relative speeds of approaching vehicles than the younger group.</p>
Sheppard & Pattinson (1988)	Interviews with 473 crash-involved older pedestrians (<i>M</i> age 75).	<p>Pedestrian behaviour</p> <p>63% did not see the vehicle, of those who saw the vehicle, 41% said it was doing something unusual. Incorrect judgements of driver behaviour by pedestrians. One-third reported functional difficulties could have contributed and one-fifth said they could have behaved in a safer manner.</p>
Oxley et al. (1997); Oxley (2000)	Observations of 80 young (estimated age 30-45 years), 80 young-old (estimated age 60-69 years) and 80 old-old (estimated age >75 years) pedestrians on two-way roads, and 40 young, 40 young-old and 40 old-old pedestrians on one-way roads.	<p>Pedestrian behaviour</p> <p>More time spent waiting at kerb, longer walking times, longer times to leave the kerb, and risky crossing decisions (i.e., shorter safety margins) amongst old-old pedestrians compared to young-old and young pedestrians. Age differences in risky behaviour were more pronounced in two-way traffic than on one-way traffic.</p>
Oxley et al. (in press)	Road-crossing decisions in a simulated road-crossing environment of 18 young (aged 30-45 years), 18 young-old (aged 60-69 years) and 18 old-old (aged >75 years) adults.	<p>Pedestrian performance</p> <p>Distance gap was the main predictor of crossing decision for all age groups. Higher proportions of old-old participants crossed in an unsafe manner compared with young-old and young participants, especially when under time pressure: 77% vs 23% vs 15%, respectively when under time pressure and 64%, 11% and 16% respectively not under time pressure.</p>

Oxley et al. (2001)	Road-crossing decisions in a simulated road-crossing environment and functional assessments of 18 young (aged 30-45 years), 18 young-old (aged 60-69 years) and 18 old-old (aged >75 years) adults.	<p>Pedestrian performance</p> <p>Performance on assessments of functional ability declined with increasing age. Logistic regression analysis on 'yes' response data to examine association between functional performance and ability to make a correct 'yes' response'. Analysis revealed all tests of functional performance were predictors of correct responses.</p>
Stutts et al. (1998)	Information from driver history files (crash involvement, infringements, etc) and performance on 5 screening tests assessing various aspects of cognitive function of 3238 drivers aged 65 years and older (<i>M</i> age 73.6 years) applying for renewal of driver's licence	<p>Driver performance and crash risk</p> <p>For all tests of cognitive function, performance declined significantly with age and scores on all tests were significantly correlated with each other. Performance on the TMT Part B and AARP reaction time tests appeared to be the most strongly associated with recent prior crash involvement, even after controlling for age, gender, race, driving exposure and other potential confounders. The observed effect, however, was relatively small – drivers scoring in the bottom 10% of performance on cognitive tests had less than a two-fold higher crash risk than those scoring in the top 10%.</p>
Daigneault et al. (2002)	<p>i) Information on driving habits of 90 older non-crash-involved male drivers and 90 older crash-involved male drivers (both groups aged >65 years).</p> <p>ii) Cognitive performance of subgroups of 30 crash-involved male drivers and 30 non-crash-involved male drivers.</p>	<p>Driver performance and crash risk</p> <p>Crash-involved drivers did not differ from non-crash-involved drivers in terms of frequency of driving, avoidance of difficult driving situations. However, crash-involved drivers reported driving more slowly than non-crash-involved drivers. In addition, the crash-involved group reported lower education level and income than the non-crash-involved group. Moreover, the crash-involved group performed more poorly on tests of speed, planning and execution and made more perseveration and attention errors.</p>
Lundberg et al. (1998)	Three groups of older drivers aged 65 years, i) 23 with suspended licences and crash involved (<i>M</i> age 75.7), ii) 14 with suspended licences and not crash-involved (<i>M</i> age 71.4), and iii) matched controls with no licence suspension and not crash-involved (<i>M</i> age 74.7) .	<p>Driver performance and crash risk</p> <p>Compared to controls, crash-involved suspended drivers performed more poorly on tests of visuoconstructive ability, and psychomotor speed. This group also differed from non-crash-involved drivers by performing more poorly on tests of visuoconstructive ability, psychomotor speed as well as on two tests of verbal and on one test of visuospatial episodic memory (free recall of a 12-word list and delayed recall on an auditory verbal learning test. Participants with suspended licences who were not crash-involved did not differ negatively from controls on any measure.</p>

Table 3: Cognitive decline in other activities of daily living

Authors	Method	Key Findings
Owsley & McGwin (2004)	342 community-dwelling older adults (aged 55-85 years) in a study on the Impact of Cataracts On Mobility (ICOM) took part in the study.	<p>Mobility</p> <p>Lower scores on visual attention/processing speed (UFOV) were significantly related to poorer scores on the performance mobility assessment, even after adjustment for age, gender, education, number of medical conditions, cognitive status, depressive symptoms, visual acuity and contrast sensitivity.</p>
Carlson et al. (1999)	406 community-dwelling older women aged 70-80 years in the Women's Health and Aging Study (WHAS). Performance on MMSE, and other tests of cognitive function and instrumental and mobility-based ADLs were assessed.	<p>Instrumental and mobility based ADLs</p> <p>Tests of executive attention were associated with performance on instrumental ADLs and, to a lesser degree, mobility-based ADLs, adjusting for demographic and disease variables. In particular, the mental flexibility component of TMT accounted for the majority of attentional variance in instrumental ADL performance.</p>
Hausdorff et al. (2004)	43 community-dwelling adults aged 62-86 years (<i>M</i> age 71.9) with no cognitive disturbances or co-morbidities.	<p>Walking ability</p> <p>Walking ability was associated with executive function but not with memory or cognitive function in general. A lower (better) stride time variability was significantly associated with higher (better) scores on the Stroop test.</p>
Di Fabio et al. (2004)	18 community-dwelling older adults (with MMSE score greater than 23, far visual acuity of at least 20/70, near visual acuity of at least 20/80 & no peripheral visual field deficits within 30° of central fixation). 15 younger control participants.	<p>Walking ability</p> <p>High-risk older participants (those who had at least one recent fall and scored poorly on physical tests) were less likely to select the appropriate foot for step initiation, showed asymmetry in foot clearance and cleared the obstacle with the lag foot at a much lower distance compared to low-risk and younger participants.</p>
DiFabio et al. (2005)	Community-dwelling normally sighted older adults with and without executive function declines. Younger control participants	<p>Walking ability</p> <p>Obstacle contact rate was greater, cue saccade prolonged and fewer down-saccades were generated amongst participants with poor executive function compared with those with high executive function and younger participants</p>

Ble et al. (2005)	926 older adults (>65 years) with no dementia, stroke, parkinsonism or visual impairment.	Walking ability No association found between performance on TMT and low attention demanding walking task. A strong associated between performance on TMT and high attention demanding walking task.
Verghese et al. (2002)	60 community-dwelling older adults aged 65 to 90 years (<i>M</i> age 79.6) with no diagnosis of dementia.	Walking ability Prospective cohort study identifying falls in a 12 month period. Poor performance on simple and complex walking while talking (a divided attention task) was highly predictive of falls.
Melzer & Oddsson (2004)	66 healthy ambulatory older adults (aged 65-90) with high scores on MMSE and berg Balance scale. 12 younger adults (aged 20-39),	Walking ability The dual task condition (Stroop test) caused significantly longer step initiation amongst elderly participants (108%). Step execution times were also delayed during the dual task condition for younger participants, but to a lesser extent than older participants (34%).
Yaffe et al. (2001)	5925 community-dwelling older women aged >65 years without baseline cognitive impairment or physical limitations.	Physical activity 6 to 8 year follow up of physical activity and cognitive performance. Women with greater baseline physical activity (blocks walked per week or total kilocalories expended per week) were less likely to develop cognitive decline (measured by MMSE) than women with lower baseline activity.

While many of the studies cited are not directly related to pedestrian performance, the majority demonstrate that advanced ageing affects, to varying degrees, general cognitive and executive functions that intuitively are related to the ability to cross roads in a safe manner. Many older adults are aware of their limitations and adopt behaviours to compensate for changes in their abilities. However, those who lack insight into their declining abilities are less likely to use compensatory strategies, placing themselves at increased risk of crashing.

In addition, there is clear evidence of an effect of cognitive and executive decline, particularly attentional limitations, on walking ability and risk of falling. Given that the ability to initiate steps and walk quickly, and react quickly in an emergency, poor walking ability and postural control (implicating cognitive/executive function decline) may compromise pedestrian safety.

These studies, collectively, provide evidence that perceptual, cognitive and physical factors play some role in the performance and safety of older pedestrians. Unfortunately, only five studies provided direct evidence of cognitive/executive function decline on the ability to cross roads safely, however, no studies were found that measured the effect of cognitive decline on crash risk. This demonstrates the critical need for more research in this area to establish what specific cognitive/executive function declines and to what extent they are associated with poor performance and increased crash risk for older pedestrians. Further, more information about the complexity of traffic situations and the effect on pedestrian performance is required.

2.3 MEDICAL CONDITIONS AND COGNITIVE IMPAIRMENT

Cognitive impairment is a feature that is distinct from normal age-related cognitive function decline. Cognitive impairment is most commonly the result of dementia and in this form is often considered a continuum of three broad cognitive states from normal age-related decline, to cognitive impairment beyond normal ageing which is not sufficient enough to warrant a diagnosis of dementia (otherwise known as mild cognitive impairment (MCI)), and dementia, of which there are various types due to different types of pathological processes as a result of age-associated diseases (Petersen, Doody, Kurz, Mohs, Morris, Rabins, Ritchie, Rossor, Thal & Winblad, 2001; Snellgrove, 2005). Some other medical conditions can also cause cognitive impairment. Amongst these, stroke is most well known, while other medical conditions such as PD, heart disease and multiple sclerosis, can also cause cognitive impairment (Ahlgren, Lundqvist, Nordlund, Aren & Rutberg, 2003).

During the last two decades, there has been a considerable amount of research related to the effect of cognitive and executive function impairment on performance in everyday activities such as driving and walking in older people belonging to different clinical populations. It should be noted at the outset that many of these studies suffer from methodological limitations and biases, such as the recruitment procedures and characteristics of study participants. An example is the recruitment of drivers with dementia – the problem is that many drivers with dementia give up driving and therefore studies generally only target mild dementia. The main limitation of most studies is essentially that the predictive strength of the different cognitive measures is quite modest. Many tests lack sensitivity, although specificity is often satisfactory. (Sensitivity refers to the rate of positive screening test results (pass) among those who pass the diagnostic test and specificity refers to the rate of negative screening test results (fail) among those who fail the diagnostic test).

Studies use very different test batteries and the overlap between methods is small. In addition, unequivocal diagnosis of dementia can only be made at autopsy. Notwithstanding these limitations, the majority of studies have found significant effects of cognitive and executive function impairment on performance in many activities of daily living including walking and driving.

The majority of studies addressing the effect of cognitive impairment on task performance have focussed on specific types of medical conditions. These studies are reviewed in the following sections. In a different approach, Bootsma-van der Wiel and colleagues examined the effects of several chronic diseases and associated impairments as determinants of walking disability (Bootsma-van der Wiel, Gussekloo, de Craen, van Exel, Bloem and Westendorp, 2002). The study involved two groups of adults aged 85 years and older; 192 with a walking disability (defined as having a walking time below the 25th percentile of the group or unable to complete a 6-metre walking test) and 397 without a walking disability. Those with a walking disability were more likely to be institutionalised and to have lower education and income levels, report difficulty walking outdoors or climbing stairs, sustained more recurrent falls, reported poor health, poor satisfaction with their life and loneliness than those without a walking disability. Chronic diseases were common, both in persons with and without walking disability, however, PD (OR = 6.0), hip fracture (OR = 4.3) and stroke (OR = 3.7) were most strongly associated with walking disability. In persons without severe cognitive impairment, depressive symptoms were present in 44 percent of those with walking disability (OR = 3.8). The effect of general impairments on walking disability was higher than the effect of common chronic diseases. Impaired cognition (measured with the MMSE), depressive symptoms (measured with the Geriatric Depression Scale), and dizziness contributed most to the presence of a walking disability. Cognition (OR = 8.2) and grip strength (OR = 7.8) were most strongly associated with walking disability. These findings have important implications for older pedestrian safety. First, presence of a walking disability may increase crash risk because of difficulties initiating actions, and adjusting walking speed if necessary to avoid potential collisions. Second, presence of impaired cognition may be associated with poor gap selection judgements which have obvious implications for pedestrian safety (refer Section 2.2.2).

2.3.1 Dementia

Dementia refers to a global deterioration of cognitive function due to atrophy of the central nervous system. The level of deterioration varies widely between individuals, however, dementia is the leading cause of cognitive and executive impairment in the elderly. The most common form of dementia, Alzheimer's Disease (AD), accounts for 50 to 75 percent of all cases of dementia. AD affects approximately 10 percent of the population over 65 years, and there are most likely many more people with MCI or pre-clinical dementia (Petersen et al., 2001). In Australia, based on these prevalence rates and population sizes for 1995, Henderson and Jorm (1998) estimated that at least 129,600 people over the age of 65 had dementia, and projected an increase of 254 percent by 2041. Another 10 to 20 percent of dementia cases are attributable to blood vessel disease of diffuse ischemia. This form of dementia is called vascular dementia. The remaining cases of dementia result from a variety of less common disorders.

As indicated earlier, the use of diagnostic criteria for the classification of dementia has generated a continuum from normal ageing to dementia with three broad cognitive states including i) normal age-related decline, ii) a transitional stage termed mild cognitive impairment (MCI), and iii) severe cognitive impairment to warrant a diagnosis of dementia.

The clinical criteria for MCI include objective memory complaint and impairment, CDR score of 0.5, reasonably intact performance on indexes of general cognitive function, essentially preserved ADLs and not demented according to diagnostic criteria. Deficits in language, executive function, and attention are also present in many patients with MCI, and deficits in more than one cognitive domain are a better indicator of MCI than memory impairment alone. The risk factors for developing MCI, and prevalence rates for MCI are not well characterised, however, it is reported that large proportions of people with MCI will progress to dementia, with estimates of 15 percent in one year after diagnosis, 40 percent over two years, 53 percent over three years, and 100 percent over five years (Davis & Rockwood, 2004; Petersen et al., 2001; Petersen, 2003). Given these high rates of conversion, some researchers contend that MCI is not a separate entity but rather a state representing very early dementia (Morris, Storandt, Miller, McKeel, Price, Rubin & Berg, 2001). For some researchers, MCI is identical to mild or early onset of dementia, while others have found that MCI may sometimes be a stable condition, and that it is only when memory decline is combined with impairments of other abilities that the risk of conversion to dementia is high (Bennett, Wilson, Schneider, Evans, Beckett, Aggarwal Barnes, Fox & Bach, 2002).

Dementia is a term used to describe the global impairment of higher cognitive and executive functions including memory, the capacity to solve problems of daily living, the performance of learned perceptuo-motor skills, and the correct use of social skills and control of emotional reactions (Lichtenberg, Murman & Mellow, 2003; O'Brien, Ames & Burns, 2000). Although dementia affects every aspect of behaviour, the cognitive/executive function impairments (and particularly the memory deficits) are the most obvious symptoms. The importance of memory to all facets of daily life is so great that memory deficits can preclude individuals from performing even the most fundamental of everyday tasks such as driving and walking successfully. Impaired awareness of the compromised cognitive condition is also very relevant for driving and walking safety, as adults with dementia often fail to take steps that might compensate for their impairments and are liable to continue to drive and walk regardless of risk (Rizzo, McGehee, Dawson & Anderson 2001). People with dementia also generally exhibit decreased psychomotor abilities; they are not as effective at controlling their own movements, they are slower and less accurate in their movements. Dementia also damages many parts of the brain including those that control planning, attention, memory and language. Patients with dementia are often described as being unable to concentrate, easily distractible, or confused when confronted by tasks that were previously easily performed (Perry & Hodges, 1999). Symptoms may include asking the same questions repeatedly, performing novel tasks or old tasks in a novel way, getting lost in unfamiliar surroundings, being unable to form plans and follow directions, becoming confused about time, people and locations, and failing to monitor personal safety.

These observations have led to speculation that adults with very early stage of AD may have executive function deficits, particularly relating to attentional processes, which precede deficits in language and visual spatial skills, (Binetti, Magni, Padovani, et al., 1996; Hulette, Walsh-Bohmer, Murray et al., 1998; Collette, van der Linden & Salmon, 1999; Chen, Sultzer, Hinkin, Mahler and Cummings, 1998). This is an important point, as it is likely that those in the early stages of the disease will be the largest group with the disorder to continue to participate in traffic as drivers and pedestrians. A word of caution, however, are the difficulties assessing which aspects of attention and executive function are affected and how early they are affected, as well as the validity of tools for these assessments (most tests for AD require a progressive memory deficit for diagnosis of probable or possible AD).

From the road safety perspective, what remains unclear is the level of impairment at which drivers and pedestrians with dementia are at increased crash risk. Moreover, there are large individual differences in the duration of the transition from early to late stages of dementia, ranging from three to twelve years (Arenberg, 1990; Hultsch et al., 1992).

2.3.1.1 Dementia and pedestrian ability

Only one study was found on the effect of dementia on pedestrian safety. Gorrie, Waite, Sachdev, Rodriguez, Duflou & Brown (2004) examined neurodegenerative change (neurofibrillary tangles [NFT], a pathological hallmark of AD) within the brains of 51 fatally injured older pedestrians compared to 49 non-pedestrian fatalities (older car passengers, drivers who had collapsed at the wheel, people who had died from medical conditions and people who had collapsed from unknown causes, all of whom had been mobile at least three months prior to death). They also examined differences in neurodegenerative change by pedestrian behaviour at the time of crashing. The brain regions studied were hippocampus, parahippocampal gyrus, temporal, parietal and anterior superior frontal cortex, areas considered sufficient for neurodegenerative disease (Braak & Braak, 1991; Mirra, Heyman, McKeel, Sumi, Crain, Brownlee, Vogel, Hughes, van Belle & Berg, 1991). Higher NFT scores were reported amongst fatally injured pedestrians compared to fatally injured non-pedestrians (37% vs. 14%). While a small correlation between NFT scores and increasing age were also found, this was apparent in both groups and cannot explain the increase in NFT distribution scores for pedestrians. Moreover, they found that pedestrians with higher NFT were involved in more crashes at intersections, walked into the path of a moving vehicle, and were not on a designated crossing facility, compared to those with lower NFT scores. Gorrie et al. argued that these findings point to a lack of good judgement about when and how to cross roads and making safe decisions, suggesting that cognitive decline was, indeed, a major contributing factor in their crashes. These findings must be treated with caution, however, as very little is known about the crash circumstances, particularly responsibility, behaviour and exposure of non-pedestrian subjects used as controls in this study. In addition, while this study provides good information about the prevalence of dementia amongst fatally injured pedestrians, what remains in question is the prevalence of crashes amongst pedestrians with dementia compared with the prevalence of dementia in the general older population. This knowledge would determine their relative risk.

2.3.1.2 Dementia and driving ability

There is substantial evidence of the effect of dementia, even in early stages, on road safety outcomes for drivers, including crashes, citations and driving performance (Freund, Gravenstein, Ferris, Burke and Shaheen, 2005; Brown, Stern, Cahn-Weiner, Rogers, Messer, Lannon, Maxwell, Souza, White & Ott, 2005), with the suggestion that drivers suffering from dementia are up to six times more likely to be crash-involved compared with cognitively intact drivers (Cooper et al., 1993). Given that functional skills underlying driving and pedestrian behaviour are most likely similar, these findings may imply that pedestrians with dementia may experience comparable problems interacting with traffic.

Zuin, Ortiz, Boromei and Lopez (2002) examined driving behaviours amongst people with dementia and normal elderly controls in Argentina. Caregivers were interviewed concerning the driving behaviour and frequency of collisions exhibited by the participants they cared for. Those with dementia displayed significantly more frequent crashes and more multiple crashes. They concluded that presence of dementia is a strong indicator of crashes and abnormal driving behaviour. Interestingly, they also found that being male was a strong predictor of crashes in the dementia group.

Rizzo et al. (2001) found that drivers with mild to moderate cognitive impairment due to AD were at greater risk for intersection crashes while driving on a virtual highway in a simulator scenario, compared to drivers without dementia. Individuals with deficits of attention, perception, response selection, response implementation and psychomotor declines were more likely than normal drivers to commit the kinds of errors that cause crashes (that is, failing to release the accelerator, apply the brake and make steering corrections to remain in the lane while averting a crash with a vehicle entering an intersection). Predictors of crash involvement included visuospatial impairment, disordered attention, reduced processing of visual motion cues and overall cognitive decline.

Most recently, Freund et al. (2005) examined the relationship between executive function impairment (using the Clock Drawing Test [CDT], a well-established test of executive function impairment and dementia) and driving errors in a driving simulator. Driving errors included hazardous errors (crashes, running red lights, lane position errors and turning position errors), traffic violations (speeding and driving dangerously slow), and rule violations (turning right on a red light, failing to turn and turning in the wrong direction). The results showed that the CDT was strongly associated with driving performance – those who scored poorly on the CDT made more driving errors, traffic violations and rule violations compared with those who scored well on the CDT.

2.3.1.3 *Dementia and task performance*

While not directly related to pedestrian performance, a number of studies report considerable difficulty with gait and postural stability associated with AD. Adults with AD generally have shorter step lengths, reduced gait speed, lower stepping frequency, and greater step-to-step variability than cognitively intact older adults (Sheridan, Solomont, Kowall & Hausdorff, 2003; O’Keefe, Kazeem, Philpott, Playfer, Gosney & Lye, 1996), and it has been argued that these changes cannot entirely be attributed to peripheral sensory and motor abnormalities, but also attributed to attentional deficits. O’Keefe et al. (1996) reported that patients with mild AD were more likely to exhibit a cautious gait, describing it as an appropriate response to ‘real or perceived instability’. In contrast, patients with moderate to severe AD displayed frontal gait disorder, characterised by prominent disequilibrium, short steps, shuffling and start and turn hesitation.

A number of studies have used the dual task paradigm (talking while walking) to demonstrate the association between attention deficits and walking amongst adults with AD, highlighting the important influence of attention and executive function on walking speed, stride variations, gait instability and increased risk of falling (Sheridan et al., 2003; Perry & Hodges, 1999; Baddeley et al., 2001; Camicioli et al., 1997). It is argued that walking ability is sensitive to the ability to divide attention, in part, because executive function input is needed to perform more than one task simultaneously.

As indicated earlier, another element of executive function is the ability to monitor one’s own actions and responses during task performance and it is suggested that executive function impairment in AD patients is related to self-monitoring failures (Perry & Hodges, 1999; Mathalon, Bennett, Askari, Gray, Rosenbloom & Ford, 2003). One technique used to assess self-monitoring and its failures is to examine a negative component, the ‘error-related negativity’ (ERN) of the event-related brain potential (ERP). Only a handful of studies have addressed this issue in the elderly and in AD patients. Studies have generally found that, although elderly subjects produce normal error rates and have normal error correction, they have smaller ERNs than younger healthy controls (Band & Kok, 2000; Falkenstein, Hoormann & Hohnsbein, 2000; Nieuwenhuis, Ridderinkof, Coles, Holroyd, Kok & van der Molen, 2002; Mathalon et al., 2003), and AD patients have reduced ERNs compared to age-matched controls (Mathalon et al., 2003). These findings suggest that,

compared with younger adults, older adults and those with AD have deficits in frontal lobe structure and function including a role in response monitoring. Mathalon et al. also found that AD patients had associated enhanced 'correct-response negativity' (CRNs), indicating that AD patients were less certain about their responses, although they managed to make a correct response. Thus, while the ERN may reflect slips, where the discrepancy between the correct and executed response is salient to the subject (reflecting deficits in the anterior cingulate cortex), the CRN may reflect mistakes due to faulty knowledge and response uncertainty (due to additional deficits of the dorsolateral prefrontal cortex).

2.3.2 Parkinson's Disease

PD is a chronic and progressive neurodegenerative disease that affects motor and sometimes cognitive function, which could potentially impair driving and walking performance. The prevalence of PD increases with age, affecting approximately one percent of individuals over the age of 65 years and increases to two percent in the population aged 70 years and older (Parkinson Society Canada, 2002).

PD is characterised by a decrease in spontaneous movements, bradykinesia (slowness of movement), gait difficulty, postural instability, tremor, and rigidity. In addition, it is now widely recognized that cognitive and executive function impairment are central features of the disease and can manifest even in the early stages (Wolters & Francot, 1998). Impairments include: difficulties in movement planning, impaired cueing of cognition, reduced performance on sequential and simultaneous tasks, subtle visuospatial defects and impairments in shifting attentional set (Low, Miller & Vierck, 2002; Lieb, Brucker, Bach, Els, Lücking & Greenlee, 1999). The short term working memory and non-verbal cognitive memory are also impaired in PD (Heikkilä, Turkka, Korpelainen, Kallanranta & Summala 1998). Some studies have also found that reaction times and information processing skills are diminished in adults with PD compared to those without PD, and that these difficulties (slowness and inaccuracy) mainly manifest themselves in complex situations (Low et al., 2002; Heikkilä et al., 1998). These features of cognitive impairment are likely to have particular relevance to the safety of drivers and pedestrians.

Many individuals with PD experience variation in how well PD medication controls their symptoms throughout the day, known as 'on-off' effects. Initially, these fluctuations can be fairly predictable, but the effects are less predictable over longer treatment periods. The effects of medication on road user performance, particularly pedestrian behaviour, are not known.

2.3.2.1 PD and pedestrian ability

Intuitively, physical and cognitive impairments associated with PD would have some impact on the ability to walk and interact safely in traffic. No studies were found, however, addressing this issue. Further, no studies were found that reported an association between PD and higher crash involvement for pedestrians.

2.3.2.2 PD and driving ability

There is some (limited) evidence that indicates that, even in the mild and moderate stages of the disease, PD significantly influences driving performance (Bootsma-van der Wiel et al., 2002; Heikkilä et al., 1998; Wood, Worringham, Kerr, Mallon & Silburn, 2005). Studies have also shown that drivers with PD are more likely to have been involved in a crash than controls (Dubinsky, Gray, Husted, Busenbark, Vetere-Overfield, Wiltfong, Parrish & Koller, 1991). In their review of driving performance in people with PD, Stolwyk, Triggs, Charlton and Bradshaw (in press) pointed out that many studies have

methodological limitations, such as recruitment bias and small sample size, and further research is warranted to investigate what specific aspects of driving performance are compromised in this population.

Stolwyk, Charlton, Triggs, Ianssek and Bradshaw (in press) examined the impact of impaired internal and external cueing on specific driving behaviours in a driving simulator among 18 adults with PD and 17 matched controls. They found that people with PD experienced difficulties using internal cues (advanced information from a map) to regulate driving behaviour around traffic signals and curves and consequently were more reliant on external cues (warnings of upcoming obstacles) to regulate driving behaviour and therefore less able to adapt their behaviour to suit driving conditions, particularly with regard to reacting to obstacles, adjusting approach speed and deceleration, adjust behaviour around curves, and maintain constant lane position. In a related study, Stolwyk, Triggs, Charlton, Ianssek and Bradshaw (2005) examined the effect of a concurrent task on driving performance amongst the same groups of participants. A concurrent task consisting of a range of 'target' and 'non-target' sounds in which participants responded when they heard two target sounds consecutively. In the concurrent tasks both groups drove more conservatively (reduced speed around traffic signals and curves and were less likely to adjust speed according to level of road curvature). Performance on the concurrent task was significantly reduced in people with PD compared to controls. These results highlighted the important role of cognition to driving performance within the PD population, pointing to reduced dual task performance in people with PD with a tendency to sacrifice internally generated action in favour of externally cued tasks, and a tendency to sacrifice concurrent task performance to maintain driving performance.

Wood et al. (2005) found that drivers with PD were rated as significantly less safe than controls by an OT and a driving instructor, and more than half of the drivers with PD would not have passed a licence-based driving test. Moreover, drivers with PD made more driving errors than controls during manoeuvres that involved changing lanes and lane keeping, monitoring their blind spot, reversing, car parking, and traffic light controlled intersections. They suggested that these errors probably stem from a combination of decreased motor control skills, impaired visuo-spatial processing, sequence control, and planning in the drivers with PD. The findings of this study not only draw attention to cognitive and executive function impairment in adults with PD and the effect on driving performance, but also show that it is not possible for patients to predict their driving safety or to deduce their driving ability from motor examination.

Likewise, in their examination of the driving performance of drivers with and without PD, Zesiewicz, Cimino, Malek, Gardner, Leaverton, Dunne and Hauser (2002) found that a group of PD drivers had more collisions on a driving simulator than control drivers, and the number of collisions rose in those in more severe stages of the disease.

2.3.2.3 *PD and task performance*

There is also some evidence that PD significantly influences walking ability. Rochester, Hetherington, Jones, Nieuwboer, Willems, Kwakkel and van Wegen, (2004) examined the interference effects of functional tasks on walking in PD and the roles of cognition, depression, fatigue and balance using a dual-task paradigm. Participants performed a simple walking task, a dual-motor task a dual-cognitive task and a multiple task, all of which were real-world activities. They found that PD participants walked at a significantly slower speed and reduced step length than controls. Performance of a concurrent cognitive task and multi-task resulted in significantly slower gait speed and reduced mean step length. These findings suggest that cognitive and executive function impairment,

depression, physical fatigue, and impaired balance are significantly related to walking for PD patients.

Morris, Iansek, Matyas and Summers (1995) noted that people with PD have most difficulty with sequential movements when they are performed with a concurrent task, for example when people with PD walk and talk their footsteps become short and the ground clearance reduces. Morris et al. developed a method of using visual cues (white strips of cardboard on the floor at desired step length) in order to assist people with PD to maintain stride length. They found that participants with PD could initiate walking, retain normal walking velocity, cadence and step length for approximately two hours, provided the focussed attention on maintaining the desired footstep pattern.

2.3.3 Cardiovascular and cerebrovascular Disease

Cardiovascular disease is a broad term for a group of disorders that affect the heart, arteries and veins, and include coronary heart disease, syncope, cardiac arrhythmias, high blood pressure and cerebrovascular disease (CVA) or stroke.

Cognitive impairment is a major sequelae of stroke, with significant cognitive deficits found in a substantial proportion of stroke patients (Tatemichi, Desmond, Stern, Paik, Sano & Bagiella, 1994; Zinn, Dudley, Bosworth, Hoenig, Duncan & Horner, 2004; Hochstenbach, Mulder, van Limbeek, Donders & Schoonderwaldt, 1998). Impairments associated with stroke and transient ischemic attack (TIA) vary considerably, depend on the location and severity of damage to the brain and may affect a range of neuropsychological and cognitive/executive abilities including memory, decision-making, attention, visuospatial perception, speech and language comprehension, and sensory and motor functions. Higher-order cognitive and executive function impairments associated with stroke and TIA may continue even after the recovery of visual perception and motor strength (Lundberg, Caneman, Samuelsson, Hakamies-Blomqvist & Almkvist, 2003). The relationship between clinical deficits as a result of stroke and driving ability or driving safety, however, is not entirely clear, with conflicting reports of driving performance and crash risk after stroke.

Severe congestive heart failure (CHF) is also associated with cognitive impairment. In particular, attentional skills have been shown to be particularly vulnerable to the effects of CHF. Almeida and Tamai (2001) examined cognitive functioning and attentional skills amongst patients with a clinical diagnosis of CHF compared with control patients with no CHF. Their results indicated that CHF was associated with significant decline in cognitive functioning, with almost $\frac{3}{4}$ of CHF patients scoring within the impaired range on tests of cognitive performance. They also found that performance of CHF patients on attention tasks was impaired relative to controls, and that the impairment became more prominent with CHF severity.

2.3.3.1 *Cardiovascular and Cerebrovascular Disease and pedestrian ability*

No studies were found providing any evidence of an association between any cardiovascular or cerebrovascular disorders and pedestrian performance or crash risk.

2.3.3.2 *Cardiovascular and Cerebrovascular Disease and driving ability*

There is some evidence of an association between driving ability and cognitive impairment associated with cardiovascular disease. Haselkorn, Mueller and Rivara (1998) compared the records of licensed drivers both before and after hospitalisation with those of non-hospitalised drivers. They found that individuals hospitalised because of a brain injury occurring from a stroke or trauma did not have an increase risk of crashing or driving

violation. However, this analysis did not include driving exposure as a variable that might influence crash and citation rates. Earlier studies report similar findings (e.g., Katz, Golden, Butter et al., 1990; Koepsell, Wolf, McCloskey et al., 1994).

The relationships among vision, attention, driving status and self-reported driving behaviours in community-dwelling stroke survivors were examined by Fisk, Owsley and Mennemeier (2002). They found that stroke survivors were impaired on all visual and attentional measures and that the severity of these deficits influence driving status and driving behaviour. However, they also found that many stroke survivors reduced driving markedly and adopted self-regulatory practices such as driving fewer miles, taking fewer trips, driving to fewer places and taking fewer long trips.

In contrast, others suggest that stroke patients have limitations that may interfere with driving performance including distractibility, inadequate scanning of the environment, poor lane positioning, judgement problems and slow responses in emergency situations and report reduced driving performance and increased crash risk amongst stroke patients (Sivak, Olson, Kewman, Won & Henson, 1981; McGwin, Sims, Pulley & Roseman, 2000; Fisk et al., 2002).

Heikkilä, Turkka, Korpelainen, Kallanranta & Summala (1999) reported on a case-control study, examining differences in cognitive and psychomotor skills between 20 male stroke patients and 20 matched controls. Stroke participants performed significantly worse than matched controls on tests of driving-related cognitive and psychomotor performance, with 60 percent of this group found to be unfit to drive by a traffic psychologist and a neurologist.

There is evidence for post-operative cognitive decline after coronary artery bypass grafting in close to 50 percent of surgery patients. Deterioration has been seen particularly on reaction time and attention tasks, and correspondingly on driving skills, observed during on-road testing. Ahlgren et al. (2002) investigated the incidence of post-operative cognitive decline and associated changes in driving performance after cardiac surgery (coronary artery bypass grafting [CABG]). They found that cognitive function declined in a group of patients that underwent CABG surgery compared with patients who underwent a less invasive surgery (percutaneous coronary intervention). Furthermore, patients with a cognitive decline after intervention deteriorated in their driving performance in simulated and on-road driving tasks to a greater extent than the patients without a cognitive decline, particularly in terms of speed adjustment to current traffic situations, lane positioning, and attention to traffic.

They also noted that between 1-6 percent of CABG patients suffer a stroke after surgery, and cognitive impairment such as memory dysfunction and concentration disturbances are reported to occur in 33-83 percent of patients. Lack of insight and difficulties with judgement are also implicated with stroke following surgery. The cognitive impairment is often transient and about 50 percent of patients have recovered after 6 weeks to 6 months, but in one-third of cases, symptoms can remain 1 year after surgery (Ricksten, 2000).

2.3.3.3 *Cardiovascular and cerebrovascular Disease and walking ability*

Given that many stroke patients suffer physical impairments that result in a reduction in mobility, it is intuitively important to understand the relationship between physical and cognitive dysfunction caused by stroke and the subsequent impact on walking ability.

Hyndman and Ashburn (2003) examined levels of attention deficits among people with stroke living in the community and explored the relationships between attention, balance, function and risk of falling. They found that the balance and function of participants with

normal attention capacity were better than those with sustained and divided attentional deficits and argued that attention deficits may contribute to accident-prone behaviour and falling.

Den Otter, Geurts, de Haart, Mulder and Duysens (2005) examined obstacle avoidance in hemiplegic stroke patients under conditions of time pressure. Stroke patients were more likely to walk slowly, to fail the obstacle avoidance task, and to lengthen their stride to reduce risk of contact with the obstacle, compared to normal older adults. Lengthening of stride, however, led to larger disturbances on the locomotor rhythm than in controls. The authors argued that gait speed is an important determinant of task complexity in adaptive gait tasks and that, for patients with stroke who walked more slowly, obstacle avoidance requires a proportionally higher degree of instantaneous adjustments in their gait pattern that places higher demands on cognitive functions.

2.3.4 Multiple Sclerosis

There is evidence that cognitive impairment is associated with Multiple Sclerosis (MS) in about half of all individuals diagnosed with MS (NINDS, 2001). These impairments can occur early in the course of the disease and can progress over time. Most commonly, people with MS exhibit slowed information processing abilities, reduced ability to focus, maintain, and shift attention, a reduced ability to learn new information and recall it, reduced visuospatial abilities (reduced ability to recognise objects, determine where they are in relation to each other and to move objects including themselves around in space), and executive dysfunction, particularly a reduced ability to perform complex tasks such as planning and carrying out a sequence of activities or problem-solving (Brassington & Marsh, 1998; Lings, 2002).

2.3.4.1 *MS and pedestrian ability*

No studies were found that investigated the effect of MS and associated cognitive impairment on pedestrian performance or crash risk.

2.3.4.2 *MS and driving ability*

A number of studies have reported an effect on driving performance and crash risk. Schultheis, Garay, Millis and DeLuca (2002) investigated the incidence of crashes and citations and driving performance amongst drivers with MS and cognitive impairment compared to drivers with MS and no cognitive impairment and matched control drivers. They found that, despite lower driving activity, individuals with MS and cognitive impairment had a significantly greater incidence of one or more crashes compared to both the MS individuals without cognitive impairment and control participants.

In an associated study, Schultheis, Garay and DeLuca (2001) examined the impact of cognitive impairment on driving skills by comparing the performance of drivers with MS and cognitive impairment, drivers with MS and no cognitive impairment and matched control drivers using the UFOV and the Neurocognitive Driving Test (NDT). Participants with MS and cognitive impairment performed slower on measures of timed responses throughout the NDT, compared to the other two groups (who performed similarly). On the UFOV overall score, the MS participants with cognitive impairment were significantly more likely than the other two groups to be categorised in the high-risk group for probability of driving difficulties. Analysis of the three subsections of the UFOV revealed that MS participants with cognitive impairment performed significantly poorer than the other two groups on central vision and processing speed. In addition, MS participants with cognitive impairment performed significantly worse than the control group on the selective

attention subsection, but were not significantly different to the MS participants without cognitive impairment. No group differences were found for performance on the divided attention subsection. The authors concluded that cognitive impairment can negatively affect driving-related skills in individuals with MS, however, additional studies are needed to clarify what specific cognitive factors influence driving performance.

Lings (2002) examined crash rates amongst 197 participants with MS and 546 matched control participants. In this study, exposure period was defined as the period of time, after the date of diagnosis, in which the individual held a driving licence. The outcome measure was treatment at the emergency department after a crash when they were the driver. Over the period of 1980 to 1989, five individuals with MS and four controls had been treated. He calculated that the crude crash rate in the SM group was 0.025 and in the control group was 0.007, resulting in a crude rate ratio of 3.46. Using relevant exposure in both groups, he calculated that the crash rate per 1000-years was 3.4 times higher in drivers with MS compared to the control cohort.

2.3.5 Summary of the effect of disease and medical conditions and associated cognitive impairment of pedestrian performance and crash risk

The majority of studies examining the effect of diseases and medical conditions have found significant effects of associated cognitive and executive function impairment on performance in a range of everyday tasks including walking and driving (see Table 4). There is a growing body of literature that provides strong evidence of the effect of cognitive and executive function impairment on fitness to drive. Cognitively impaired older drivers often make serious errors during driving tests or when driving an advanced driving simulator and are over-involved in serious injury and fatal crashes.

Like for normal age-related declines, only one study was found that directly examined the effect of cognitive and executive function impairment (associated with dementia) on pedestrian safety (see Table 4). This study provided evidence that cognitive impairment is a major contributing factor in pedestrian performance, particularly with regard to judgement about when and how to cross roads and making safe decisions. However, with sampling biases and methodological limitations, the conclusions drawn from this research must be treated with caution.

Moreover, there is strong evidence of a link between cognitive and executive function impairment as a result of disease or medical conditions and walking disability (particularly slowed gait, instability and falling) (see Table 5). These findings have wide implications for older pedestrian performance and safety.

Table 4: Cognitive impairment in driving and pedestrian risk

Authors	Method	Subject Matter / Key Findings
Gorrie et al. (2004)	Post-mortem examination of neurodegenerative change of 51 fatally injured older pedestrians and 49 fatally injured older adults from other sources.	AD and pedestrian crash risk Higher NFT scores amongst the pedestrian group compared to non-pedestrian group. Pedestrians with higher NFT were involved in crashes in which they may have been responsible for the crash.
Freund et al. (2005)	119 community-dwelling drivers aged >60 years referred for driver evaluation.	AD and driving performance Driving performance in a driving simulator was correlated with performance on the clock-drawing test (CDT). Poor performance on the CDT was significantly related to higher errors on the driving task.
Brown et al. (2005)	75 older adults (aged 40 to 90 years) (17 with mild AD, 33 with very mild AD and 25 elderly controls).. On-road driving tests and ratings of driving performance by a professional driving instructor.	AD and driving performance Performance of very mild AD and mild AD participants were similar and worst than control participants. The vast majority of participants with AD rated their driving ability as safe. Only neurologist's ratings of participants' driving abilities were significantly related to on-road driving score.
Zuin et al. (2002)	56 adults with dementia and 31 matched, healthy elderly controls. Driving behaviours examined and caregivers interviewed on demented driver behaviour, habits and crash involvement.	AD and driving performance and crash risk Drivers with dementia displayed significantly more frequent crashes and more multiple crashes than control drivers.
Rizzo et al. (2001)	18 case drivers with probable AD (M age 73), 12 control drivers without AD (M age 70).	AD and driving performance 33% of drivers with AD experienced 'crashes' in a driving simulator, compared to no control drivers. Driving errors amongst the AD group included inappropriate or slow control responses and inattention.
Bootsma-van der Wiel et al. (2002)	599 community-dwelling older adults aged 85 years old.	PD and stroke and walking ability Chronic diseases were common, both in people with and without walking disability, however, PD (OR=6.0), hip fracture (OR=4.3), and stroke (OR=3.7) were most strongly associated with walking

		disability. Cognition (OR=8.2) and grip strength (OR=7.8) were also strongly associated with walking disability, contributing more substantially than chronic diseases.
Heikkilä et al. (1998)	20 male adults with mild to moderate PD (<i>M</i> age 59) and 20 healthy matched controls (<i>M</i> age 55). Examination of cognitive status (MMSE), functional performance tests and driving ability assessed on a structured on-road driving test.	PD and driving performance PD participants performed worse than controls on all tests of functional performance, particularly in the visual memory test, in the choice reaction time test, and in the test for information processing capacity. PD participants committed significantly more risky faults and offences in the driving test than controls (errors driving in a traffic flow and turning).
Wood et al. (2005)	25 community-dwelling adults with PD and 21 age-matched control participants. On-road driving assessment and completed a questionnaire on driving experience and habits.	PD and driving performance Drivers with PD reported similar driving experiences and habits, although they drove fewer kms than control drivers. Drivers with PD made significantly more errors involving lane keeping and observation or monitoring of the blind spot than did the controls. Overall safety ratings by an occupational therapist and driving instructor were lower for drivers with PD, however, participants with PD did not rate the driving route as harder than the control participants.
Dubinsky et al. (1991)	150 adults with PD and 100 control adults without PD. Interviews on driving experiences and habits and examination of driving records. Cognitive status measured by MMSE.	PD and driving performance and crash risk Significantly higher crash rate per million vehicle miles of travel for participants with more severe PD (Hoehn and Yahr stage III) than participants with less severe PD (Hoehn and Yahr stage I) and control drivers.
i) Stolwyk et al. (in press) ii) Stolwyk et al. (in press)	18 adults with PD and 17 matched controls. Performance of driving in a simulator i) manipulating external and internal cues and ii) under dual task conditions.	PD and driving performance Drivers with PD experienced difficulties using internal cues and more reliant on external cues than control drivers. Performance of drivers with PD on concurrent task significantly reduced in dual task conditions, driving performance changed, but more conservative (similar to controls)..
Haselkorn et al. (1998)	Examination of CHARS database of people hospitalised in Washington State during 1992 aged >16 years and with CVA, TBI or extremity fractures. Examination of licensing and crash database.	Cardiovascular disease and driver crash risk Drivers who had sustained a CVA or TBI were at slightly decreased risk of receiving a citation after hospitalisation compared to their comparison group. Nor were the risks of experiencing two or more crashes in the 12 months after hospitalisation significantly elevated amongst driver with CVA or TBI.
Fisk et al. (2002)	50 stroke survivors and 105 control older adults without neurological or visual impairment	Cardiovascular disease and driving behaviour Correlations between functional performance scores (MMSE, MOMSSE, UFOV), driving status (Driving Habits Questionnaire) and self-reported crashes (verified by state records) revealed a

		relationship between degree of impairment , driving status and driving habits after stroke, but no correlation with crash risk.
McGwin et al. (2000)	Survey of 901 drivers (aged >65 years) selected from Alabama Department of Public Safety driving records: 249 at-fault drivers involved in crashes; 182 not at-fault drivers involved in crashes; and 475 drivers not involved in crashes.	Cardiovascular disease and driver crash risk After adjustment for age, gender, race and annual mileage no differences were noted for at-fault and not at-fault drivers. Older drivers with heart disease were more likely to be involved in both at-fault and not at-at fault automobile crashes than those without the medical condition (adjusted OR=1.5).
Heikkilä et al. (1999)	20 male stroke participants and 20 matched controls. Performance on neuropsychological tests and observations of behaviour as to their suitability to drive.	Cardiovascular disease and driving performance Drivers with stroke performed significantly worse on tests of driving related cognitive and psychomotor performance compared to control drivers, with 60% being found unfit to drive. Agreement between the traffic psychologist and neurologist was 75%.
Ahlgren et al. (2002)	27 case patients scheduled for CABG and 20 control patients with percutaneous coronary intervention (PCI).	Cardial surgery and driving performance More patients in the study group showed a cognitive decline after intervention, and a decline in on-road driving behaviour compared to control patients. No group difference in simulator driving performance.
Schultheis et al. (2002)	13 adults with MS and cognitive impairment (<i>M</i> age 40.9),, 14 adults with MS and no cognitive impairment (<i>M</i> age 45.5) and 17 healthy matched controls (<i>M</i> age 43.8).. Examination of DMV licensing and crash records. Comparison of driving-related skills using UFOV, WAIS-R, Stroop Colour Word test and TMT	MS and driving performance and crash risk MS group with cognitive impairment performed significantly below controls and drivers with MS and no cognitive impairment. MS group with cognitive impairment showed a significantly greater incidence of one or more crashes compared with drivers with MS and no cognitive impairment and control drivers. No group differences in incidence of a motor vehicle violation.
Schultheis et al. (2001)	13 adults with MS and cognitive impairment (<i>M</i> age 40.9),, 15 adults with MS and no cognitive impairment (<i>M</i> age 45.6) and 17 healthy matched controls (<i>M</i> age 43.8).. Comparison of driving-related skills using UFOV and Neurocognitive Driving Test (NDT).	MS and driving performance The MS group with cognitive impairment performed markedly slower on measures on timed responses throughout the NDT, and on central vision and processing speed and divided attention sections of the UFOV than both the MS group without cognitive impairment and healthy controls. No group differences were found for number of errors in the NDT. On the selective attention subsection of the UFOV, the MS group with cognitive impairment performed below the healthy controls, but did not differ in comparison with the MS group without cognitive impairment.

Table 5: Cognitive impairment in other activities of daily living

Authors	Method	Key Findings
Sheridan et al. (2003)	28 adults diagnosed with probable AD (M age 77.9).	AD and walking ability Participants walked slowly and with considerable stride-to-stride variability and introduction of dual task walking markedly influenced gait. Correlations between MMSE, CDT and verbal fluency and gait indicated that as cognitive function decreases, the ability to maintain a stable gait while performing a simple secondary task decreased in parallel.
O'Keefe et al. (1996)	55 adults with AD (21 with mild, 20 with moderately severe, and 14 with severe dementia) and 55 control participants (M overall age 78).	AD and walking ability 40% of AD participants had a high level of gait disorder, compared with 17% of control participants. The pattern of gait disturbance in AD participants varied according to the stage of the disease. Disequilibrium, short stepping gait, gegenhalten, primitive reflexes and apraxia were more common in AD participants compared with control participants.
Baddeley et al. (2001)	41 adults with a diagnosis of probable AD, 36 elderly controls and 36 young adults (aged 20-50 years). Different attentional resource systems were examined, i) simple and choice reaction time, ii) visual letter search, iii) dual-task performance (box crossing and memory span) and iv) dual task performance (visual search and auditory detection).	AD and walking ability No group differences were found in simple and choice reaction times, some difference in visual search, and highly significant group differences in overall reaction time, speed and accuracy of visual search on both dual-task paradigms.
Camicioli et al. (1997)	3 groups of community-dwelling adults: 20 old-old (M age 86), 23 young-old (M age 72) and 15 adults with probable AD without PD (M age 74).. Simultaneous performance of a verbal fluency task (effect of reciting male or female names) on the time and number of steps taken to walk 30 ft.	AD and walking ability AD group slowed more than young-old and old-old groups (who did not differ from each other) during dual task performance.
Mathalon et al. (2003)	12 adults with probable AD, 10 older adults and 10 younger adults (controls). Response monitoring during a picture name verification	AD and walking ability

	monitoring during a picture-name verification task.	Older and younger controls showed equivalent accuracy, error awareness and relative error-related negativity (ERN) > correct-response negativity (CRN) amplitude, older controls showed shower behavioural responses and decreased ERN amplitude. AD participants showed decreased accuracy, decreased ERN and a loss of relative ERN > CRN error amplitude compared to older and younger controls. No group differences were found for error awareness.
Rochester et al. (2004)	20 participants with PD (<i>M</i> age 64.6) and 10 matched controls (<i>M</i> age 63.5). Performance in simple, dual-motor, dual-cognitive and multiple cognitive/motor task conditions (walking, walking and carrying tray, walking and talking and walking, carrying tray and talking)	PD and walking ability Significant differences in walking speed and step length – PD participants walked slower and took smaller steps than controls, particularly in dual-cognitive task and multiple cognitive/motor task conditions. Logistic regression revealed that walking speed was significantly related to executive function, depression, and physical fatigue. Amongst the PD participants, balance accounted for 54% of the variance for walking.
Hyndman & Ashburn (2003)	48 mobile community-dwelling adults with stroke (<i>M</i> age 68.4). Interviewed on health, fall events, equipment, medication, co-morbidity, etc) and tested for visual inattention (Star Cancellation test), balance (Berg Balance Scale), and ADLs.	Stroke and walking ability Moderately high attention deficits, particularly older stroke participants. Significant correlations between ADL ability, balance and divided attention and sustained attention. Fall status correlated with divided attention, balance and ADL activity. Significant differences between fall groups. ‘Repeat fallers’ had greater divided attention deficits, and worst balance and ADL activity than ‘non-fallers with no near-falls’.
Den Otter et al. (2005)	11 hemiplegic stroke adults (<i>M</i> age 62.7), 7 healthy controls (<i>M</i> age 69.1). Walking performance on a treadmill with an obstacle.	Stoke and walking ability Higher proportion of failed trials in stroke group compared to controls (14% vs 0.5%). Stride lengthening among stroke group, particularly slower walking participants (up to 131% compared to 27-37% amongst controls).

3 CONCLUSIONS AND FUTURE RESEARCH

Older pedestrian crashes are a significant road safety problem and providing for the ongoing, safe mobility of this group requires a complete understanding of the factors associated with crash and injury risk. Given that crashes involving older road users more often occur in complex situations, in which the driving or walking task is not self-paced and there is a particular risk of cognitive and executive function overload, it seems plausible that cognitive and executive function limitations would affect performance and therefore play a part in their crash causation.

Research has gone some way towards identifying normal age-related functional changes and changes associated with medical conditions that have a significant association with older driver performance and crash risk. However, the list remains short and, in most cases, the association seems to be fairly moderate and conjectural. The outcome of this component of the review is summarised as follows:

Issue	No. studies	Outcome
Age differences in road-crossing behaviour	6	No direct evidence of the effect of cognitive decline on pedestrian performance
Effect of cognitive decline on road-crossing decisions	5	Some evidence of effect of multiple cognitive declines on ability to select safe gaps
Effect of cognitive decline on pedestrian crash risk	0	No evidence
Effect of cognitive decline on driving ability and crash risk	5	Moderate associations found
Effect of cognitive decline on walking ability	3	Moderate associations found

More substantial evidence of an association between cognitive impairment and driving ability and ability to perform activities of daily living was found. Only one study was found that investigated the effect of dementia on pedestrian crash risk (Gorrie et al., 2004). This was a post-mortem examination of neuro-degenerative change amongst fatally injured pedestrians, compared to fatally injured older adults from other sources. The findings are somewhat speculative however, considering the samples chosen, subjectivity about attribution of crash responsibility, and the assumption that the 'control' group was a sample of non-pedestrians on the basis of their death while undertaking some other activity. The conclusions drawn must be treated with caution. The outcome of this component of the review is summarised as follows:

Issue	No. studies	Outcome
Effect of cognitive impairment associated with dementia and pedestrian crash risk	1	High proportion of fatally injured pedestrians with neurodegenerative change
Effect of medical conditions on driving ability and crash risk	24	Moderate to strong associations found
Dementia	5	
Parkinson's disease	8	
Cerebrovascular disease	8	
Multiple Sclerosis	3	
Effect medical conditions on walking ability	10	Moderate to strong associations found
Dementia	5	
Parkinson's disease	2	
Cerebro-vascular disease	2	

In addition, there is wide variation in the methods used to examine these issues and there are many methodological considerations and limitations. For example: there is frequent lack of adjustment for potential confounding variables; wide debate concerning representativeness, selection of participant samples, and selection of cognitive/neuropsychological measures; concerns about measuring of performance on the road; and, the use of a wide variety of assessment tools to identify cognitive impairment and classify the level of impairment. These factors make it extremely difficult to differentiate between people with various forms of cognitive decline and impairment who are able to walk and cross roads safely, and those who are not. Despite these limitations, the evidence suggests the following may play some role in older pedestrian safety:

- Most people experience some level of cognitive and executive function decline as they age, and functional limitations are most prevalent towards the end of normal life.
- Normal age-related declines in single cognitive and executive functions appear to have little effect on performance in less demanding traffic situations.
- Declines in multiple relevant cognitive and executive functions appear to have some effect on performance in demanding traffic situations. The most relevant declines for road-crossing performance include: slowed information processing, declines in attentional processes, memory problems, difficulty in selecting and integrating information, poor decision-making and slowed response initiation.
- Most older adults have the capacity to compensate for declines in cognitive and executive functions, although the ability to compensate may be inadequate where there are multiple declines in several cognitive and executive functions, especially amongst those approaching the end of their lives.
- Adoption of compensation strategies which rely on insight or awareness of abilities. This insight may be affected where there are multiple declines in cognitive and executive functions.
- Cognitive and executive function impairment associated with some diseases and medical conditions may have functional implications for older pedestrian performance.

- Cognitive and executive impairment associated with moderate to severe dementia may greatly affect pedestrian performance, as it affects attention, memory, accuracy of movement, risk perception, ability to perform novel tasks and awareness of their compromised cognitive condition, skills necessary for safe negotiation of traffic and road-crossing decisions.
- Cognitive and executive impairment associated with mild, moderate and severe PD may greatly affect the ability to walk and interact safely in traffic, as it affects slowness of movement, gait difficulty, postural instability, planning and executing movement, attention, and memory, skills necessary for safe negotiation of traffic and road-crossing decisions.
- Cognitive and executive impairment associated with cardio- and cerebrovascular disease may affect pedestrian performance, as attention, memory, judgement, decision-making, and gait difficulty are affected in some of these diseases, particularly stroke.
- Cognitive and executive impairment associated with MS may affect pedestrian performance, as it can affect information processing, attention, recognition of objects, problem-solving, ability to perform novel tasks, and physical skills.

3.1 RECOMMENDATIONS FOR FUTURE RESEARCH

Given that these associations are somewhat speculative and predominantly based on studies that have investigated cognitive and executive functions on walking and driving abilities, related to pedestrian performance, but not focussed on road-crossing performance, further research in the following areas is clearly warranted. It is essential to, first, understand the basic problems that older adults face as pedestrians, particularly understanding the relationship between cognitive impairment and pedestrian performance and crash risk. It is only with this knowledge that appropriate countermeasures can be developed. The following research priorities are recommended:

1) An understanding of the prevalence of cognitive/executive function decline and among older people who walk

Clearly, there is no information currently available in Australia on the prevalence of cognitive/executive function decline and impairment amongst older people who still walk. It is important to understand this prevalence to gain a good understanding of the magnitude of the problem. There are a number of ways in which this information can be attained including:

- Longitudinal case/control study of crash-involved and non-crash-involved pedestrians to gain information on the effect of progressive cognitive impairment on walking and road-crossing ability. Information on changes in pedestrian activity, exposure, behaviour and travel patterns, changes in cognitive and health status and crash-involvement among pedestrians with cognitive impairment could be collected.
- In-depth study of crash-involved pedestrians. An in-depth study of older pedestrians seriously injured and hospitalised would provide important information on road user characteristics, road user behaviour including adoption of compensatory strategies, cognitive status, health status and incidence of medical conditions, information on crashes and contributing factors, crash severity and health outcomes.
- Analysis of databases on fatal pedestrian crashes. For example, analysis of the National Coroner's Information System (NCIS) would provide information on the

proportion of older pedestrians with a medical condition (e.g., a diagnosis of dementia) who have been involved in a fatal crash, the types of crashes they are involved in, and other key characteristics including medications and the presence of co-morbid conditions.

2) An understanding of the effect of cognitive/executive function decline and impairment on pedestrian performance, particularly the specific skills and severity of impairment that affect road-crossing ability.

This review has demonstrated that there are many gaps in our knowledge and understanding of the effect and extent of functional decline and impairment on road-crossing behaviour and further comprehensive research will be critical to understand the specific skills and severity of impairment that affect road-crossing safety. These issues may be examined in an experimental research program designed to investigate the effects of a range of diseases and medical conditions and general impairments on the ability to make safe road-crossing decisions and identify ‘high-risk’ pedestrians.

3) An understanding of the effect of road complexity on pedestrian performance

As indicated, older road user crashes commonly occur in complex situations. A number of complex manoeuvres and road environments have been identified for older drivers and pedestrians, particularly in the work conducted by Oxley et al., showing that two-way traffic is problematic for older adults, however, much is still to be learned about other types of complex environments and tasks for older pedestrians. An investigation of these issues using an experimental design should be undertaken in order to understand the effect of complexity on road-crossing performance amongst pedestrians with and without cognitive impairment.

4) Development of countermeasures

Many countermeasures have been suggested to improve the mobility and safety of older pedestrians, however, the functional difficulties experienced by cognitively impaired pedestrians are rarely considered and the majority of countermeasures are not evaluation. There is a clear need to first understand the basic problems older people face as pedestrians, identify the problems experienced by cognitively impaired pedestrians and to develop and evaluate countermeasures designed with the needs of these pedestrians in mind. In their review of measures to reduce crash and injury risk to older vulnerable road users, Oxley et al. (2004) identified world ‘best-practice’ solutions that may have some effect on older pedestrian safety and suggested a comprehensive strategy that includes educational, training and awareness initiatives, improvements to vehicle design and ensuring a safe and comfortable road environment in which to walk.

Improved infrastructure and road design can achieve immediate and cost-effective results and the provision of a safe road environment can markedly improve the mobility and safety of all-aged vulnerable road users. Road design improvements that may particularly benefit older pedestrians include: measures to moderate vehicle speeds in high pedestrian activity areas, measures to separate or restrict vehicular and non-vehicular traffic in high pedestrian activity areas, measures to reduce the complexity of intersections and road lengths.

3.2 CONCLUSION

In conclusion, there are obvious benefits of walking for health and well-being of individuals and the environment and pedestrian travel is a major mode of transport. Indeed, there are many programs world-wide that actively promote increased walking and cycling. However, older pedestrians are at increased risk of death and serious injury as pedestrians. While there is evidence that functional declines and impairments contribute to increased crash risk amongst older pedestrians, there is still much to be learned, however, about the effect and extent of cognitive decline and impairment on pedestrian safety. Unless there is a good understanding of how cognitive decline and impairment contributes to crash risk of older pedestrians and development of appropriate countermeasures, the problems and risks associated with pedestrian travel will worsen in the coming decades.

REFERENCES

- Ahlgren, E., Lundqvist, A., Nordlund, A., Aren, C., & Rutberg, H. (2003). Neurocognitive impairment and driving performance after coronary artery bypass surgery. *European Journal of Cardio-thoracic Surgery*, 23, 334-340.
- Albert, M., Heller, S., & Millberg, W. (1988). Changes in naming ability with age. *Psychology and Aging*, 3, 173-178.
- Albert, M., Wolfe, J., & Lafleche, G. (1990). Differences in abstraction ability with age. *Psychology and Aging*, 5, 94-100.
- Almeida, O., & Tamai, S. (2001). Congestive heart failure and cognitive functioning amongst older adults. *Arquivos de Neuro-Psiquiatria*, 59(2-B), 324-329.
- Arenberg, D. (1990). Longitudinal changes in cognitive performance. *Advances in Neurology*, 51, 207-209.
- Australian Transport Safety Bureau [ATSB] (2003). Road crash data and rates Australian States and Territories 1925-2002. Canberra, Australia, Department of Transport and Regional Services.
- Baddeley, A. (1999). *Human memory theory and practice* (Revised Edition). East Sussex, UK, Psychology Press Ltd.
- Baddeley, A., Baddeley, H., Bucks, R., & Wilcock, G. (2001). Attentional control in Alzheimer's Disease. *Brain*, 124, 1492-1508.
- Ball, K., & Owsley, C. (1993). The useful field of view test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association*, 64, 71-79.
- Band, G., & Kok, A. (2000). Age effects on response monitoring in a mental-rotation task. *Biological Psychology*, 51, 201-221.
- Beauchet, B., Dubost, V., Stierlam, F., Blanchon, M., Mourey, F., Pfitzenmeyer, P., Gonthier, R., & Kressig, R. (2002). [Influence of a specific cognitive task on spatial-temporal walking parameters in elderly frail individuals]. *La Presse Médicale*, 31, 1117-1122.
- Bennett, D., Wilson, R., Schneider, J., Evans, D., Beckett, L., Aggarwal, N., Barnes, L., Fox, J., & Bach, J. (2002). Natural history of mild cognitive impairment in older persons. *Neurology*, 59(2), 198-205.
- Bergland, A., & Wyller, T. (2004). Risk factors for serious fall related injury in elderly women living at home. *Injury Prevention*, 10(5), 308-313.
- Binder, E., Schechtman, K., Ehsani, A., Steger-May, K., Brown, M., Sinacore, D., Yarashaki, K., & Holloszy, J., (2002). Effects of exercise training on frailty in community-dwelling older adults: Results of a randomised, controlled trial. *Journal of American Geriatrics Society*, 50, 1921-1928.
- Binetti, G., Magni, E., Padovani, A., et al., (1996). Executive dysfunction in early Alzheimer's disease. *Journal Neurology, Neurosurgery and Psychiatry*, 60, 91-93.
- Birren, J., & Schaie, K. (1996). *Handbook of the psychology of aging*. San Diego, USA, Academic Press.
- Ble, A., Volpato, S., Zuliani, G., Guralnik, J., Bandinelli, S., Lauretani, F., Bartali, B., Maraldi, C., Fellin, R., & Ferrucci, L. (2005). Executive function correlates with walking

- speed in older persons: The InCHIANTI study. *Journal of the American Geriatrics Society*, 53(3), 410-415.
- Bootsma-van der Wiel, A., Gussekloo, J., de Craen, A., van Exel, E., Bloem, B., & Westendorp, R. (2002). Common chronic diseases and general impairments as determinants of walking disability in the oldest-old population. *Journal of American Geriatrics Society*, 50, 1405-1401.
- Botwinick, J., & Siegler, I. (1980). Intellectual ability among the elderly: Simultaneous cross-sectional and longitudinal comparisons. *Developmental Psychology*, 16, 49-53.
- Braak, H., & Braak, E. (1991). Neuropathological staging of Alzheimer-related changes. *Acta Neuropathologica*, 82, 239-259.
- Brassington, J., & Marsh, N. (1998). Neuropsychology of multiple sclerosis. *Neuropsychological Review*, 8, 43-77.
- Brody, H. (1994). Structural changes in the aging brain. In R Copeland, M Abou-Saleh, & D Blazer (Eds.). *Principles and practice of geriatric psychiatry*, (pp. 30-33). Chichester, Britain, Wiley.
- Brown, L., Shumway-Cook, A., & Woollacott, M. (1999). Attentional demands and postural recovery: The effects of aging. *Journal of Gerontology A: Biological Science and Medical Science*, 54a, M165-M171.
- Brown, L., Stern, R., Cahn-Weiner, D., Rogers, B., Messer, M., Lannon, M., Maxwell, C., Souza, T., White, T., & Ott, B. (2005). Driving scenes test of the Neuropsychological Assessment Battery (NAB) and on-road driving performance in aging and very mild dementia. *Archives of Clinical Neuropsychology*, 20(2), 209-215.
- Camicioli, R., Howieson, D., Lehman, S., & Jeffrey, K. (1997). Talking while walking. The effect of a dual task in aging and Alzheimer's Disease. *Neurology*, 48, 955-958.
- Carlson, M., Fried, L., Xue, Q., Bandeen-Roche, K., Zeger, S., & Brandt, J. (1999). Association between executive attention and physical functional performance in community-dwelling older women. *Journal of Gerontology B: Psychological Science and Society Science*, 54(5), S262-270.
- Carsten, O., Hodgson, F., & Tight, M. (1990). Pedestrian behaviour in Bradford. In I.N.L.G. van Schagen, A database for pedestrian and pedal cyclist traffic model. (Drive project V1031 Report 6). Haren, the Netherlands, Traffic Research Centre.
- Carthy, T., Packham, D., Salter, D., & Silcock, D. (1995). Risk and safety on the roads: The older pedestrian. Basingstoke, UK, AA Foundation for Road.
- Charlton, J., Oxley, J., Fildes, B., Oxley, P. (2003). Self-regulatory behaviours of older drivers. Proceedings of the 47th Annual AAAM Conference, Lisbon, Portugal.
- Chen, J., March, L., Schwarz, J., Zochling, J., Makaroff, J., Sitoh, Y., Lau, T., Lord, S., Cameron, I., Cumming, R., & Sambrook, P. (2005). A multivariate regression model predicted falls in residents living in intermediate hostel care. *Journal of Clinical Epidemiology*, 58, 503-508.
- Chen, J., Sultzer, D., Hinkin, C., Mahler, M., & Cummings, J. (1998). Executive dysfunction in Alzheimer's disease. *The Journal of Neuropsychiatry*, 10, 426-432.
- Clark, D. (1996). The effect of walking on lower body disability among older blacks and whites. *American Journal of Public Health*, 83, 1443-1450.

- Collette, F., van der Linden, M., & Salmon, E. (1999). Executive dysfunction in Alzheimer's Disease. *Cortex*, 35, 57-72.
- Cooper, P., Tallman, K., Tuokko, H., & Beattie, B. (1993). Vehicle crash involvement and cognitive deficit in older drivers. *Journal of Safety Research*, 24, 9-17.
- Daigneault, G., Joly, P., & Frignon, J-F. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical and Experimental Neuropsychology*, 24(2), 221-238.
- Davies, D. (1999). Research, development and implementation of pedestrian safety facilities in the United Kingdom. (Report No. FHWA-RD-99-089). Washington DC, USA, Federal Highway Administration, US Department of Transportation.
- Davis, H., & Rockwood, K. (2004). Conceptualisation of mild cognitive impairment. A review. *International Journal of Geriatric Psychiatry*, 19, 313-319.
- Den Otter, A., Geurts, A., de Haart, M., Mulder, T., & Duysens, J. (2005). Step characteristics during obstacle avoidance in hemiplegic stroke. *Experimental Brain Research*, 161, 180-192.
- DiFabio, R., Kurszewski, W., Jorgenson, E., & Kunz, R. (2004). Footlift asymmetry during obstacle avoidance in high-risk elderly. *Journal of the American Geriatrics Society*, 52(12), 2088-2093.
- DiFabio, R., Zampieri, C., Henke, J., Olson, K., Rickheim, D., & Russell, M. (2005). Influence of elderly executive cognitive function on attention in the lower visual field during step initiation. *Gerontology*, 51(2), 94-107.
- Dixon, R., Kramer, D., & Baltes, P. (1985). A life-span developmental perspective. In B Wolfman (Ed.). *Handbook of intelligence. Theories, measurements, and applications*, (pp. 301-352). New Jersey, USA, Lawrence Erlbaum Associates.
- Draskòszy, M. (1990). Pedestrian and pedal cyclist behaviour in Växjö. In I. Van Schagen. A database for pedestrian and pedal cyclist traffic model. (Drive Project V1031, Report 6). Haren, the Netherlands, Traffic Research Centre.
- Dubinsky, R., Gray, C., Husted, D., Busenbark, K., Vetere-Overfield, B., Wiltfong, D., Parrish, D., & Koller, W. (1991). Driving in Parkinson's disease. *Neurology*, 41, 517-20
- Eberhard, J. (1996). Safe mobility for senior citizens. *IATSS Research*, 20(1), 29-37.
- Eck, R., & Simpson, E. (1996). Using medical records in non-motor-vehicle pedestrian accident identification and countermeasure development. *Transportation Research Record*, 1538, 54-60.
- Elliott, D., Elliott, B., & Lysaght, A. (1995). Older driver risks and countermeasures: Source book. (Report No. CR 163). Canberra, Australia, Federal Office of Road Safety.
- Eustache, F., Rioux, P., Desgranges, B., Marchal, G., Petit-Taboue, M., Dary, M., Lechavalier, B., & Baron, J. (1995). Healthy aging, memory subsystems and regional cerebral oxygen consumption. *Neuropsychologia*, 33, 867-887.
- Falkenstein, M., Hoormann, J., Hohnsbein, J. (2001). Changes of error-related ERPs with age. *Experimental Brain Research*, 138, 258-262.
- Federal Highway Administration [FHWA] (1999). Injury to pedestrians and bicyclists: An analysis based on hospital emergency department data. (Report No. FHWA-RD-99-078). Washington DC, USA, Federal Highway Administration, US Department of Transportation.

- Fisk, G., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviours in community-dwelling stroke survivors. *Archives Physical Medicine and Rehabilitation*, 83, 469-477.
- Folstein, M., Folstein, S., & McHugh, P. (1975). Mini-Mental State: A practical method for grading the state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189-198.
- Fontaine, H., & Gourlet, Y. (1997). Fatal pedestrian accidents in France: A typological analysis. *Accident Analysis and Prevention*, 29(3), 303-312.
- Forward, S., (1998). Behavioural factors affecting modal choice. Analysis and Development Of New Insight into Substitution of short car trips by cycling and walking (ADONIS). Research project for the EU Transport RTD programme, European Commission, Directorate General for Transport, Swedish National Road and Transport Research Institute, Linköping, Sweden.
- Freund, B., Gravenstein, S., Ferris, R., Burke, B., & Shaheen, E. (2005). Drawing clocks and driving cars. *Journal General Internal Medicine*, 20(3), 240-244.
- Gorrie, C., Waite, P., Sachdev, P., Rodriguez, M., Duflou, J., & Brown, J. (2004). Fatalities in older drivers and pedestrians: Neuropathological evaluation of pre-clinical dementia. Motor Accident Authority, Sydney, NSW.
- Grant, D., & Berg, E. (1948). A behavioural analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology*, 38, 404-411.
- Green, M., Kaye, J., & Ball, M. (2000). The Oregon brain aging study: neuropathology accompanying healthy aging in the oldest old. *Neurology*, 54, 105-113.
- Hagenzieker, M. (1996). Some aspects of the safety of elderly pedestrians and cyclists. (Report No. D-96-4). Leideschendam, the Netherlands, SWOV Institute for Road Safety Research.
- Harkey, D. (1995). Intersection Geometric Design Issues for Older Drivers and Pedestrians. Institute of Transportation Engineers 65th Annual Meeting.
- Harruff, R., Avery, A., & Alter-Pandya, A. (1998). Analysis of circumstances and injuries in 217 pedestrian traffic fatalities. *Accident Analysis and Prevention*, 30(1), 11-20.
- Haselkorn, J., Mueller, B., & Rivara, F. (1998). Characteristics of drivers and driving records after traumatic and non-traumatic brain injury. *Archives of Physical Medicine and Rehabilitation*, 79, 738-742.
- Hasher, L., & Zacks, R. (1988). Working memory, comprehension, and aging: A review and a new view. In G Bower (Ed.). *The Psychology of Learning and Motivation*, (pp. 193-225). San Diego, USA, Academic Press.
- Hauer, K., Pfisterer, M., Weber, C., Wezler, N., Kliegel, M., & Oster, P. (2003). Cognitive impairment decreases postural control during dual tasks in geriatric patients with a history of severe falls. *Journal of the American Geriatrics Society*, 51(11), 1638-1644.
- Hausdorff, J., Yogev, G., Springer, S., Simon, E., & Giladi, N. (2005). Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Experimental Brain Research*, online first publication, <http://www.springeronline.com>.
- Heikkilä, V-M., Turkka, J., Korpelainen, J., Kallanranta, T., & Summala, H. (1998). Decreased driving ability in people with Parkinson's disease *Journal of Neurology, Neurosurgery and Psychiatry*, 64, 325-330.

- Heikkilä, V-M., Turkka, J., Korpelainen, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke participants. *Acta Neurologica Scandinavica*, 99(6), 349-355.
- Henderson, A., & Jorm, A. (1998). *Dementia in Australia*. Canberra, Australia, Commonwealth Department of Health and Family Services.
- Hochstenbach, J., Mulder, T., van Limbeek, J., Donders, R., & Schoonderwaldt, H. (1998). Cognitive decline following stroke: A comprehensive study of cognitive decline following stroke. *Journal of Clinical Experimental Neuropsychology*, 20, 503-517.
- Holland, C., & Rabbitt, P. (1992). People's awareness of their age-related sensory and cognitive deficits and the implications for road safety. *Applied Cognitive Psychology*, 6, 217-231.
- Hulette, C., Walsh-Bohmer, K., Murray, M., et al., (1998). Neuropathological and neuropsychological changes in normal aging: Evidence for preclinical Alzheimer's disease in cognitively normal individuals. *Journal Neuropathology and Experimental Neurology*, 57, 1168-1174
- Hulsch, D., Hertzog, C., Small, B., McDonald-Mizczak, L., & Dixon, R. (1992). Short-term longitudinal change in cognitive performance in later life. *Psychology and Aging*, 7, 571-584.
- Hunter, W., Stutts, J., Pein, W., & Cox, C. (1995). Pedestrian and bicycle crash types of the early 1990s. (Report No. FHWA-RD-95-163). Washington DC, USA, Federal Highway Administration, US Department of Transportation.
- Hydén, C., Nilsson, A., & Risser, R. (1998). WALCYNG – How to enhance WALKing and CyclING instead of shorter car trips and to make these modes safer. Final Report. Department of Traffic Planning and Engineering, University of Lund, Sweden & FACTUM Chaloupka, Praschl & Risser OHG, Vienna, Austria.
- Hyndman, D., & Ashburn, A. (2003). People with stroke living in the community: Attention deficits, balance, ADL ability and falls. *Disability and Rehabilitation: An International Multidisciplinary Journal*, 25(15), 817-822.
- Janke, M. (1994). Age-related disabilities that may impair driving and their assessment: Literature review. Sacramento, California Department of Motor Vehicles.
- Jensen, S. (1999). Pedestrian safety in Denmark. *Transportation Research Record*, 1674, 61-69.
- Jorm, A., & Jolley, D. (1998). The incidence of dementia: a meta-analysis. *Neurology*, 51, 728-733.
- Katz, R., Golden, R., Butter, J., et al., (1990). Driving safety after brain damage: Follow-up of twenty-two patients with matched controls. *Archives of Physical Medicine and Rehabilitation*, 71, 133-137.
- Kenny, R., Kalaria, R., & Ballard, C. (2002). Neurocardiovascular instability in cognitive impairment and dementia. *Annals of the New York Academy of Sciences*, 977, 183-195.
- Koepsell, T., McCloskey, L., Wolf, M., Vernez-Moudon, A., Buchner, D., Kraus, J., & Patterson, M. (2002). Crosswalk markings and the risk of pedestrian-motor vehicle collisions in older pedestrians. *Journal of the American Medical Association*, 288(17), 2136-2143.

- Koepsell, T., Wolf, M., McCloskey, L., et al. (1994). Medical conditions and motor vehicle collision injuries in older adults. *Journal of the American Geriatrics Society*, 42, 695-700.
- Kukull, W., & Ganguli, M. (2000). Epidemiology of dementia: concepts and review. *Neurologic Clinics*, 18, 923-950.
- LaCroix, A., Guralnik, J., & Berkman, L. (1993). Maintaining mobility in late life II. *American Journal of Epidemiology*, 137, 858-869.
- Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Attentional demands for walking: Age-related changes. In A Ferrandez & N Teasdale (Eds.). *Changes in sensory motor behaviour in aging*, (pp. 235-255). New York, USA, Elsevier Science.
- Lee, D., Young, D., & McLaughlin, C. (1984). A roadside simulation of road-crossing for children. *Ergonomics*, 27(12), 1271-1281.
- Lichtenberg, P., Murman, D., & Mellow, A., (2003). *Handbook of dementia: psychological, neurological and psychiatric perspectives*. New Jersey, USA. Wiley & Sons Inc.
- Lieb, K., Brucker, S., Bach, M., Els, T., Lücking, C., & Greenlee, M. (1999). Impairment in preattentive visual processing in patients with Parkinson's disease. *Brain*, 122, 303-313.
- Lings, S. (2002). Driving crash frequency increases in participants with multiple sclerosis. *Acta Neurologica Scandinavica*, 105, 169-173.
- Low, K., Miller, J., & Vierck, E. (2002). Response slowing in Parkinson's disease: a psychophysiological analysis of premotor and motor processes. *Brain*, 125, 1980-1994.
- Lundberg, C., Caneman, G., Samuelsson, S., Hakamies-Blomqvist, L., & Almkvist, O. (2003). The assessment of fitness to drive after a stroke. The Nordic Stroke Driver Screening assessment. *Scandinavian Journal of Psychology*, 44, 23-30.
- Lundberg, C., Hakamies-Blomqvist, L., Almkvist, O., & Johansson, K. (1998). Impairments of some cognitive functions are common in crash-involved older drivers. *Accident Analysis and Prevention*, 30(3), 371-377.
- Lundin-Olsson, L., Nyberg, L., & Gustafson, Y. (1997). 'Stops walking when talking' as a predictor of falls in elderly people. *Lancet*, 617.
- Manton, K. (1988). A longitudinal study of functional change and mortality in the United States. *Journal of Gerontology*, 43, S153-S161.
- Marottoli, R., & Richardson, E. (1998). Confidence in, and self-rating of, driving ability among older drivers. *Accident Analysis and Prevention*, 30(3), 331-336.
- Marottoli, R., Richardson, E., Stowe, M., Miller, E., Brass, L., Cooney, L., & Tinetti, M. (1998). Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *Journal of the American Geriatrics Society*, 46(5), 562-568.
- Masunaga, H., & Horn, J. (2000). Characterising mature human intelligence: Expertise development. *Learning and Individual Differences*, 21(1), 5-33.
- Mathalon, D., Bennett, A., Askari, N., Gray, E., Rosenbloom, M., & Ford, J. (2003). Response-monitoring dysfunction in aging and Alzheimer's disease: an event-related potential study. *Neurobiology of Aging*, 24, 675-685.
- Mattis, S. (1976). Mental status examination for organic mental syndrome in the elderly patient. In L Bella & T Karasu. (Eds.). *Geriatric Psychiatry*, (Second Edition). New York, USA, Oxford University Press.

- McGwin, G., Sims, R., Pulley, L., & Roseman, J. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: A population-based case-control study. *American Journal of Epidemiology*, 152, 424-431.
- Melzer, I., & Oddsson, L. (2004). The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. *Journal of the American Geriatrics Society*, 52, 1255-1262.
- Mesken, J., & Davidse, R.J. (2001). De verkeersveiligheid van oudere verkeersdeelnemers in Drenthe. (Report R2001-27). Leidschendam, the Netherlands, SWOV Institute for Road Safety Research.
- Mirra, S., Heyman, A., McKeel, D., Sumi, S., Crain, B., Brownlee, L., Vogel, F., Hughes, J., van Belle, G., & Berg, L. (1991). The consortium to establish a registry for Alzheimer's disease (CERAD). Part II. Standardization of the neuropathological assessment of Alzheimer's disease. *Neurology*, 41, 479-486.
- Mitchell, C. (2000). Some implications for road safety of an ageing population. *Transport trends*, (pp. 26-34). London, UK, Department of the Environment, Transport and the Regions, The Stationary Office.
- Morris, J., Storandt, M., Miller, J., McKeel, D., Price, J., Rubin, E., & Berg, L. (2001). Mild cognitive impairment represents early-stage Alzheimer disease. *Archives of Neurology*, 58, 397-405.
- Morris, M., Iannsek, R., Matyas, T., & Summers, J. (1995). Stride length regulation in Parkinson's disease: normalization strategies and underlying mechanisms. *Brain*, 119, 551-568.
- National Highway Traffic Safety Administration [NHTSA] (2001). Traffic safety facts 2000: Pedestrians. (Report DOT HS 809311). Washington, DC, US Department of Transport.
- National Institute of Neurological Disorders and Stroke (NINDS). Multiple sclerosis information page. http://www.ninds.nih.gov/health_and_medical/disorders/multiple_sclerosis.htm
- Nieuwenhuis, S., Ridderinkhof, K., Coles, M., Holroyd, C., Kok, A., & van der Molen, W. (2002). A computational account of altered error processing in older adults: dopamine and the error-related negativity. *Cognitive, Affective and Behavioural Neuroscience*, 2, 19-36.
- O'Brien, J., Ames, D., & Burns, A. (2000). *Dementia (Second Edition)*. London, UK. Arnold Press.
- O'Keefe, S., Kazeem, H., Philpott, R., Playfer, J., & Gosney, M., & Lye, M. (1996). Gait disturbance in Alzheimer's Disease: A clinical study. *Age and Ageing*, 25, 313-316.
- Organisation for Economic Co-operation and Development [OECD] (2001). Ageing and Transport: Mobility needs and safety issues. Paris, France, Organisation for Economic Co-operation and Development.
- Öström, M., & Eriksson, A. (2001). Pedestrian fatalities and alcohol. *Accident Analysis and Prevention*, 33, 173-180.
- Owsley, C., & McGwin, G. (2004). Association between visual attention and mobility in older adults. *Journal of the American Geriatrics Society*, 52(11), 1901-1906.
- Oxley, J. (2000). Age differences in road crossing behaviour. Unpublished PhD Thesis. Melbourne, Australia, Monash University.

- Oxley, J., Corben, B., Fildes, B., O'Hare, M., & Rothengatter, J. (2004). Older vulnerable road users – measures to reduce crash and injury risk. (Report No. 218). Melbourne, Australia, Monash University Accident Research Centre.
- Oxley, J., Fildes, B., Ihsen, E., Charlton, J., & Day, R. (1997). Differences in traffic judgements between young and old adult pedestrians. *Accident Analysis and Prevention*, 29(6), 839-847.
- Oxley, J., Ihsen, E., Fildes, B., & Charlton, J. (2001). Age-related functional impairments and the impact on the ability to cross roads safely. *VTI Konferens*, 18A, 426-39. Linköping, Sweden, Swedish National Road and Transport Research Institute.
- Oxley, J., Ihsen, E., Fildes, B., Charlton, J., & Day, R. (2005). Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. *Accident Analysis and Prevention*, 37, 962-971.
- Parkin, A., & Java, R. (1999). Deterioration of frontal lobe function in normal aging: Influences of fluid intelligence versus perceptual speed. *Neuropsychology*, 13(4), 539-545.
- Parkinson Society Canada (2002). Parkinson's Disease. <http://www.parkinson.ca/pd/nd.html>
- Perry, J., & Hodges, J. (1999). Attention and executive deficits in Alzheimer's Disease: A critical review. *Brain*, 124, 383-404.
- Petersen, R. (2003). *Mild cognitive impairment. Aging to Alzheimer's disease*. New York, USA. Oxford University Press.
- Petersen, R., Doody, R., Kurz, A., Mohs, R., Morris, J., Rabins, P., Ritchie, K., Rossor, M., Thal, L., & Winblad, B. (2001). Current concepts in mild cognitive impairment. *Archives of Neurology*, 58, 1985-1992.
- Rankin, J., Woollacott, M., Shumway-Cook, A., & Brown, L. (2000). Cognitive influence on postural stability: A neuromuscular analysis in young and older adults. *Journal of Gerontology A: Biological Science and Medical Science*, 55a, M112-M119.
- Raz, N., Gunning-Dixon, F., Head, D., Dupuis, J., & Acker, J. (1997). Neuroanatomical correlates of cognitive aging: Evidence from structural magnetic resonance imaging. *Neuropsychology*, 12, 95-114.
- Reitan, R. (1958). Validity of the Trail Making Test as an indication of organic brain damage. *Perceptual and Motor Skills*, 8, 271-276.
- Rey, A., & Osterreith, P (1993). Translations of excerpts from Rey's 'Psychological Examination of traumatic Encephalopathy' and Osterreith's 'Complex Figure Test'. *The Clinical Neuropsychologist*, 7, 2-21.
- Ricksten, S. (2000). Cerebral dysfunction after cardiac surgery. Are we moving forward? *Current Opinions in Anaesthesia*, 13, 15-19.
- Rizzo, M., McGehee, D., Dawson, J., & Anderson, S. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Disease and Associated Disorders*, 15(1), 10-20.
- Rochester, L., Hetherington, V., Jones, D., Nieuwboer, A., Willems, A., Kwakkel, G., & van Wegen, E. (2004). Attending to the task: interference effects of functional tasks on walking in Parkinson's disease and the roles of cognition, depression, fatigue and balance. *Archives of Physical Medicine and Rehabilitation*, 85(10), 1578-1585.

- Rogers, W., Fisk, A., & Walker, N. (1996). *Aging and skilled performance: Advances in theory and applications*. Hillsdale, USA, Erlbaum Press.
- Salthouse, T. (1991). *A theory of cognitive aging*. Amsterdam, the Netherlands, Elsevier Press.
- Salthouse, T. (2000). Steps toward the explanation of adult age differences in cognition. In T Perfect & E Maylor (Eds.) *Models of cognitive aging*, (pp. 19-49). Oxford, Britain, Oxford University Press.
- Schaie, K. (1990). The optimisation of cognitive functioning in older age: predictions based on cohort-sequential and longitudinal data. In P Baltes & M Baltes (Eds.), *Successful aging: Perspectives from the behavioural sciences*, (pp. 94-117). Cambridge, England, Cambridge University Press.
- Schultheis, M., Garay, E., & DeLuca, J. (2001). The influence of cognitive impairment on driving performance in multiple sclerosis, *Neurology*, 56(8), 1089-1094.
- Schultheis, M., Garay, E., Millis, S., & DeLuca, J. (2002). Motor vehicle crashes and citations among drivers with multiple sclerosis. *Archives of Physical and Medical Rehabilitation*, 83, 1175-1178.
- Sheppard, D., & Pattinson, M. (1986). Interviews with elderly pedestrians involved in road crashes. (Report No. RR98). Crowthorne, UK, Transportation Road Research Laboratory.
- Sheridan, P., Solomont, J., Kowall, N., & Hausdorff, J. (2003). Influence of executive function on locomotor function: Divided attention increases gait variability in Alzheimer's Disease. *Journal of American Geriatrics Society*, 51, 1633-1637.
- Shumway-Cook, A., & Woollacott, M. (2000). Attentional demands and postural control: The effect of sensory context. *Journal of Gerontology A: Biological Science and Medical Science*, 55a, M10-M16.
- Sivak, M., Olson, P., Kewman, D., Won, H., & Henson, D. (1981). Driving and perceptual/cognitive skills: Behavioural consequences of brain damage. *Archives Physical Medicine and Rehabilitation*, 62, 476-483.
- Smiley, A. (1999). Adaptive strategies of older drivers. Paper presented at the Conference on Transportation in an Aging Society: A decade of Experience, Maryland, USA, Transportation Research Board.
- Snellgrove, C. (2005). Cognitive screening for the safe driving competence of older people with mild cognitive impairment or early dementia. Canberra, Australia. Australian Transport Safety Bureau.
- Ståhl, A. (1991). Mobility and accessibility for elderly and disabled in Sweden. *IATSS Research*, 16(2).
- Ståhl, A., Brundell-Freij, K., & Makri, M. (1993). The adaptation of the Swedish Public Transportation System – Yesterday, today and tomorrow. An evaluation. (TFB Report No. 1993:14). Stockholm, Sweden, Swedish Transport Research Board.
- Stolwyk, R., Charlton, J., Triggs, T., Ianssek, R., & Bradshaw, J. (submitted). The effect of a concurrent task on driving performance in people with Parkinson's disease. *Brain*.
- Stolwyk, R., Triggs, T., Charlton, J., & Bradshaw, J. (submitted). Driving performance in people with Parkinson's disease: A review. *Manuscript submitted to Parkinson and Related Disorders*.

- Stolwyk, R., Trigs, T., Charlton, J., Iansek, R., & Bradshaw, J. (2005). The impact of internal versus external cueing on driving performance in people with Parkinson's disease. *Movement Disorders*, (early view, articles online, <http://www3.interscience.wiley.com/cgi-bin/fulltext/109933768/html.start>).
- Stroop, J. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643-662.
- Stutts, J., & Hunter, W. (1999). Motor vehicle and roadway factors in pedestrian and bicyclist injuries: An examination based on emergency department data. *Accident Analysis and Prevention*, 31, 505-514.
- Stutts, J., Stewart, J., & Martell, C. (1998). Cognitive test performance and crash risk in an older driver population. *Accident Analysis and Prevention*, 30(3), 337-346.
- Sweeney, J., Rosano, C., Berman, R., & Luna, B. (2001). Inhibitory control of attention declines more than working memory during normal aging. *Neurobiology of Aging*, 22, 39-47.
- Tatemichi, T., Desmond, D., Stern, Y., Paik, M., Sano, M., & Bagiella, E. (1994). Cognitive impairment after stroke: Frequency, patterns and relationship to functional abilities. *Journal Neurology, Neurosurgery and Psychiatry*, 57, 202-207.
- Toivonen, S., & Niskanen, R. (1998). Safety problems of rural roads. Finland's material for RS8 Scientific Expert Group. (Report No. 17/1998). Helsinki, Finland, Finnish National Road Administration.
- Transport Accident Commission (2005). Pedestrian statistics. <http://www.tac.vic.gov.au>.
- Valcour, V., Masaki, K., & Blanchette, P. (2002). Self-reported driving, cognitive status, and physician awareness of cognitive impairment. *Journal of the American Geriatrics Society*, 50(7), 1265-1267.
- van der Heiden, E., & Rooijers, A. (1994). Meningen et motieven ten aanzien van vervoermiddelgebruik in de Vervoerregio Groningen. Groningen, the Netherlands, Centre for Environmental and Traffic Psychology, University of Groningen.
- Vergheese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., & Lipton, R. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society*, 50(9), 1572-1576.
- Visser, M., Pluijm, S., Stel, V., Bosscher, R., & Deeg, D. (2002). Physical activity as a determinant of change in mobility performance: The longitudinal aging study Amsterdam. *Journal of American Geriatrics Society*, 50, 1774-1781.
- Wang, L., van Belle, G., Kukull, W., & Larson, E. (2002). Predictors of functional change: A longitudinal study of non-demented people aged 65 and older. *Journal of American Geriatrics Society*, 50, 1525-1534.
- Wannamethee, S., Shaper, A., & Walker, M. (1998). Changes in physical activity, mortality, and incidence of coronary heart disease in older men. *Lancet*, 351, 1603-1608.
- Weschler, D. (1955). *Weschler Adult Intelligence Scale. Manual*. New York, USA, Psychological Corporation.
- Wigan, M. (1995). Treatment of walking as a mode of transportation. *Transportation Research Record*, 1487, 7-13.
- Williams, P., & Lord, S. (1997). Effect of group exercise on cognitive functioning and mood in older women. *Australia and New Zealand Journal of Public Health*, 21, 45-52.

- Winter, D. (1988). Older drivers – their perception of risk. SAE. Effects of aging on driver performance SP762. Passenger Car Meeting and Exposition, Michigan, USA.
- Wood, J., Worringham, C., Kerr, G., Mallon, K., & Silburn, P. (2005). Quantitative assessment of driving performance in Parkinson's disease. *Journal Neurology, Neurosurgery and Psychiatry*, 76, 176-180.
- Yaffe, K., Barnes, D., Nevitt, M., Lui, L., & Covinsky, K. (2001). A prospective study of physical activity and cognitive decline in elderly women: Women who walk. *Archives of Internal Medicine*, 161(14), 1703-1708.
- Yanik, A., & Monforton, R. (1991). At fault crash patterns of older drivers. *Journal of Traffic Medicine*, 10(2), 87-92.
- Zegeer, C., Stutts, J., Huang, H., Zhou, M., Rodgman, E. (1993). Current trends in crashes to older pedestrians and related safety treatments in the United States. *VTI Konferens*, 1A(2), 53-71.
- Zesiewicz, T., Cimino, C., Malek, A., Gardner, N., Leaverton, P., Dunne, P., & Hauser, R. (2002). Driving safety in Parkinson's disease. *Neurology*, 59(11), 1787-1788.
- Zinn, S., Dudley, T., Bosworth, H., Hoenig, H., Duncan, P., & Horner, R. (2004). The effect of post-stroke cognitive impairment on rehabilitation process and functional outcome. *Archives of Physical Medicine and Rehabilitation*, 85, 1084-1090.
- Zuin, D., Ortiz, H., Boromei, D., & Lopez, O. (2002). Motor vehicle crashes and abnormal driving behaviours in participants with dementia in Mendoza, Argentina. *European Journal of Neurology*, 9, 29-34.