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Older Pedestrians: A Critical Review of the Literature

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EXECUTIVE SUMMARY

Objectives

This report reviews literature relevant to the impact of the ageing process on pedestrian safety. The review has three main objectives:

- To provide a critical review of research on older pedestrians and road safety. It is intended that this will provide a reference source in formulating future policy and research decisions;
- To identify those groups within the population of older pedestrians who are most at risk;
- To identify and review initiatives, schemes and strategies that have been developed either at the local or national level, with a view to identifying, where possible, those that are examples of best practice.

Because relatively few studies have directly investigated older pedestrians, we have used data from related areas, such as research on older drivers, to support the analysis.

Background

The number of older people has been increasing and is forecast to continue to increase. Older people are expected to form an increasing proportion of the population, with the largest percentage increase being for those people aged 80 years and over. Most older car drivers reduce driving as they age, and many ultimately give up and become dependent on other forms of transport.

The ability to travel is important for the quality of older people's lives. As people age, fewer journeys are as car drivers and, up to about 75 years old, more are as pedestrians. Except in rural areas, people over 70 years old in Britain make more journeys on foot than as car drivers.

Older pedestrians

Research from New Zealand has concluded that the risk of an accident crossing the road increases substantially with age after about 79 years. The risk of fatality increases more rapidly with age from the early 60s, and very rapidly from 70 years. Accidents are closely related to the times and places older people most often walk. For example, they are more common during the day and 73% are within 1km of home. There is some evidence that risk is higher than for younger adults at intersections and in accidents involving reversing vehicles. However, this may in part reflect a higher likelihood that lower speed accidents involving older people will be reported because they are more likely to lead to injury. Like other pedestrian accident victims, older people often fail to see the vehicle that hits them.

The damage done to an older pedestrian by a given collision is more severe than for a younger person. The proportion of injuries to pedestrians that are fatal increases rapidly with age, from less than 2% for people in their 30s to more than 9% for those aged 80 and over. This excess fatality rate is attributed to the physical frailty of older people, who generally recover less well from physical injuries. Even if they had the same number of accidents as younger adults, older pedestrians would be over-represented in fatality records. The psychological consequences of pedestrian accidents for older people have not been widely studied, but they can be expected to be serious. Accidents are likely to make victims anxious about future travel, as well as causing conditions such as depression or post-traumatic stress disorder.

Older men have higher pedestrian fatality rates per capita than older women, and the older old have higher rates than younger old people. However, the increase compared to younger adults is greater for older women. Further research is needed to establish the risk of pedestrian accident for different groups in relation to their exposure to traffic. We believe that slow-walking older people and people who have recently stopped driving will be high-risk groups, as well as those with certain kinds of medical condition, but direct links could not be made because of the absence of relevant accident data.

Effects of ageing

The review considers the effect of ageing on older people's vision, hearing, physical mobility, and cognitive processes. Although the changes experienced are well established, there has been little direct research linking functional decline to older pedestrian accidents. The principal changes most likely to affect pedestrian skill are listed below. The age at which difficulty is experienced, and the extent of impairment, varies greatly between individuals.

Vision and hearing

Older people tend to have poorer vision, seeing objects less clearly both close up and at a distance. They cope less well with seeing in poor light conditions, and adapt more poorly to glare. Their ability to detect and identify moving objects also decreases.

Some results of vision tests are:

Accommodation	4.5 dioptres at 40 years reduced to 0.5 dioptres at 65 years old
Dynamic acuity	exponential decline from around 40 years
Contrast sensitivity	28% decline per decade between 65 and 84 years old

Dark adaptation threshold doubles every 13 years	
Glare recovery time	compared to adults under 39: people aged 65–69 and women over 69, 50% longer; men over 69, 75% longer
Visual field	men in their 20s, 175°; 40s, 172°; 60s, 162°; 70s, 153°; 80 and over, 140°

In the USA, 50% of 65–74 year olds, and 75% of those aged 75+, have been estimated to have cataract. Macular degeneration affects 25–30% of those aged 60–75 and 40–60% of those aged over 75. By the time people are aged 70, low frequency hearing loss is about 13dB and high frequency loss 36–47dB.

These visual and hearing problems could make it harder to detect or locate vehicles or other hazards, especially in darkness.

Physical mobility

As people age, the proportion reporting mobility difficulties increases. The UK National Travel Survey (NTS) found that about 50% of men and 70% of women aged over 80 years who were interviewed reported that they had physical problems that made walking outdoors difficult. Most of those who report some difficulty are able to get out and down the street, although some need help to do so.

Older people walk more slowly, making it more difficult to cross roads safely, especially when the time available to cross is restricted by short gaps in traffic flow or short “green man” times at pedestrian crossings. Measurements of walking speed have shown great variation among older people and between studies. The largest reductions in waking speed are caused by illness. Consequently, even quite conservative fixed signal timings will not allow enough time for some older people.

Reduced ability to make head and neck movements could affect looking behaviour. Older people are less able to change speed or direction quickly to avoid hazards, and are more likely to have problems with balance. Older people, particularly women, are vulnerable to falling in the road environment. Several studies suggest that falls on footways cause more slight and serious injuries for older people than do collisions with road vehicles.

Cognitive processes

Reaction time slows with age, and the ability to divide or switch attention reduces. Research with children has linked attention switching to looking behaviour in the road environment. A composite measure of cognitive function termed UFOV (useful field of view) has been correlated with accident risk for older drivers, particularly accident risk at intersections. It is also believed that older people with sensory loss or physical mobility changes need to allocate more of their available cognitive resources to function adequately. These changes would be expected to affect older people's ability to cope with complex situations and their capacity to respond quickly and flexibly to changing circumstances.

Health

Certain medical conditions, including some psychopathologies, lead to abnormal levels of decline of vision, hearing, physical mobility, and cognition. Cerebro-vascular accidents (strokes), in particular, can lead to severe impairment. Eye diseases such as cataract can seriously impair vision. Dementia affects sensory and cognitive processes, and is known to be associated with higher accident risk for drivers. These conditions are common among older people, and prevalence increases with greater age. Many older people will be coping with more than one condition alongside the effects of normal ageing. The medication required for a number of conditions is known to affect abilities and behaviour in ways that could influence road safety. Little research has assessed the practical impact of health problems on pedestrian behaviour or their relationship with accident risk.

A British survey of 302 people with visual impairments found that 29% had had an accident crossing the road, 94% just walking and 33% while climbing steps. These rates are much higher than published rates for the whole population.

Compensation

Studies of older people's perception of their own declining capacity suggests that they have good awareness when there is clear feedback from the environment. This is most likely to come in the form of difficulty experienced with everyday tasks, such as reading small print, but can also be given by professionals such as eyesight experts. However, older people's reports of cognitive problems may be an indirect reflection of depression. Conditions such as dementia impair insight into declining capacity. Older people who believe they are performing less well modify their behaviour in ways that, on the face of it, ought to reduce accident risk. For example, many older drivers reduce night driving. However, there is no direct evidence that older pedestrians are effective in reducing their accident risk through such compensatory behaviour.

Pedestrian behaviour

Older people's road-crossing behaviour suggests that they are trying to be more cautious. They typically look a little more carefully than younger adults, and wait for longer gaps between vehicles before trying to cross. However, they appear sometimes to accept gaps that are not long enough to allow them to cross safely unless the approaching vehicle slows down. They may be basing their judgements on distance rather than allowing for the speed of a vehicle as well as its distance. It is not clear whether they have a conscious strategy of relying on drivers to help create safe gaps. In general, the kind of systematic cognitive psychological research that could tell us what older people see when they look for traffic, and what strategies they use for crossing roads, has not been done. The magnitude of differences in pedestrian behaviour between older and younger adults is relatively small, and may be less than the variation in crossing behaviour caused by differences in road layout or the presence of parked cars.

Older pedestrians are more likely than younger adults to stop at the kerb before crossing. One observational study carried out in the 1970s found that the proportion of pedestrians who look both ways increased with age, to 69% for those of 70 years and over. The number of head movements to look during crossing also increased with age, from 5.5 at 18 years to 6.5 at 80. The differences between older and younger pedestrians in crossing behaviour were small. A recent observational study found that older women appear to be more likely than other pedestrians to take account only of nearside traffic before starting to cross, attending to farside traffic once they have reached the middle of the road.

What situations are particularly difficult or dangerous

In one recent study in the USA, around 10% of older old pedestrians reported that crossing roads was difficult, and most of these said there was insufficient time to cross at signalled crossings. Junctions where traffic may turn during a pedestrian phase cause difficulties for older pedestrians. In surveys in Britain, older pedestrians expressed particular concern about fast traffic and busy roads. They were also concerned about crossing "where several roads meet", and wanted more signal-controlled pedestrian crossings. In the USA, 31% of older pedestrian fatalities, and 51% of injuries, were at junctions. Most were while the pedestrian was on a crosswalk, and half while the pedestrian signal was green.

The large majority of pedestrian accidents involving vehicles happen in urban areas. For example in Canada, 85% of fatalities for pedestrians aged over 64 years were in urban areas. Most accidents with vehicles happen while crossing roads. In France, for those aged 65 and over, 73% of pedestrian fatalities occurred while crossing.

In the USA, one study of accident data found that older pedestrians were particularly at risk crossing wide roads with four or more lanes. A smaller UK study found a high accident rate per crossing on main roads for older people. Despite the fact that only 35% of roads crossed by older pedestrians were main roads, 85% of this group's injuries were on these roads.

Accidents to pedestrians that involve falls on footways rather than collisions with vehicles are more common than collisions with vehicles, and may well cause more slight and serious injuries. They are particularly common for older women. Poor footway surfaces contribute to these accidents. In countries with cold climates, slippery surfaces caused by snow and ice are a major cause.

Improving the situation

Intervention can address older people themselves, other road users such as drivers, or the road environment. There is little evidence that information campaigns directed at older pedestrians reduce accident risk, although they may serve ancillary purposes. Education of drivers directing them to understand their responsibility to vulnerable road users has been shown to be effective, although few evaluations have been published. Driver behaviour at intersections, at pedestrian crossings, and when turning or manoeuvring is especially important, but above all drivers should moderate speed when they are near vulnerable road users.

The best evidence for effective intervention comes from studies of physical and regulatory changes. International studies have shown that measures such as lower speed limits, roundabouts, and appropriate signal timing for both cars and pedestrians reduce pedestrian accidents. People-detectors on crossings can adjust the length of the pedestrian phase to match the walking speed of the pedestrians. Older pedestrians often request the provision of signal-controlled crossings and central pedestrian refuges. One trial of a recorded spoken reminder to watch for turning traffic at a signal-controlled crossing reduced pedestrian–vehicle conflicts. Improving the visibility of pedestrians, and of traffic by the use of running lights, is also effective. Design guidance issued centrally has a key role to play. This kind of intervention has been shown to be cost effective, and benefits road users in general, not just older pedestrians.

Older people themselves can play an active role in accident prevention programmes within their local communities. They can help identify local problems that make walking more difficult or increase the risk of falls. For example, the quality of the pavement is very important for older pedestrians. This participation should be encouraged, but community-based interventions cannot be relied on to deliver reduced accident rates, particularly for serious accidents.

A striking feature of the literature on older pedestrians is how few the directly relevant published studies are, and how unsystematic the evidence. We have used studies of related topics to fill in the gaps where this was reasonable. However, the report makes a number of recommendations for further research, some of which have been mentioned in this summary.

1 INTRODUCTION

1.1 Overview

This report reviews research relevant to the road safety of older pedestrians, a vulnerable group of road users. In this introduction, we set out the context. There are more old people than ever before, and they are expected to form an increasing proportion of the population. Many give up or reduce driving at some stage, and become dependent on other forms of travel. Their travel is important, but much of it will be on foot, a more hazardous form of transport than the car. Older people have a high risk of pedestrian accident involvement, and accident statistics show that old people are at greater risk of fatal injury than other pedestrians. This is partly explained by their greater frailty.

Against this background, in subsequent chapters we go on to review factors that affect the ability of older people to cope with the road environment. The ageing process impairs functions that underpin road behaviour: perceptual, cognitive, and motor capabilities decline, and physical changes affect movement. For many older people, their health also begins to decline. We review the impact of some common medical conditions, medication, and psychological illness, identifying particular groups with elevated risk. The final sections consider ways in which the vulnerability of older pedestrians can be ameliorated. We examine the way problems can be offset through compensating changes in behaviour made by older people themselves, and public interventions that can improve their safety. In each section we identify areas for research. Thus, the review analyses the impact of the ageing process on pedestrian safety to highlight areas in need of research, to characterise effective remedial measures, and to identify high-risk groups.

1.2 Scope of review and terminology

We have consulted the scientific literature systematically, using bibliographic databases such as PsychInfo and Medline, and the online library catalogues of various institutes, including VTI in Sweden, and SWOV, to identify sources. The bibliographies of reports were used to help identify additional relevant material, and we benefited from the annotated bibliography published in Chapman et al. . Published government statistics and reports have been used in places. However, although we have occasionally made fresh calculations from published data, extensive new data analysis of accident or exposure figures was beyond the scope of this project.

Because there has been relatively little research directly on the older pedestrian, it has been useful also to consider research from related fields, such as child pedestrian safety or the ageing driver, which can inform understanding of the older pedestrian. As well as applied research, a brief review of relevant basic research into ageing is included, and the review also includes studies of falls and non-traffic accidents, which lead to more injuries than traffic accidents but are poorly recorded. We have not systematically considered issues faced by pedestrians with disabilities because that is the subject of a review being prepared by others.

Reviews and meta-analyses were consulted as well as the primary literature. We made particular use of Holland (2001) on older drivers; Schneider and Pichora-Fuller (2000) on ageing and perception; Willott (1991) on hearing; Weale (1963) on vision; Shumway-Cook and Woollacott (2001) on physical mobility; McDowd and Shaw (2000) on age-related changes in attention; and PROMISING (2001) on evaluating measures to improve safety.

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When referring to age groups reported in research papers, we typically give the mean age or age range of participants involved. Otherwise, the adjective "older" is normally used here to refer to people over 60 years old. In some circumstances, "old" is further divided into "younger old" and "older old". Chronological age is a convenient index, and it is socially significant because it determines events such as retirement. It is also clear that chronological age correlates at least moderately with changes in many relevant measures such as visual acuity. However, it is equally clear that chronological age does not correlate perfectly with such measures, and there is considerable individual variation in performance and in the rate of change in performance. Some older people do as well as some young adults on measures of function. It has, indeed, been cogently argued that age should not be considered an explanatory variable at all in research on ageing (e.g. Li and Schmiedek, 2002), and that it requires more reflective evaluation as a scientific construct than it typically receives in research on road behaviour (Sirén et al., 2001).

We have used a number of terms interchangeably: sidewalk and pavement; crosswalk and pedestrian crossing; junction and intersection. Typically, we stick to the terminology used by whichever study is under discussion.

1.3 Background – older pedestrians as a population

Across OECD countries, the size, and relative size, of the older population is increasing. Almost all these people are pedestrians some of the time. However, older people appear to have a slightly increased risk of being involved in a pedestrian accident, and a greatly increased risk of being fatally injured. Providing a transport framework that lets them maintain an appropriate level of mobility in safety is a significant goal.

1.3.1 *The number of older people is increasing*

Table 1 shows current and projected population figures for older men and women in the UK (adapted from Maycock, 2000). The over 85 age group in general has shown the biggest percentage increase over the last 10 years. People over 65 are about 15% of the UK population now, and are expected to form about 19% of the population by 2021 (HAS, 1997). A pattern of increasing numbers, with older people constituting a larger proportion of the population, is common to OECD countries (OECD, 2001). It is a function of demographics (the post-war "baby-boom" population bulge is reaching old age), and better health care and living standards leading to longer life.

Table 1: UK population projections for people over 60 years old (millions)

	1998		2002		2022	
Age group (years)	Men	Women	Men	Women	Men	Women
60–74	3.6	4.0	3.6	4.0	5.1	5.3
75+	1.5	2.7	1.6	2.8	2.4	3.3

1.3.2 *Older people desire to travel*

The growing constituency of older people will have high expectations about remaining mobile (OECD, 2001). Mobility is a key aspect of quality of life for older people (Mathey, 1983b), affecting for example their use of health care services (Rittner and Kirk, 1995). Age-related physical and cognitive impairment can restrict mobility, in part because older people with such impairments tend to reduce or cease driving. Metz (2000) listed five benefits of mobility:

- Actual travel to people and places
- Psychological benefits of movement and of "getting out and about"
- Exercise benefits of everyday mobility
- Involvement in the local community – benefits from informal local support networks
- Potential travel – the security of knowing that a trip could be made if needed

Being able to travel or "get out and about" has value beyond simple access to places and services. Bly et al. (1995) observed that it is difficult to quantify some of these social and personal benefits, whose importance may not be given enough weight. A longitudinal study in the USA, where dependence on the car for transport is high, found that driving cessation was one of the strongest predictors of an increase in symptoms of depression among older people (Marottoli et al., 1997).

Older people tend to believe that walking has health benefits. A survey in San Antonio, Texas, in the 1970s found that 99% of retired pedestrians (mean age 67.5 years, but 4% under 50 years) saw health and exercise as a good thing about walking (Carp, 1971). In San Francisco, the figure was 92% (Carp, 1972). Carp found that about 15% and 85% in San Antonio and San Francisco, respectively, identified sociability, independence, and cost-effectiveness as good things about walking. Carp found that people living in inner-urban areas, or areas where non-Anglo-Americans predominated, and those without cars were more likely to walk in San Antonio. Most journeys on foot were reported to be under 15 minutes each way, with 74% and 83% in San Antonio and San Francisco, respectively, saying distance was the main barrier to pedestrian travel. Hills were also a problem in San Francisco. Fears about crime, isolation from other people, being hit by a car, falling, getting lost, or not being able to cross roads before signals changed were mentioned by over 60% of the older pedestrians in both cities. Fear of crime was a greater concern for women. Health was reported to be an obstacle by 32% of the sample as a whole.

Many older people who were used to driving continue to use private motor transport (Mori and Mizohata, 1995). However, an ageing population, public policies to reduce car driving, the cost of car driving, and concerns over driver competence and safety may in the future contribute to an increase in pedestrian activity among older people. Over the age of 70, in the UK, even in rural areas, the proportion of all journeys made on foot increases, although at any age, car travel still accounts for most distance travelled (Noble, 2000). Those who have been used to driving may feel a loss when they give up driving, and may be particularly vulnerable as pedestrians. Declining functional capacity that can prompt people to reduce or cease driving affects the pedestrian task, too. We explore this point further in section 0 on risk factors.

1.3.3 Older people travel less than younger people

The analysis by Noble (2000) of the travel characteristics of older people based on the UK National Travel Surveys for 1985–86 and 1996–98 noted that older people were travelling substantially more (in terms of miles per year) than older people were 10 years before. However, older people travel less than younger people, considering all modes of travel (Noble, 2000; OECD, 1985; 1986; 2001). Noble compared men and women over 80 to people aged 50–54. Older men made less than half, and women about a third of the number of journeys by all modes. This pattern of less travel by older people was also reported in the Netherlands by Van Wolffelaar (1988; cited in Hummel, 1999). The main reason is, of course, retirement. There is less need to travel for work or for education (e.g. Noble, 2000, Table B.8). The reduction is not so great if only journeys on foot are considered. In 1996–98, men and women over 80 made 93% and 56%, respectively, of the journeys on foot made by people aged 50–54 years. Nevertheless, FEPA (1995), surveying the circumstances of older pedestrians across Europe, reported that as many as 50% of the retired did not go out on any given day, and that by retirement one in three had a disability that limited their activity. A recent UK survey found that older men and women had on average 61 and 67, respectively, days in the year when their activity was restricted by acute illness, and that about 60% of older people reported a longstanding illness such as arthritis or a heart condition (Walker et al., 2001).

Hopkin et al. (1978) looked at 1975–76 data on travel patterns of older people (over 65) in the UK. Then, too, older people made fewer journeys for work or education, and fewer journeys overall than adults in general. However, then only 28% of their journeys were made by car, and 51% were on foot, partly due to lower levels of car ownership. Hopkin et al. cited their own survey in one town, which found that 44% of older people reported health problems that they said made walking difficult. Economic and health differences produced wide variation between older people in travel patterns, and Hopkin et al. pointed out that those living alone faced particular difficulties. They recommended both improving public transport generally, which would benefit many older people, and also specific help for those with the greatest mobility problems, such as demand-responsive transport services, delivery of some services at home, and reallocating public sector housing to make access easier for older people.

Other changes with increasing age are relevant. Although a survey by Sheppard (1987) found that people walked an average of 300 metres more per day if there was no car available to their household, the proportion of people who walk to do their shopping locally reduces with age, despite lower car ownership, which suggests that older people find this task more difficult. Distance travelled annually by all transport modes is related to density of urbanisation, with those living in rural areas travelling furthest (Noble, 2000). However, the greater the population density, the more people walk (Hillman and Whalley, 1979).

Sheppard (1987) found no significant difference in the percentages of older men and women who went out on foot more than once a week. However, several UK studies show that older women walk less distance than older men, which is perhaps surprising, given that fewer older women drive. Ward et al. (1994) surveyed pedestrian activity in Northampton, a town selected to be representative of the UK population. Over all ages, men walked less than women, but for the over 65s, men walked further than women, with a lower proportion of older women walking at all on the survey day. Across all transport modes, the National Travel Survey (2000) found that older women made fewer journeys per year than older men, although the reverse held for people aged 26–59.

There are three things to note from Table 2, which shows the distances older men and women walk. First, the data from Ward et al. (1994) appear to underestimate the amount of walking done by an average older person, except for women aged 60–64.

The underestimate is largest for women over 65, who would be expected to walk an average of about 53 miles a year on their data, lower even than the lower NTS figure for over 80s. Second, NTS data indicate that older people are walking less than they used to, except for the over 80s. There is a similar reduction in the average number of journeys made on foot (Noble, 2000, Table B.3). The average pedestrian journey length has not reduced, but the number of journeys decreased by about 10% for older men and 14% for older women between the surveys. Third, the relationship between the relative distance walked by men and women is very similar across the two NTS surveys. Men walk further, and the ratio increases steadily from about 70 years old. The data of Ward et al. are similar, but suggest a much larger difference between men and women over 65. It has to be borne in mind that their sample size was relatively small (n = 56 and 124 for the 60–64 and over 65 groups, respectively), and that estimates may be distorted by projecting from those who walked on the "survey day" given the relatively low proportions who actually walked.

Table 2: Amount of walking by older men and women in the UK. Source: *Ward et al. (1994) and **Noble (2000)

Age (years)	Men	Women
Proportion walking on survey day*		
60–64	0.66	0.71
>65	0.64	0.55
Distance walked on survey day (mean in metres of those who did walk)*		
60–64	777	881
>65	1030	421
Distance walked per year 1985–86 (miles)**		
60–64	214	198
65–69	273	188
70–74	203	212
75–79	183	80
>80	107	55
Distance walked per year 1996–/98 (miles)**		
60–64	179	145
65–69	210	158
70–74	200	157
75–79	168	99
>80	117	61

Older people on average also cross fewer roads each day. Ward et al. (1994) examined the number of roads crossed per day by people in Northampton. For those who reported walking outdoors on the randomly chosen "survey day", people aged 16–19 made the most crossings at 11.5 on an average day, with people aged over 65 crossing 4.9 roads, a little below the overall average. Keall (1995) reported that in New Zealand the number of roads crossed and hours spent walking each day decreased with age, although the New Zealand Travel Survey had not recorded distance travelled. Noble (2000) found a similar pattern, in terms of distance and number of trips in the UK after 65.

Patterns of pedestrian travel vary between European countries (DUMAU, 1998). PROMISING (2001) reported that of seven countries (Denmark, Finland, France, UK, the Netherlands, Sweden and Switzerland), the UK had the highest percentage of trips made by walking. For example, in the UK over 40% of short trips (under 5km) were made by walking, a proportion that did not vary with age. However, in the UK older people tend to walk shorter distances (Department of Transport, 1995), whereas in some other European countries older people walk longer average distances than younger adults (Hagenzieker, 1996). It is not clear how cultural, geographical, and social differences influence these different patterns of walking in different countries.

Ward et al. (1994) "re-walked" the routes described by respondents. They calculated that one seventh of all walking was done on footways with irregular or cracked paving, or badly worn surfaces of other types, and suggested that this was representative for the UK in general. Indeed, DTI 1990 figures suggested that up to 10 times as many people attend accident and emergency departments with injuries sustained in falls on footways and other transport areas as are injured in vehicle accidents. According to Jensen (1999) 70–75% of all pedestrian injuries in the "traffic area" in Denmark result from falls. NCC (1987) cited data recording that in 1984 in England and Wales 189 people of all ages died from falls in the road environment. NCC's MORI poll found that half of the pedestrian accidents reported by a random sample of people of all ages were trips or slips. Although only 1% of pavement falls needed hospital treatment, they accounted for 90% of all street accidents requiring medical attention. Falls appear to be more common for older women, and are examined in more detail in sections 2.3.2 and 4.3.

1.3.4 Older pedestrians have a relatively high risk of injury or death

This section looks at older people's relative risk of being killed in pedestrian accidents, and their risk of involvement in accidents. For older people, pedestrian accident risk rises with age, but the number of accidents (excluding falls) is lower than would be expected given the number of older people. However, their risk of being killed in a pedestrian accident is higher than would be expected, and rises rapidly with increasing age.

Pedestrian accident risk rises in old age. In the UK there is a rise in the level of reported pedestrian accidents per capita from late middle age (Mitchell, 2000, Figure C.4). But even with this rise, older pedestrians in the UK and USA have fewer accidents of all levels of severity than would be expected given their representation in the population (Table 3). Zegeer et al. (1993b) put it like this:

> "... the elderly are less likely than other pedestrians to be involved in a crash, but once in a crash they are more likely to be killed." (p. 39)

Hauer (1988) examined fatality rates for pedestrians and cyclists in the USA "net of frailty", and drew the same conclusion as Zegeer et al. (1993b). Hauer's graph (Figure 5, p.197, 1984 data) shows that, when this net rate peaked at 85 years, it was still lower than the level of 25 year olds. However, after declining up to the age of 65, the net rate then rose steadily from 65 to 85 years by about 67%, from 1.2 to 1.8 per 100,000. This is an important increase, although the rise of about 170% in (unadjusted) fatalities across the same age range was much greater. The risk of being involved in a fatal pedestrian accident increases with age, and this is substantially, but not entirely, due to older people's greater vulnerability to the consequences of physical injury.

Table 3: Representation (as a percentage of the total) of older people in pedestrian injury accidents and fatalities compared to their representation in the population. Data from Katz (1991), Mitchell (2000) and Zegeer et al. (1993b).

Data	Age (years)	% of injuries of all severities	% of population	% of fatalities
UK 1998	60+	14.6	20.5	46.6
UK 1998	80+	4.1	4.6	19.0
USA 1989	65+	8.4	13.0	22.4
USA 1986	65+		10.0	28.0
Israel 1986	65+		10.0	37.0

Casualties can be considered in absolute numbers, but it is normally useful to evaluate the relative risk of a casualty occurring. This allows comparison between, for example, populations of different sizes. Measures of risk compare the frequency of occurrence of an event to exposure, which represents the opportunities the event has to occur. In road accident research, exposure can be measured in different ways. Risk can be reported as a function of population (e.g. casualties per 100,000), per distance travelled, per roads crossed, per trip, and so forth. Compton (1982) found that population figures were better predictors of pedestrian casualty rates for older people than a measure of pedestrian activity. The fit could be improved using information on car and home ownership. Data on population are more readily available, and other measures of exposure have to be gathered through surveys or observations of pedestrians. However, researchers frequently argue that these less easily obtained measures are more appropriate. For example, Fontaine and Gourlet (1997) suggested that the most appropriate measure of exposure for older pedestrians is the number of roads crossed. The differences are relevant because populations being contrasted on the basis, say, of age, may make different numbers of trips, of different lengths, and so on.

Walking is a dangerous way to travel, especially for older people, with a relatively high risk of being killed or seriously injured. In the UK, the Department of Transport has estimated that the risk per distance travelled of being killed or seriously injured is 15 times greater for pedestrians than car drivers. Data from OECD (1985) showed that the ratio of pedestrian to car driver fatalities per kilometre was 15.9 for those over 65 and 6.9 for 25–64 year olds. Mitchell (2000) showed that the fatality rate per journey was higher for older pedestrians than older car drivers or passengers (Chart C.9), although the size of the difference was much smaller by this measure (about 138 fatalities per billion journeys for pedestrians and 85 per billion for drivers at 75 years). FEPA (1995) reported that in the UK the fatality risk per population for older pedestrians relative to other adults doubled from 60–69, trebled from 70–79, and quadrupled over 80 for men. For women over 80, the multiple was 11. Händel (1981) reported that, although under 16% of the West German population were over 65, 49% of pedestrian fatalities were over 65. Lane et al. (1994) found older pedestrians over-represented among pedestrian fatalities in Canada. The picture is similar in the UK and USA, as shown in Table 3. Hagenzieker (1996) reported 1990 pedestrian fatality rates per population for nine European countries, the USA, and Japan. Compared to adults aged 25–64 years, older pedestrians were typically between 3.1 (France) and 5.1 (Japan) times as likely to suffer a fatal accident, although the ratio was 8.1 in Switzerland and 8.9 in Denmark. An increased risk of accident and especially fatality for older pedestrians was noted in earlier reviews. Cohen and Preston (1968) attributed the high number of pedestrian fatalities among older people to "the ill-effects of age" (p. 233).

Peng and Bongard (1999) reported data based on 5000 hospital admissions in Los Angeles. The mortality rate for pedestrians was 7.7%, averaged over all ages, but was 27.8% for the over 65s. Elevated mortality for older people was also reported from Gröningen by Kingma (1994). Kingma's figures were 6% for 50–59 year olds, 13% for 60–69 year olds, and 20% for those aged 70 years and over. Ward et al. (1994) found that the percentage of pedestrian casualties that were fatal or serious in Northampton (over five years) rose from about 25% at 60–64 years, to almost 60% among over 65s. Older people are more vulnerable to the physical consequences of an accident.

Leaf and Preusser (1999) analysed data from single-vehicle pedestrian accidents in Florida between 1993 and 1996, and found that older people were more easily injured at all speeds. Even below 20mph, the risk of fatality was three times greater for those over 65. From 21–30mph, those over 45 have more than double the risk of fatality of younger adults and the risk compared to younger adults is about five times greater for those over 65. Over 45mph, older people were found to die in about 60% of accidents. Those over 65 had higher injury rates than younger people at all speeds.

Fatality rates can be compared in a way that makes allowance for the different amount of walking done by people of different ages. Jensen (1999) reported that the fatality rate per million kilometres walked in Denmark rose steadily from 0.07 for 45–64 year olds to 0.45 for those over 85. Table 4 shows data from four OECD countries indicating that the fatality risk for pedestrians 65 years or older was between four and seven times greater than for younger adults. Hagenzieker (1996) reported data from the Netherlands for 1992–94 indicating rather lower risks for all age groups, but still large relative risks of fatality for older people. The risk per 100 million km (assuming a billion was 10^9) was 0.8 for 30–39 year olds, who had the lowest rate per distance, 2.5 for 60–64 year olds, and 10.5 for those aged 65 or older. When examined by distance walked, the data show an even larger increase in fatality risk for older people than per capita figures.

Table 4: Pedestrian fatality risk per 100 million km walked in four OECD countries by age. Source: OECD (1985).

Age (years)	Denmark	West Germany	Netherlands	UK
25–64	4.9	8.2	3.8	6.2
Over 65	20.0	33.0	21.0	43.0

Older pedestrians are clearly at high risk of being fatally injured. Casualty data (including all injury accidents) and frailty indices, can be used to try to assess whether they also have an increased risk of being involved in an accident. Some qualifications to conclusions based on casualty rate data need to be considered. First, statistics based on injury accidents over-estimate the number of accidents for older people because a given accident is more likely to injure an older person and so be recorded (OECD, 2001). Second, data based on population size may underestimate risk per journey or per road crossing if older people travel less or cross fewer roads. However, Hakamies-Blomqvist (1998) suggested that road users who travel less may have their true risk exaggerated by data standardised on the distance travelled. Identifying valid measures of exposure is critical to establishing the true change in accident risk.

Several studies internationally have found that older pedestrians have an elevated risk of accident when exposure rates, measured by distance walked or number of roads crossed, are taken into account, as well as an increased likelihood of fatality (Fontaine and Gourlet, 1997; Händel, 1981; Keall, 1995; Kingma, 1994; Klemenjak, 1991; OECD, 1985). Seneviratne and Shuster (1989) found that people over 60 were the victims of about 23% of pedestrian accidents in Montreal city centre between 1985 and 1987, but constituted only 5% of the resident population. However, the figure of 5% may underestimate participation in pedestrian activity because, of course, people from other parts of the city would often travel into the centre. Jacobs and Wilson (1967) estimated exposure from pedestrian flow at different kinds of road-crossing situation in English towns. Using historical (30 months) accident data from those towns they estimated that casualty risk was between three and four times greater for over 60s compared to those aged 16–60. These data included all injury accidents, and it is unclear whether fatalities were included. Todd and Walker (1980) looked at casualties per hour walking in the UK, and found that the rates for people aged over 80 were more than five-fold those for people aged between 18 and 29 for men, and more than nine-fold for women. OECD (1985) using data from five European countries reported casualty risks between 1.5 and 3.2 times greater for older pedestrians compared to those aged 25–64 by distance walked (data from 1978 or 1981).

Mitchell (2000) analysed UK data, based on 1998 statistics from Road Accidents Great Britain (1999), the Office of National Statistics, and the National Travel Survey 1996–98. He used several measures of risk (per population, per journey, and per distance) contrasting the casualty rate and the fatality rate at different ages. Mitchell (2000, Figures C.8 and C.10) showed rises in injuries per journey and per distance travelled for older people. The rise was slight from late middle age, but rose more steeply from 65 years. The rate per 100,000 journeys rose from 156 (at 65 years) to 406 (at 85 years) (estimated from C.8). Jensen (1999) reported a similar upward trend in the rate of injuries per pedestrian journey for older people in Denmark. What Mitchell found, in general, was that although the casualty rate increased modestly for older people, the fatality rate increased much more strongly. The increase in fatality rate was especially strong when measured per distance travelled. Even the elevated casualty rate might not mark a true change in accident involvement because older people's accidents are more likely to be reported because they more often lead to injury. Mitchell argued that older people are not markedly more at risk of involvement in a pedestrian accident, as much as more vulnerable to its consequences. He showed that the percentage of all injuries that are fatal was higher for pedestrians than car occupants, and increased in relation to age for all older road users. His estimates of relative vulnerability for older people were in line with those reported by Evans (1991) and Li et al. (in press) for car occupants. Li et al. found that the increased fatality risk for drivers began earlier for women (60–64) than men (70–74), with substantially higher accident risk only from 75 years.

The very careful analysis of Keall (1995) found that a large increase in accident involvement is seen only among the older old. Keall's conclusion, based on data from New Zealand, was that only the over 79 year olds could be seen as being "at risk" crossing roads once allowance was made for frailty. It is important, then, to consider the factors that influence accident risk to inform policies and interventions that will be effective in managing and reducing it. We return to this in later sections.

The percentage of all transport fatalities for older people that are pedestrian accidents varies greatly between OECD countries, ranging from over 40% in the UK, Spain and Norway, to under 6% in the Netherlands (OECD, 2001). Katz (1991) compared a figure of 29% in the USA to 79% in Israel. Relevant differences include the extent of existing interventions to reduce accidents and different levels of pedestrian activity or car ownership.

Rates of reported pedestrian casualties rise with age from about 65 years, and there is evidence for a substantial increase in accident risk over 79 years, but the most important finding is that the risk of death from a pedestrian accident is much greater for older people. Den Hertog et al. (2000) provided parallel data for burns victims. Half of all burns fatalities in their study in the Netherlands were over 54, but older people were less likely than other age groups to be admitted to hospital for burn injuries. Older people are highly vulnerable to the consequences of physical injury and it is therefore important to protect them from hazardous situations. Even if older pedestrians' accident rates could be kept to the low levels of middle-aged adults, they would still have very high death rates. Until about 80 years, older pedestrians do not appear to be especially "accident prone". This implies a responsibility for the system designer. In general, older road users are not so much responsible for disproportionate numbers of accidents, as disproportionately likely to be killed or seriously injured because of their physical frailty (OECD, 2001). Considering UK data, Mitchell (2000) concluded that:

> "Policies that cause elderly car drivers to become car passengers or pedestrians would, on current casualty statistics, increase road fatalities overall." (Mitchell, 2000, p. 34)

OECD (2001) argued for helping the older driver to continue driving as long as possible, and for supporting this by adapting cars, adapting the road environment, and encouraging other road users to have confidence in older drivers. In section 7, as well as considering interventions aimed at the older pedestrian him or herself, we look at interventions directed at other road users and the road environment that can improve older pedestrian safety.

1.3.5 Older pedestrian accidents have characteristic features

Accidents involving older pedestrians have characteristic features. This is partly explained by the pattern of their pedestrian activity, and is discussed further in section 4.1. Nevertheless, it may be that older people are more vulnerable than others in certain kinds of situation, even before their overall accident risk increases substantially. Here, we briefly summarise some key points.

Zegeer et al. (1993b) found that pedestrians aged 65 or over had more accidents in daylight, on weekdays and in winter. This echoes the conclusions of OECD (1970), and many other studies have made similar findings.

Older pedestrian accidents are more common in urban areas (e.g. Transport Canada, 2001). Several studies have reported a high incidence of accidents at junctions (intersections) for older pedestrians (e.g. Hauer, 1988; OECD, 1970). Snyder (1972) found that more than half the pedestrians involved in "vehicle turn or merge with attention conflict" accidents in the USA were over 55 years old. Zegeer et al. (1993a,b; 1994) also found that older pedestrians were over-represented in collisions at intersections, especially collisions involving turning vehicles, and in collisions involving wide street crossings. Stutts et al. (1999) reported over-involvement in accidents at intersections in their sample of pedestrian accidents in the USA. Only 9.2% of pedestrian accidents of all types involved people over 65 year olds as victims, but about 14% of intersection accidents involved older people. In some of these accidents, the driver is partly at fault, but it is often suggested that older pedestrians have difficulty with complex situations or time pressure because of functional impairment (e.g. Staplin et al., 2001; van Wolffelaar, 1988). It is important to bear in mind that most of these data are from the USA, where there is a particular problem with the convention applied in some places that vehicles may turn against a red light, so coming into conflict with pedestrians crossing under the shelter of that light.

Oxley et al. (1997a) found older pedestrians to be more likely than younger ones to be involved in collisions with vehicles in "other" circumstances, such as in car parks, collisions with vehicles turning into lanes or driveways crossing the pavement, and collisions with vehicles reversing from parking positions. This confirms findings from Sheppard and Pattinson (1986), who interviewed older pedestrian accident victims and found that 41% reported that the vehicle that had hit them was doing something unexpected, such as reversing. Jensen (1999) also reported that older people were the predominant victims of reversing vehicles. Stutts et al. (1999) reported that 18.6% of pedestrians hit by a reversing vehicle were over 65 year olds. About 70% of the accidents involving reversing vehicles happened on private property and in daylight. Reversing vehicle accidents tended to lead to less severe injury, probably because of low vehicle speeds, but 1.7% were fatal and they did account for 6.9% of all pedestrian accidents.

1.4 Summary

In summary, the key points of this section are:

- The ageing population of OECD countries relies heavily on the car for mobility.
- The amount of travel declines in old age, but having to give up driving because of impairment or for financial reasons will negatively affect quality of life if it limits mobility.
- Older people replace some driving by increased walking or use of public transport, but at least in the UK, these options do not currently appear to be able to satisfy mobility needs fully, and walking may be more dangerous than continuing to drive.
- Falling is an important component of pedestrian risk for older people, particularly older women.
- In the UK in 1998, people aged 60 or older, who were 20.5% of the population, accounted for 14.6% of pedestrian accidents involving physical injury, but accounted for 46.6% of pedestrians killed.
- The injury rate per 100,000 pedestrian journeys in the UK rises from about 156 at 65 years to about 406 at 85 years.

- Accidents involving older pedestrians are more likely to lead to death or serious injury, at least in part because older people are less physically robust.
- Evidence from New Zealand suggests that, allowing for frailty, only those aged 80 and over are at substantially increased accident risk when crossing the road.
- Older pedestrians have a pattern of accident involvement that is slightly different from other age groups. For example, older people are more likely than other adults to be victims in daylight, because that is when they go out. They are also particularly likely to have accidents in urban areas, especially at junctions.

1.5 Research implications

Later sections will articulate research issues raised by the material in this section in more detail, such as the reasons why older pedestrian accidents occur in characteristic situations. However, there are three obvious general areas for future research that can be listed now:

1. There is a need for further research into the best way to measure exposure to risk, as well as ongoing collection of data regarding accident rates. Although no one measure will be appropriate for every study, there is scope for empirical work on the validity of different measures for specific purposes. Unless accident rates can be standardised appropriately, it becomes difficult to evaluate interventions or to make other comparisons required for research.
2. Increased understanding of the mobility needs of older people would inform policy in relation to public transport. Patterns of pedestrian activity will be affected by the accessibility and availability of alternative transportation. Finding ways to help people carry on driving as they age may be needed. This is considered further in the section on intervention.
3. Research on ways to protect vulnerable and less physically robust older people would benefit older road users generally, not just older pedestrians.

2 AGE-RELATED FUNCTIONAL IMPAIRMENT AND PEDESTRIAN SAFETY

The biological processes of ageing impair a number of functions that are relevant to pedestrian behaviour. In general, little is known about the precise relationship between specific impairment and accident risk. Nevertheless, in this section we set these patterns of functional loss in the context of the demands of the pedestrian task. The functions considered are vision and hearing, walking, and attention. Although we often summarise patterns of change using averages, one of the key conclusions of research in all these areas is that variation increases with age. Some 80 year olds have 20/20 vision; some have become blind. This increased variation is not fully understood, but is partly a consequence of the increased prevalence of disease.

2.1 The pedestrian task

A number of studies have analysed the pedestrian task. Older and Grayson (1974) emphasised road crossing, and identified six steps, which might be repeated or omitted in the completion of a given road crossing. First, a place to cross needs to be chosen. Then, a time to cross is selected, and this involves looking for traffic, perceiving traffic, judging available gaps for example, and deciding whether to cross. The final step is walking across the road. Older and Grayson suggested that for both children and adults accidents were most often precipitated by lapses of attention. Rumar (1986; 1989) has suggested that late detection is the most fundamental error made by drivers and pedestrians, and results because the road environment is an artificial environment to which humans are not well adapted.

Bailey et al. (1992) provided a detailed consideration of the relationship between the task of using a signal-controlled pedestrian crossing and functional impairment associated with age. The pedestrian must see, interpret and if appropriate, operate the signal. They must see and respond to the signal when it changes. They must scan the environment for traffic and obstacles in their path. In some jurisdictions, they must also scan the area behind them that may be approached by vehicles "turning on red". Bailey et al. highlighted the role of peripheral vision, static acuity, dynamic acuity, tracking moving objects, visual search, changes in accommodation and depth perception, sensitivity to glare, dark adaptation, hearing loss, cognition, walking speed, and postural stability. A similar list was given 20 years earlier by Carp (1971). In the following sections we review the effect of ageing on these relevant physical and psychological capabilities of older people.

2.2 Vision and hearing

Hearing loss and reduced visual acuity occur with increasing age to the extent that they have been proposed as indices of functional age (Shock, 1981; cited in Arking, 1998). Shock (1981) reviewed correlations between chronological age and a variety of indices of functional decline. For hearing loss, correlations ranged from 0.42 to 0.66. For visual acuity and accommodation the ranges were −0.42 to −0.57, and 0.57 to 0.88, respectively. The distinction between loss due to pathology or ageing per se is not easily drawn (Weale, 1963). Among older people, pathological conditions such as cataract or macular degeneration are more common, and so on average older people have poorer eyesight, to take the example of vision. However, some decline in visual function with age is due to the straightforward progression of normal physiological processes. For example, the protein composition of the lens changes progressively, so that the shape and hence the functional capacity of the lens change throughout life. From a practical point of view, however, the distinction between normal and pathological change is secondary. In the same way, the theoretically important distinctions among types of cause, such as peripheral versus central problems, which investigations frequently address, will not be developed in detail here. Our immediate concern is the level of functional performance. Impaired function in a given case will often arise through a combination of disease and normal ageing, and will be linked to both central and peripheral changes. Unravelling these effects is important theoretically, and can be relevant in determining individual treatment, but here we focus on characterising patterns of change in a general way.

Todd and Walker (1980) carried out an extensive survey of pedestrians in the UK, and asked about health problems. When asked in a general way whether they had health problems, 24% of people over 60 who said they had a problem but were able to go out walking mentioned vision, 21% mentioned hearing, and 32% mentioned problems walking. When asked about difficulties crossing the road, 23% of those over 60 said that they had problems, and many mentioned health problems (14% vision, 4% hearing, and 21% walking). Todd and Walker drew attention to the relatively lower emphasis given to hearing in relation to road crossing.

A survey of UK road safety officers, who delivered pedestrian safety information to older people in local areas, found that 94% said it was important for older people to have their eyesight checked, and 87% said that it was important for them to have their hearing checked. However 24% and 42% of the officers, for vision and hearing, respectively, thought that few would in fact do so even after being given such advice.

Roberts and Norton (1995) indicated the possible role of sensory difficulty in pedestrian accidents. Using parental report as a measure of deficit, they found that children killed or seriously injured as pedestrians were more likely to have problems with vision or hearing. Compared to a control group, and allowing for sex, age, socio-economic status and ethnic group, accident victims had double the risk of hearing problems (8% versus 4%) and more than four times the risk of having vision problems (6.8% versus 1.7%). If accidents in which drivers failed to yield at a pedestrian crossing were excluded, on the assumption that fault could not be attributed to the child, the odds ratio for vision increased to 5.3. Roberts and Norton acknowledged that parents of injured children may have been more likely to mention problems, and their study does not provide direct evidence of a causal relationship. Nevertheless, it shows a link with functions that one would expect to be important in the pedestrian task. OECD (1970) cited an earlier study by Read et al. (1963) showing an association between poor vision and pedestrian accidents in childhood.

2.2.1 *Vision*

Older people experience decline across a range of visual functions. After considering the relationship between vision and accident rates, this section maps out the nature of those changes. The relationship between vision and falling is discussed in section 2.3.3.

Gallon et al. (1995) questioned 302 volunteer participants who were visually impaired, ostensibly for a travel survey, but in practice to learn about their involvement in transport accidents. Most respondents were registered blind, although many had some residual vision, and 43% were over 60 years old. They were asked whether they had ever had an accident crossing the road (29%), just walking (94%), or climbing steps (33%). These rates are much higher than official rates for the UK population generally, but those may be subject to under-reporting. NCC's (1987) MORI survey also found lower levels of walking accidents in a general population, but direct comparison is difficult because they asked only about accidents in the previous 12 months. It is also possible that people who had experienced travel problems, including accidents, would have been more likely to volunteer for a travel survey, and so the rates may not be representative. Gallon et al. found no significant difference in the road-crossing accident rate for those with or without residual vision, but people using a mobility aid, such as a guide dog or cane, were less likely to report accidents crossing the road. It is also clear from the descriptions of accidents that in many cases drivers at least contributed to causing the accident. Overall, the survey of Gallon et al. provides suggestive evidence that the most severe visual problems increase pedestrian accident risk.

Retting (1988; cited in Langlois et al., 1997) found that older pedestrians with poor vision had trouble distinguishing pedestrian signals across a very wide (175–225 feet, 12 traffic lanes) road in New York, and detecting the boundary between the kerb and the roadway. The latter was found to lead to some accidents in which the pedestrian stepped into the path of vehicles.

North (1993) reviewed studies relating accident risk to visual function for drivers. Driving has a lot in common with the pedestrian task, and it is useful to make this comparison. North's conclusions are summarised in Table 5. Owsley and McGwin (1999) in a more recent review came to similar conclusions about visual acuity, colour vision, and peripheral vision. However, they advocated further research to clarify the relationship between driving safety and other visual functions.

Table 5: Relationship between visual function and driving based on North (1993).

Function	Relation to driving	Link to driving ability and accident risk
Static acuity	Identifying objects; reading signs; ''slows the action''	Weak association
Dynamic acuity Colour vision	Dealing with moving objects Detecting and identifying coloured signals	Strong association No evidence for increased risk
Peripheral visual fields	Maintaining orientation and relationships among objects	Increased accident risk
Stereopsis and oculomotor control Night vision	Depth perception under 500m; main cue in darkness Poorer acuity; night myopia; problems with glare	Weak evidence only for increased risk Increased accident risk

Table 6 summarises the pattern of decline with age over a range of visual functions. Schneider and Pichora-Fuller (2000) argued that these levels of sensory decline may understate the deterioration of perceptual function. It is important to understand that the precise values of sensory measurement depend on a range of factors, such as the conditions of testing and the method used. This means that figures vary between studies.

Table 6: Summary of decline in visual function with age.

Function	Task relevance	Profile of decline	Source
Optical changes	Identifying and detecting objects (and general influence on visual function)	Deterioration in cornea, lens, iris and retina, and reduction of pupil size	Weale (1963)
Sensitivity (by static perimetry)	Detecting objects	0.6dB/decade	Henson (2000)
Accommodation	Focusing on objects	4.5 dioptres at 40 reduced to 0.5 dioptres at 65	Grundy (1987; cited in North 1993)
Static acuity	Detecting and identifying objects	Declines from middle-age, with greater decline after 60 years	Staplin et al. (1997)
Dynamic acuity	Identifying moving objects	Exponential decline starting from 38–45 years	Hills (1975; data from Burg, 1967; 1968)
Ratio of dynamic to static visual acuity	Detection and tracking of fast moving objects	Exponential decline starting from 46–49 years	Hills (1975; data from Burg, 1967; 1968)

Function	Task relevance	Profile of decline	Source
Contrast sensitivity	detecting and identifying objects and depth perception	18–39 years versus 45–66 years – little change up to 0.5 cycles/degree but about halved for higher spatial frequencies	Arundale (1978; cited in North 1993)
		20–29 years versus 60–69 years – little change up to 1.0 cycle/degree but loss of up to 0.3 log units of sensitivity at higher spatial frequencies	Higgins et al. (1988)
		65–84 years 28% decline per decade for photopic vision	Rubin et al. (1997; cited in Fozard and Gordon-Salant 2001)
Dark adaptation	Detecting objects in darkness	Threshold doubles every 13 years	North (1993); Pitts (1982); original data from McFarland et al. (1960)
		Several minutes longer to achieve a given level of adaptation	Birren and Shock (1950; cited in Weale 1963)
Glare recovery time	Detecting objects in darkness with veiling luminance	Compared to adults under 39 years: 65–69 year olds and women over 69 about 50% longer; men over 69 about 75% longer	Burg (1967, Table 1, p. 1284)
Stereopsis	Perceiving relative distance	Evidence for age differences weak	Schneider and Pichora-Fuller (2000)
Colour vision	Discriminating colour-based signals	Blue–yellow confusion	Weale (1963)
		Blue–green confusion	Verillo and Verillo (1985)
Visual field	Detecting objects not located straight ahead	Young adults 170°; older adults 140°	Johnson and Keltner (1983)
		20–24 men 175.2° women 176.1°; 40–44 men 172.5° women 173.5°; 60–64 men 161.5° women 163.7°; 70–74 men 152.8° women 157.6°; >80 men 139.5° women 138.5°	Burg (1968)
Movement detection	Detecting changes in movement	Minimum displacement threshold increases 0.07 log arc min per decade	Wood and Bullimore (1995)
Oculomotor control	Tracking moving objects	Older people change fixation more slowly	Sharpe and Sylvester (1978); Scialfa et al. (1988)

Optical changes include reduced elasticity of the lens, which means that older people are not able to bring objects at different distances into sharp focus so readily. This reduction in the ability to accommodate declines throughout the lifetime (Weale, 1963, Fig. 7.8; after Brückner, 1959), with reductions requiring optical correction typically arising from about 40 years. This means, in particular, that it takes longer to change focus from a near object to distant objects. It has been reported that these effects begin earlier for people living at warmer latitudes (Weale, 1963). Bailey at al. (1992) pointed out that street crossing requires changes in accommodation as objects at different distances, such as cars, pedestrian signals or obstacles, are brought into focus. There is also a reduction in the number of rods, i.e. retinal cells sensitive to light. The loss of rods would affect peripheral vision and vision in poor light. Light is transmitted less effectively by an old eye, and this also increases the relative difficulty of seeing in darker conditions. The lens yellows with age, and the pupil reduces in size, reducing the amount of retinal illumination for a given level of light for a 60 year old to one third of that for a 20 year old (Weale, 1963).

Standard screening tests for vision and hearing do not detect all problems (Schieber, 1988; Schneider and Pichora-Fuller, 2000). An older person can screen as normal for visual acuity on a standard Snellen letter chart, for example, yet have poorer vision in low light or a reduced field of view compared to a younger adult with the same Snellen score. For such reasons, corrections that improve focus (spectacles) or increase loudness (some hearing aids) are not effective for many problems with vision and hearing.

Acuity reflects the clarity of the retinal image, and people with better acuity can resolve visual detail from greater distances (North, 1993). Visual acuity and dynamic visual acuity decline with age. Slataper (1950; cited in Weale, 1963) reported that 80% or so of people aged 20–50 had static acuity of 1.0, but that this declined rapidly to about 45% of 70 year olds and just 10% of those aged 80. Static acuity thresholds are affected by viewing conditions in ways that may differ between older and younger people (Fozard and Gordon-Salant, 2001). For example, older people need more light to achieve a given degree of static acuity (Weale, 1963) and show greater relative impairment in poor light conditions (Staplin et al., 1997). Weale cited the finding of Wilson and McCormick (1954) that reduced static visual acuity was not related to increases in industrial accidents, but Era et al. (1996) reported a correlation with performance on balance tests, and North (1993) reviewed a number of studies showing significant relationships with driving performance. A recent study found a strong relationship between visual acuity and the extent of everyday activities (Marsiske et al, 1997). However, Marsiske et al. compared a number of models and concluded that age-related differences in basic physical activity were better explained, at a statistical level, by a balance–gait score than by variance in visual acuity.

Contrast sensitivity is important for recognising objects or faces, but is also important for depth perception (Orr, 1998). It is measured as a family of threshold values recording the minimum contrast required to detect a pattern at different spatial frequencies. For a given subject, contrast sensitivities at spatial frequencies a factor of two apart are statistically independent (Schieber, 1988). Owsley and

McGwin (1999) reviewed several studies showing an association with driving problems. For example, Rubin et al. (1994) found that contrast sensitivity problems were associated with self-reported difficulty in making distance judgements, night driving and mobility. Estimates of the rate of decline with age vary between studies, and are affected by the method of testing (Higgins, 1988). Representative values are shown in Table 9. Contrast sensitivity at higher spatial frequencies is affected by optical variables such as the clarity of the lens, pupil size, and the ability of the lens to accommodate (Schieber, 1988). Consequently, thresholds tend to decline with age. At lower spatial frequencies, sensorineural properties, which also contribute to decline at higher spatial frequencies, set the limits. Peak sensitivity has been reported to decline from four cycles/degree at 20 years to two cycles/degree at 65 years (Schieber, 1988). Contrast sensitivity is also reduced in poor light, and at lower spatial frequencies the reduction in sensitivity with reduced luminance is slightly greater for older people (Sloane, 1988). Finally, at low spatial frequencies older people, unlike younger adults, do not perform better with moving patterns, implying that they are less able to detect large moving objects like cars (Schieber, 1988).

Staplin et al. (1989) looked at correlations between measures of contrast sensitivity and two tasks related to driving. Contrast sensitivity accounted for just 11% of variance in identifying whether a simulated change in road direction was to the left or the right, and 27% of variance in a sign-reading task. Older people (65–85 years) had sensitivity thresholds on average 2–2.5 times higher than younger adults (25–49 years), but there was great variation with some older people having thresholds 20 times higher. Performance was poorer and more variable among those older participants obtained by random sampling than among volunteer older participants, implying that research that uses self-selected participants may underestimate population levels of visual deficit. Older people’s relative decrement was greatest at lower levels of luminance.

The sensitivity of the eye as measured by static perimetry declines by between 0.4 and 0.8dB per decade, with faster decline over 50 years and greater loss at the edge of the visual field. Henson reported greater variability among older people.

Burg (1968) examined the extent of the visual field in over 17,000 Californian drivers. He gave details for monocular and binocular fields, and reported that the total field and temporal fields declined from about 35 years for both men and women, with accelerating decline from the late 50s. Wolf (1967) also reported accelerating decline from 55 years old, using slightly different methods. Burg found that, apart from the group over 80 (there were only 13 women of this age), women had larger visual fields than men (total field about 2° difference). For older people (over 60), but not younger adults, the left temporal field was about 2° smaller than the right temporal field, in both men and women. The overall decline in visual field could be caused by reduced sensitivity to light rather than a specific decline of the peripheral retina. Visual field can also be reduced by monocularity (Owsley and

McGwin, 1999) or obstructions such as spectacle frames (North, 1993). However, as Burg pointed out, the underlying mechanism is secondary to the practical effect of functional decline. In Burg's data, no relationship was found between visual field loss and accident rates for drivers over 54 years (Hills. 1980).

Older people are less able to notice movement or to track objects moving at high speed. This would affect their reaction to vehicles that start to move as well as their ability to follow the path of fast-moving vehicles. It could also affect their ability to negotiate the environment while moving themselves. Trick and Silverman (1991) varied the number of dots that moved coherently together in a visual display. The dots moved up, down, left or right. When a large enough proportion of the dots move coherently, motion is perceived. Trick and Silverman found a significant association between age and the threshold for motion detection. The threshold was roughly 9% for those under 50, but then rose to 12.1% for 51–60 year olds, 13.1% for 61–70 year olds, and 14.4% for 71–80 year olds. Trick and Silverman found no relationship with pupil size, and no significant effect of blurring the stimulus by up to 4.0 dioptres. This implies that the raised thresholds are not a consequence of straightforward optical changes. An earlier study using a different method found an age-related in decline in the threshold for detecting angular movement, with a steeper decline in simulated night-viewing (Hills, 1975). Hills' results also indicated that motion towards the observer tended to be more easily detected than motion away.

Motion creates characteristic patterns of deformation of the texture of the visual field. Lamellar (uniform translation) and radial (expanding from a point) optic flow patterns specify passing objects and heading, respectively. Atchley and Andersen (1998) examined the detection of lamellar and radial optic flow. Thresholds were measured as the proportion of coherently moving dots in a display necessary for the detection of motion. For radial flow patterns, no differences between older and younger adults were found. For lamellar flow, different results were obtained for slow (4.8°/s) and fast (22°/s) targets. With slow targets, older and younger adults had similar thresholds except for targets directly ahead. Over both target speeds older women but not older men had elevated thresholds for central targets. With fast targets, thresholds overall were lower than for slow targets, but older adults had higher thresholds than younger adults up to 20° eccentricity. Correlations with static acuity thresholds measured at the corresponding points of the visual field were near zero for both types of flow pattern.

In contrast with Atchley and Andersen's conclusion that radial flow thresholds were similar for older adults, Warren et al. (1989) found they had higher thresholds. However, they used a different criterion to measure threshold: the angle of displacement required for 75% accuracy in a categorical (left or right of target) judgement about heading. Warren et al. also found that the threshold for accurately detecting heading on a curved path was higher at 2.9° for their group of 64–75 year olds, compared to 1.4° for a group of college students. These studies indicate that older people have difficulty detecting motion compared to younger adults. The largest differences have been found in darkness and with faster targets.

There is also evidence that older people are less able to judge relative distance. Hoffman et al. (1959) used a laboratory task to compare depth perception in older (60–69 years) and younger (23–38 years) adults. Participants had to align two objects from a distance of about 10 feet (3m). The mean error was larger for older (22.8cm) than for younger (14cm) people.

Older people's vision is more strongly affected by darkness. Rods and cones, the lightdetecting cells in the retina, adapt to darkness at different rates. The cones, associated with central vision, adapt more quickly (5–10 minutes), whereas the rods adapt gradually over about 40 minutes. These rates of adaptation are similar for older people, but the level of sensitivity achieved is less. Between 60 and 80 years, the amount of light needed for detection after the eyes have become fully adapted to darkness more than doubles (North, 1993). North explained that older drivers often use tinted glasses at night to compensate for problems seeing in the dark, but that in fact this is normally unhelpful. It reduces acuity and increases time for dark adaptation and recovery from glare.

It has been argued that the relatively robust performance of peripheral, or ambient, vision in reduced lighting can lead to overconfidence in drivers who find that their ability to maintain dynamic spatial orientation and so steer adequately is not reduced greatly in relative darkness (Leibowitz and Owens, 1977). Leibowitz and Owens suggested that this could explain why drivers do not slow down at night, even though focal vision is greatly affected by darkness. Owens and Tyrrell (1999) found that older drivers' steering in a simulator was more affected by reduced luminance than that of younger adults. There was little relationship between daylight acuity and the effect of reduced luminance on steering, but there was a relationship with pupil dilation, suggesting a link to senile miosis. Interestingly, this group of older drivers did not report reduced night time driving except in poor weather. They also were as comfortable with night time driving as younger adults (although the sample size was small, n = 8. This implies that older people may not appreciate their visual difficulties in darkness. Awareness of perceptual impairment is discussed in detail in section 6.2.

Older people have particular problems with glare (Burg, 1967; Schieber, 1988), but Owsley and McGwin (1999) suggested that firm evidence for a link with driving problems is lacking, and that the construct of glare requires more careful definition. Sjögren et al. (1993) reported that glare from the sun contributed to 3% of older pedestrian fatalities in northern Sweden in the period 1977–86.

There are changes in colour vision with age, due to the yellowing of the lens, which then selectively filters blue wavelengths (Weale, 1963), and to changes in the cones. Such changes are typically relatively subtle, more relevant to delicate tasks such as sorting yellow from white diamonds (Weale, 1963) than, say, discriminating coloured objects against the road surface or discriminating coloured road signals. There is also some evidence for declining sensitivity with age of the sensorineural mechanisms for colour vision throughout the lifespan (Werner and Steele, 1988). Werner and Steele reported rates of decline between 0.05 and 0.14 log units of sensitivity at the retina, depending on wavelength. Johnson et al. (1988) reported broadly similar rates for short-wavelength cone pathways, with slightly larger differences between older people (60−72 years) and other adults at 20−30° than at the centre of the visual field. Most studies have found no link between colour vision deficits and driving problems (Owsley and McGwin, 1999).

Information picked up by the visual system has to be processed to be used. A number of psychological tasks assess spatial abilities that require the processing of relationships in visual information. In a typical task, the subject is asked to trace a target figure embedded in a complex pattern of lines. Some assessment of spatial ability usually forms a component of general ability scales like IQ tests. Laboratory research has consistently shown reduced performance for older people on tests of memory for the spatial location of a target, analysis of complex spatial patterns, and estimates of spatial relationships between objects. Salthouse did cite one intriguing study in which there was no difference between older and younger people when the objects being considered were pictures of familiar rather than unfamiliar buildings (Kirasic, 1989), and there is evidence of an association with driving problems in older people (Marottoli, 1994).

The ability to navigate or use maps to navigate is another cognitive aspect of spatial processing. Wilkniss et al. (1997) found that healthy older adults (59−81 years, mean age about 70) were less able than college students to learn a new route. Participants were walked through a novel route in a medical building. After a 20 minute break, during which they completed a different task, participants first attempted to retrace the route from the beginning, and were then shown photographs of landmarks on the route and asked to arrange them in order. Older people made three times as many errors when retracing the route and were less accurate at ordering the landmarks. However, there was no difference in the groups' ability to recognise the landmarks correctly. This study appears to show that older people have specific problems with learning and sequencing route information.

Burns (1999) surveyed motorists in the UK and found that older people and women were more likely to report difficulties wayfinding. For example, women and older people rated finding their way through an unfamiliar city as more difficult. Burns also found that people reporting more difficulty had lower mileages, even after allowing for the effects of age, sex, health, and driving experience. Of course, it is possible that low mileage leads to low confidence in navigation skills, but Burns concluded that those experiencing low wayfinding performance had, as a consequence, lowered mobility.

Older people tend to be less able to resolve visual detail, to detect objects, to detect motion or position in depth, or to cope with adverse light conditions. They also show deficits in processing visual and spatial information to establish more complex relationships among aspects of their environment. There is little direct evidence that these changes cause an increase in the pedestrian accident rate, but associations have been found with driving accidents, and analysis of the pedestrian task suggests that they would be important.

2.2.2 *Eye disease*

Three diseases commonly responsible for visual impairment among older people are characterised in terms of their early functional effects in the following list (after Orr, 1998).

- Cataract – poor acuity and contrast sensitivity; difficulty seeing in poor light
- Macular degeneration – blurred or distorted central vision; scotomas
- Glaucoma – loss of peripheral vision, which the person may be unaware of; difficulty adapting to darkness

These diseases are common among older people. For example, it has been estimated that in the USA 50% of 65–74 year olds and 70% of over 75 year olds have cataract (Orr, 1998). Physiologically, cataract occurs when the normally clear crystalline lens becomes cloudy. People with cataract tend to be aware of problems with visual function and, for example, drivers self-regulate their driving patterns as a result (Owsley and McGwin, 1999). However, the onset of cataract can be slow, and so sufferers may not be immediately aware of problems. The balance of evidence is that drivers with cataract have a higher accident risk (Owsley, 1990). There have been reports of greater prevalence among women than men (Klein et al., 1992; cited in Whitbourne, 2001).

Age-related macular degeneration (AMD) affects the part of the retina 5–6mm in diameter centred on the fovea, the part of the retina that does high-acuity seeing. AMD leads to slight loss of visual acuity and contrast sensitivity, decreased central visual field sensitivity and slowed dark adaptation (Berger, 1999). Macular degeneration involves permanent destruction of photoreceptors in this central region of the retina. Among children and younger adults, the prevalence among people with impaired sight is below 10%, but this rises to between a quarter and a third between 60 and 75, and then to 40–60% among those over 75, with higher rates in more recent studies (Lovie-Kitchin and Bowman, 1985). Recent population-based studies from the USA, Netherlands, and Australia report a prevalence of early AMD of about 2% for 55–64 year olds, 8% for 65–74 year olds, and about 14% for 75–84 year olds, though a much higher prevalence was found in the USA study (Berger et al., 1999).

People with AMD often experience low confidence with road crossing and reading street signs and signals. Mobility training that focuses on using hearing and residual vision, and employs "low vision training runs" has been reported to be successful (Lovie-Kitchin and Bowman, 1985). People with AMD have good peripheral vision, and tend not to have difficulty with steps or obstacles (Lovie-Kitchin and Bowman, 1985).

It is estimated that 3–5% of people over 65 years have glaucoma (Schieber, 1988), which results in optic nerve damage caused by excess fluid in the eyeball. Medication used to treat glaucoma is reported to increase the risk of falling (Glynn, 1991).

2.2.3 Hearing

Hearing loss is common among older people, with almost half the participants in recent population-based studies in the USA and Australia showing average pure tone thresholds (0.5–4kHz) 25dB or worse (Fozard and Gordon-Salant, 2001). Some data drawn from a summary by Willott (1991) of eight studies run between 1938 and 1963 are shown in Table 7. Thresholds elevate more quickly for men, and at higher frequencies, although longitudinal data suggest that the rate of increase for higher frequencies (over 6kHz) may slow beyond 70 years (Willott, 1991). Frequency discrimination also reduces with age (Willott, 1991).

Table 7: Age-related loss of hearing acuity (pure tone thresholds in dB). Source: Willott (1991, data estimated from Fig. 8.2, p. 171).

Group and frequency	50 years	60 years	70 years	80 years
Male 1kHz	4	7	13	20
Female 1kHz	4	8	13	20
Male 6kHz	21	32	47	62
Female 6kHz	15	25	36	48

Some forms of hearing loss are age-related. The prevalence of sensorineural hearing loss increases from 4% between 31 and 50 years old to 17% between 51 and 70, but rises to 62% in those over 70 (Browning, 1998, p. 50, figures for the better ear). This type of hearing loss affects the ability to detect sounds, particularly high-frequency sounds. Many older people complain of problems understanding speech, especially in noisy environments (Fozard and Gordon-Salant, 2001; Schubert, 1980). This form of hearing loss is less easily corrected using hearing aids, and high-frequency hearing loss can affect the ability to fix the location of a sound (Stephens, 1982).

Hearing loss in older people is also caused by disease and the consequences of exposure to loud noise over the lifetime (Fozard and Gordon-Salant, 2001). Hearing loss is not always reported by older people, who may accept it as an inevitable part of ageing, and often it may not be recognised by people caring for an older person (Lysons, 1984).

Hearing can serve the function of spatial localisation. A sound originating to one side will arrive with a slightly different intensity at each ear, and there will be a small difference in its arrival time at each. These cues are used to work out the position of the source in space. A number of studies have found that older people are less able to identify the location of sounds, and this appears to be associated with sensorineural hearing loss as well as conductive loss (Noble, 1994; Willott, 1991). Masking level difference (MLD), a cue that can be used to locate sounds against noise, is less effective in older people with bilateral hearing loss (Pichora-Fuller and Schneider, 1991; Stephens, 1982). It should be possible, in principle, to compensate by using head and body movement to assist localization, although a study using signals 0.9s in duration and that permitted head and body movements still found localisation deficits for hearing impaired people (Noble et al., 1994). Schneider and Pichora-Fuller (2000) pointed to recent evidence of age-related deficits in neural synchrony within the auditory system as one possible cause of problems with localisation and other functions.

The direct bearing of hearing loss on pedestrian safety is unclear, but Lysons (1996) pointed out that it might at the very least reduce the feeling of security one has when looking in one direction if one loses the expectation of an aural warning of anything that approaches unexpectedly from another direction. Hagenzieker (1996) reported that cyclists tend to depend on hearing to detect vehicles approaching from behind. Bailey et al. (1992) suggested that older people with hearing loss will have particular difficulty localising approaching vehicles coming from directly behind them. Dewar (1995) makes a similar point, emphasising turning vehicles.

2.2.4 *Vision and hearing summary*

Older people experience decline in vision and hearing as a result of normal ageing and disease, with considerable variation between individuals. Visual impairment can affect the ability to detect, identify, and locate objects, especially moving objects, and is greatest in darkness or poor light. There can also be decline in higher order visual processing. Hearing problems are also likely to affect the detection and localisation of objects in the road environment. These functions are believed to be important in the pedestrian task, in which vehicles, other pedestrians, obstacles, and the physical relationships between them need to be perceived. There is some evidence that problems with vision or hearing affect pedestrian safety, but few direct links have been drawn with specific sensory losses. On the other hand, there is good evidence that problems with, for example, dynamic acuity, peripheral vision, and night vision affect the safety of drivers, and so, because the pedestrian task has much in common with driving, it can be expected that the same problems will be associated with increased pedestrian accident risk.

Older people and those caring for them are not always aware of the extent of sensory problems, an issue discussed in more detail in section 6.2, and this may make older pedestrians more vulnerable. In sections 7.2.3 and 7.2.4 we examine the effectiveness of increasing older people's ability to see and be seen, with, for example, street lighting and daylight running lights for cars. The next section looks at physical changes related to walking, and we will see that visual problems affect walking and balance directly.

2.3 Walking

Young adults take the ability to walk for granted. Many older people cannot. Walking speed reduces, and the likelihood of falling increases. The distance that can be walked comfortably becomes less, and the effort required becomes greater. In this subsection we summarise these changes, focusing on walking speed and balance.

Older people tend to be less physically fit. Respiratory function reduces with age, but effects are only typically apparent when demand is high (Arking, 1998). Maximum breathing capacity declines by 50% between young adulthood and 85 years, to about 75 litres/minute, with maximum oxygen uptake declining at the rate of about 1% each year. This decline can, however, be moderated by exercise (Arking, 1998). Cardiovascular decline in older people at rest is linked to disease rather than ageing as such (Arking, 1998), but as the prevalence of cardiovascular disease rises with age, there will be a tendency for older people to have lower heart performance (measured as the volume of blood that can be pumped in a unit of time). Older people have lower cardiovascular and respiratory capacity.

The physical frame and the levers that generate movement also tend to decline with age. Bone mineral content and strength decline from age 40. Women show more rapid decline than men, especially after menopause, when the average women loses 1.5% of bone mass per year (Arking, 1998). Muscle strength also tends to decline. Leg muscle strength, important for walking and balance, is up to 40% weaker at 80 years than at 30 years (Aniansson et al., 1986; cited in Shumway-Cook and Woollacott, 2001). In older people, the number and size of fast-twitch muscle fibres decline. There are also slightly fewer slow-twitch fibres, which are important for posture, and the functional differentiation of fast and slow-twitch fibres is diminished (Arking, 1998). Older people are not as strong as younger adults.

Walking is a complex movement, requiring balance and coordination as well as power. The vestibular system, which assists balance, loses 40% of sensory cells by age 70 (Rosenhall and Rubin, 1975; cited in Shumway-Cook and Woollacott, 2001), and we will see that there is evidence that older people tend to rely more on vision to maintain balance. Ketcham and Stelmach (2001) reviewed current research on changes in motor control related to ageing. In general, older adults move more slowly. When high accuracy is required, older adults tend to decelerate more slowly as they approach the target in a movement task. This is believed to be because they are monitoring the progress of the movement more carefully, with increased reliance on visual feedback. Movements, particularly small movements, made by older people are also more variable. For example, repetition by an older person of a given arm movement will be less consistent. This affects the duration, velocity, and trajectory of movement, as well as a number of other measures. Older people may thus come to control and pattern their movement in different ways as sensory and motor functions decline.

In the remainder of this section, we review in more detail changes in walking speed, and studies of balance and falling, before briefly discussing interventions that have been developed to improve the physical mobility of older people.

2.3.1 *Walking speed*

There have been many studies of walking speed. Shumway-Cook and Woollacott (2001) reviewed some of the early research as well as more recent studies. As Dahlstedt (1978a,b) pointed out, there is considerable variation in results. In some cases this arises from methodological flaws, but estimates also vary with sex, age of subjects, between countries, and according to the task and instructions given. In observational studies, walking speed is seen to be affected by road location and presence of traffic. Generally speaking, older people walk more slowly. For example, Lord et al. (1996) found a correlation of −0.36 between age and self-selected comfortable walking speed in a sample of 160 Australian women over 60.

A number of studies have looked at walking speeds at different types of location. Bowman and Vecellio (1995) observed pedestrian walking speeds at various urban and suburban locations on arterial roads in three cities in the USA. Pedestrian age was estimated from video recordings. Pedestrians crossed two-way left turn sites more quickly than undivided roads (1.3m/s and 0.63m/s, respectively, for pedestrians over 60 years at signal-controlled intersections, for example). Pedestrians also crossed a little more quickly at midblock locations than at signal-controlled intersections (1.19m/s and 0.99m/s, respectively, for older people). In contrast, others have found faster crossing times at signal-controlled crossings. In outdoor observations made covertly at a small number of sites in Calgary, Coffin and Morrall (1995) estimated 15th percentile crossing speeds of 1.0 and 1.2m/s at midblock and signal-controlled crossings, respectively, but speeds below 0.6m/s and above 1.8m/s were observed at signal-controlled crossings, where the range was greater. These outdoor speeds were measured from stepping off the kerb to stepping on the opposite kerb. In the UK, Griffiths et al. (1984) reported mean walking speeds on zebra crossings for “young, middle-aged, and elderly” people of 1.72m/s, 1.47m/s, and 1.16m/s, respectively. These means were based on observations of about 20,000 pedestrians at 26 sites.

Knoblauch et al. (1996) observed crossings at signal-controlled intersections in four cities in the USA, judging older pedestrians to be those who appeared to be over 65 years old. As indicated in Table 8, men crossed faster than women, and older adults crossed more slowly. Consistent with these figures, Dahlstedt (1978a) reported that older women were on average 0.15m/s slower than older men at normal walking speed. Knoblauch et al. also reported that pedestrians who crossed against the signals crossed more quickly, something previously observed in Hong Kong for pedestrians of all ages (Lam et al., 1995). Knoblauch et al. also found that people tended to cross more quickly in rain, on colder days, and on Fridays, although these differences were small. When pedestrians waited for the signal, their start-up time was recorded, and delays were found to be slightly longer for women and older people. For young pedestrians the mean start-up time was 1.93s. For older pedestrians, the means for men and women were 2.39s and 2.57s, respectively, and the 85th percentiles were 3.66s and 3.95s.

Table 8: Pedestrian road-crossing speeds (m/s) by age and sex. Source: Knoblauch et al. (1996).

	Mean	15th percentile	Men	Women
Younger adults	1.51	1.25	1.56	1.46
Older adults	1.25	0.91	1.32	1.19
Older adults complying with signals	1.20	0.94	1.26	1.14

Part of the explanation for variations in walking speed at different locations may be that pedestrians walk more quickly when they perceive a greater risk of conflict with a vehicle. Knoblauch et al. (1996) cited data from Moore (1956), indicating that pedestrians walk faster when traffic is closer (1.52m/s when vehicles were less than 3s away, compared to 1.22m/s otherwise). Moore (1953) reported that pedestrians walked faster when the nearest vehicle was likely to arrive before they had completed crossing the first lane. There are many reports that older people feel anxious about crossing roads (see section 5.1). For example, Bailey et al. (1992) found that in a sample of older pedestrians (19 males and 57 females aged over 56) 77% reported that they were given enough time at signal-controlled crossings, but 45% reported normally experiencing anxiety about crossing in time, 55% said they frequently or always hurried across the street, and 87% increased pace further when the flashing signal was displayed. Even some of those who can walk fast enough find the experience unpleasant.

Older people's concerns about being able to cross in time are validated by observational data. Hoxie and Rubenstein (1994) observed pedestrians crossing at a signal-controlled crossing at an intersection (21.8m wide) in Los Angeles. The mean walking speed for older people, those appearing to be 65 or older, was 0.86m/s (SD = 0.17m/s), and over a quarter were unable to cross within the time allowed by the signal. Job et al. (1998), observing crossing in Sydney, found that, although mean walking speeds were higher than in Los Angeles, some older people who began crossing during the "green" signal did not complete their crossing in the time allowed.

Table 9: Older pedestrian crossing speeds (m/s) for different road widths. Source: Knoblauch et al. (1996).

Road width	Mean	15th percentile
8.5–13m	1.15	0.91
13.1–15.6m	1.27	0.99
15.7–31.7m	1.35	1.06

Knoblauch et al. (1996) found that pedestrians crossed narrower roads slightly more slowly. The mean and 15th percentiles for different road widths are shown in Table 9. The trend was similar for younger adults, but the magnitude of the difference was smaller. Tarawneh (2001) found a rather smaller (0.01m/s averaged across age groups), although still statistically significant, increase in crossing speed for roads 14–16m wide, compared to narrower roads, in an observational study in Amman. The overall mean and 15th percentile for pedestrians over 65 were 1.17 and 0.97m/s. Interesting and statistically significant interactions of variables, such as an age × street width effect, were noted but not discussed by Tarawneh. In contrast with Knoblauch et al., Coffin and Morrall (1995) did not find consistent relationships between road width and crossing speed for pedestrians "assumed to be over the age of 60". They speculated that fatigue might slow walking, observing that at one site, a shopping centre, walking was slower on the return journey. In their study, differences that could be attributed to road width were much smaller than differences attributable to aspects of road layout such as the presence of pedestrian signals.

Todd and Walker (1982) estimated time spent walking (self-report) and distance walked (calculated from time taken by interviewers to re-walk reported routes) for people of different ages in the UK. We will discuss their survey in more detail in later sections, but it is interesting to use their figures to project average walking speeds. These projections may give an indication of the comfortable sustained walking speeds for older people, although their reliability is obviously affected by the method of estimating speed and distance. The projections are given in Table 10. One or two anomalies are apparent. For example, speeds are probably underestimated for men aged 50–59, suggesting that time was overestimated or distance underestimated in the survey.

Many studies have assessed walking speed in standardised conditions, away from the road environment. These afford more controlled measurement, and allow us to begin to examine the contribution of medical conditions to reduced walking speed.

Table 10: Average walking speeds (m/s) over a one day period by age and sex. Projected from time and distance data reported by Todd and Walker (1982).

Age (years)	Men	Women
18–29	1.06	0.97
30–39	1.28	0.99
40–49	1.28	0.96
50–59	0.92	0.93
60–69	1.06	0.73
70–79	0.89	0.74
80+	0.54	0.59

Langlois et al. (1997) measured walking speed over two runs on a 2.4m course indoors, from a standing start, in a population study of people from New Haven aged 72 or over (mean 79.2 years). Mean walking speeds were 0.38m/s (SD = 0.18) and 0.59m/s (SD = 0.22) for those reporting difficulty crossing streets and the rest, respectively. Less than 1% of their sample averaged 1.22m/s, and only about 7% exceeded 0.92m/s. These speeds were the standards assumed for local crosswalk design, the lower one assumed in areas with high numbers of older people. Self-reported difficulty crossing the road was significantly associated with slower walking speed.

Dahlstedt (1978a,b) tested a representative sample of people aged 70 or over living in Linköping in 1977 over 10m of level asphalt. They were asked to walk at normal speed, fast speed, and very fast speed. The median and 10th percentile for each speed are shown in Table 11. These are faster speeds than those recorded by Langlois et al. (1997) in the USA, but this is at least in part because Dahlstedt recorded speed from a moving start and finish. The Linköping sample excluded "non-pedestrians" (28.5% of the original sample), such as those who were unable to go out walking at all, and it may also be that the New Haven group included a larger representation of people with medical problems that affected physical mobility. Covert measurement of walking speeds for a subset of the Linköping sample showed a good correlation with test measurements, and showed that people walked a statistically significant 0.1m/s faster at signal-controlled crossings than at crossings without signals. Dahlstedt estimated a decrease in normal walking speed of about 4cm/s per year over 70 years.

Table 11: Walking speed (m/s) of Swedish people over 70 years old in 1977. Source: Dahlstedt (1978a,b).

	Normal speed	Fast speed	Very fast speed
Median	0.9	1.1	1.3
10th percentile	0.6	0.8	1.0

A more recent Canadian study using a fairly similar method to measure walking speed found somewhat higher mean speeds. Coffin and Morrall (1995) evaluated the walking speeds of older people (over 60 years old) in Calgary over a 13m level stretch of corridor. The mean self-selected normal walking speeds of men and women were 1.29m/s and 1.24m/s, respectively, although the mean fast walking speed of women was 1.55m/s. The mean fast walking speed of men was not reported. Coffin and Morrall did not use as systematic a sampling procedure as Dahlstedt, and it may be that their recruitment was more strongly biased towards healthy, active people. Furthermore, there may be many uncontrolled relevant differences between Calgary and Linköping, and we are anyway comparing a mean to a median. On the other hand, Dahlstedt did employ an element of screening for physical mobility problems, and an alternative hypothesis would be that more recent cohorts are faster walkers than earlier ones.

Studies of people with physical mobility problems confirm that they typically walk rather more slowly. For example, Shumway-Cook and Woollacott (2000) asked three groups of participants to walk for three minutes at their preferred speed. The mean speeds were 1.7m/s (young adults, 24–50 years), 1.2m/s (healthy older adults, mean age 74.6 years), and 0.47m/s (older people with balance problems, mean age 85.3 years). To put this concretely, whereas an average younger adult would have covered 306m by the end of three minutes, and a typical healthy older person would have been 90m behind, the average older person with balance problems would have covered less than 90m. A typical 500m journey would take a younger adult about 5 minutes, but an average person in the slowest group would need almost 18 minutes, if they could maintain that walking speed. Among younger people, evidence of balance problems is not necessarily associated with such large reductions in walking speed. Armstrong et al. (1996) tested 116 Nottingham women aged 45–70 (mean age about 60 years) with a history of wrist-fracture resulting from falls. The mean self-paced "normal speed" over 150m was a respectable 1.4m/s, although we have to bear in mind the inclusion of middle-aged women in this sample. Average walking speed of people who have had a stroke is reported to be 0.65m/s (Shumway-Cook and Woollacott, 2001). In Parkinson's disease (PD) walking speed is sensitive to disease progression, effects of medication and other factors (Shumway-Cook and Woollacott, 2001). Blin et al. (1990; cited in Shumway-Cook and Woollacott, 2001) reported a mean of 0.44m/s. These results indicate that large differences in walking speed are caused by the effects of illness.

A recent study has examined the nature of the relationship between muscle strength and walking speed (Kwon et al. 2001). Kwon et al. found that muscle strength and gait speed declined earlier in women than men. Younger women had a similar gait speed to younger men, but older women, from about 40 years at fast gait speed, and from about 50 years at comfortable gait speed, were slower than older men. Older people took more steps to cover the standard distance in this test, implying a shorter step length. There was a non-linear relationship between leg (quadriceps) muscle strength and speed such that speed increased linearly with muscle strength to about 130Nm (Newton metres) at comfortable gait speed, but there was little further increase in comfortable gait speed for stronger people. For fast speeds, the plateau occurred at about 190Nm, but few women of any age were that strong, and few men over 60 years. Those whose strength lies above these thresholds can be thought of as having reserve muscle strength when walking. People without this reserve, including most women, will find that reductions in strength lead to reductions in speed, as their ability to compensate by, for example, taking more steps declines. The analysis of Kwon et al. suggested that height and weight moderated these relationships between strength and speed only slightly, and the amount of physical activity did not moderate the relationship at all.

A number of important conclusions can be drawn from these studies (the implications for crossing timings are discussed in section 7.3.1 below). Older people walk more slowly than younger people, but vary their speed according to circumstances. For example, they speed up crossing the road if traffic is near. They are less able to walk quickly in part because they are not as strong, but the largest reductions in walking speed appear to be caused by illness. Walking speed measured over short distances, or from a stationary start, tends to be slower. Not all of the site-specific features that influence walking speed have been precisely characterised. Slower walking speeds make it more difficult to cross roads comfortably, but also increase the time taken to make a given journey.

2.3.2 Balance and falls

Older people often have increased difficulty maintaining balance, and are vulnerable to falls. As noted in section 1.3.3, falling is a more common cause of accidents for older pedestrians than collisions with vehicles. In section 4.3 below, data on these accidents are discussed in more detail. Problems with stability affect the way older people walk, and their ability to combine walking with cognitive tasks. In this section we look in detail at changes in older people's balance and stability.

Many aspects of the way older people walk point to more conservative patterns of movement. Older people walk more slowly than younger people, and take smaller steps (Ketcham and Stelmach, 2001). Older people with a history of falling tend to show larger reductions (Wolfson et al., 1996). Older people also tend to place their feet further apart when stepping, and tend to have both feet on the ground for longer during each stride (Shumway-Cook and Woollacott, 2001). Laboratory studies suggest that they need to notice obstacles earlier to avoid them (Patla et al., 1992), and that their walking is more affected by a concurrent task (Chen et al., 1996). Chen et al. (1991) found that older adults stepped over obstacles more conservatively than younger adults, moving more slowly and taking a smaller step over the obstacle.

Falls are the seventh leading cause of death in the USA among people aged over 75, and about half of the over 75s who have a fall causing injury become afraid of further falls, many to the extent that they avoid certain kinds of situation (Ochs et al. 1985; cited in Shumway-Cook and Woollacott, 2001). Older women are more likely to fall than older men. Although the liability to fall is affected by environmental variables, such as the stability of the walking surface, as well as the constitution of the person, changes in muscle strength, joint mobility, and strategies that recruit different muscle groups to maintain stability all affect the capacity of older people to maintain balance (Shumway-Cook and Woollacott, 2001). Three sensory systems, each of which performs less well in older people, contribute to the maintenance of balance (Woollacott, 2000). Somatosensory systems detect mechanical events occurring in contact with the body and the relative position of the limbs; the vestibular system provides information about position within a frame of reference defined by acceleration (i.e. gravity); and vision locates the viewer in relation to other objects. In certain situations, some created artificially in the laboratory, these systems can provide conflicting information, and older people appear to change the relative weight they give to them, perhaps becoming more dependent on visual information in particular (Maylor and Wing, 1996).

Tests of balance can be directly linked to dynamic mobility. Tang et al. (1998) found that their older participants' capacity to cope with a sequence of walking tasks in a laboratory, which they called the Sensory-oriented Mobility Assessment Instrument (SOMAI), correlated with static tests of balance in conditions in which visual, vestibular, and somatosensory information was reliable. That is, those who were good at the SOMAI tended to be the best static balance performers when they had all three sources of information. However, in general, there was not a correlation between SOMAI performance and static balance with restricted sensory input. The exception was that those who did poorly on static balance tests without reliable somatosensory information tended to do less well on the SOMAI when peripheral vision was obscured. The SOMAI task thus shows the importance of all three balance senses to dynamic mobility, and that studies of balance have wide relevance to the physical mobility of older pedestrians.

When an incident such as a trip occurs, older people have greater difficulty avoiding a fall, and may use different strategies to younger adults. Laboratory studies of recovery from loss of balance are summarised by Shumway-Cook and Woollacott (2001). Older adults, particularly those with a history of falls, are more likely to use hip movements than ankle movements to recover balance than younger adults (e.g. Sundermier et al., 1996). A strategy based on hip movement recruits larger muscle groups and could reflect a loss of confidence in ankle strength. Another strategy is to take steps. Maki et al., (2000) subjected participants to a lateral movement of the platform they were standing on. They found that healthy older adults (average age 69 years) were more likely than younger adults (average age 24 years) to make extra arm movements or to knock the standing leg with the other one as they tried to recover balance. Maki et al. hypothesised that older adults would be more likely to use a stepping strategy. In fact the difference was small, and a majority of adults of all ages used a stepping strategy. However, older people tended to take more steps when stepping to recover balance, whether they had been simply standing in place until perturbation or had been walking on the spot.

There has been a lot of interest in the role of attention in recovering balance and posture, and a number of studies have looked at responses in dual task situations. Typically, participants are asked to perform a mental task such as counting while standing on a platform that is moved backwards. In dual task situations both younger and older adults are adversely affected, but the effect tends to be greater for older adults. For example, Brown et al. (1999) found that the time to perform an arithmetic subtraction increased more following platform movement in older adults (68–89 years) than for younger adults (21–36 years). Stepping responses were far more common for older people, who in this study only rarely used hip strategies, and strategy selection was similar in dual and single-task conditions. However, when there was a second task, adults of all ages initiated stepping further from the limit at which balance would have been lost. That is, they kept a greater safety margin in the dual-task condition.

The way older people respond to a sudden perturbation is affected by the level of their concurrent cognitive processing. If the cognitive load is greater, they respond more conservatively. One practical reason why studies of balance recovery in dual-task conditions are relevant is that the pedestrian task normally is a dual task. The pedestrian has to control their movement while scanning and evaluating the environment, looking in shop windows, negotiating other pedestrians, or monitoring traffic while crossing the road. Pedestrians may also be talking to people they are walking with, or thinking about the goals of their journey.

One hypothesis is that older people respond more conservatively to loss of balance because they have less strength. Chen (1993; cited in Shumway-Woollacott, 2001) argued, on the basis of a model, that recovery from a trip relies on the ability to build up force quickly, rather than muscle strength as such, something older adults do less effectively (Thelen et al., 1996). A similar study to the one described in the previous paragraph focused on muscle activity on trials in which an ankle strategy was used to recover balance (Rankin et al., 2000). Muscle activity in the lower leg began slightly later in the older group (about 12ms later for the agonist muscle) in both single and dual-task settings, with no dual-task decrement for either group. The amplitude of muscle response was reduced for both age groups in the dual-task condition, but there was a larger reduction in the amplitude of agonist response for older than for younger people. Rankin et al. argued that the agonist muscle response is more important for retaining balance in this situation, and that increased frequency of stepping strategies in dual-task situations is a consequence of this reduced muscle response. However, Brauer et al. (2001), using a slightly different method, did not find a decrease in muscle response in dual-task conditions for healthy or balance-impaired older people. The detailed relationship between muscle activity and balance recovery therefore remains an open question for future research.

Older people with balance difficulties are less able to cope when the sensory information used to maintain balance is restricted. Shumway-Cook and Woollacott

(2000) used a choice reaction time auditory task to compare the dual-task performance of healthy older adults to older people with balance or falling difficulties. In different conditions they restricted different sensory cues. For example, "sway-referencing" (tilting the platform in a manner that tracked body sway) was used to reduce somatosensory input. For healthy older adults, dual-task performance was worse only when both visual and somatosensory cues were removed. For those with balance difficulties a reduction of visual or somatosensory information was sufficient to produce a decrement in the dual-task condition. When both vision and somatosensory input were compromised, people in this group all fell in both single and dual-task conditions. As Shumway-Cook and Woollacott carefully noted, the impaired group were also older, more likely to be living in an institution, taking more medication, and typically had poorer health. Although it is, therefore, not possible to say that the differences are directly linked to balance status, it is clear that more frail older people will have particular problems with mobility when environmental conditions are sub-optimal.

Other studies have analysed the way older people respond to balance perturbation in simple situations. Tang and Woollacot (1998) induced slips in older (60–84 years old) and younger (21–29) adults in a laboratory, and found that older adults returned the swinging foot to the ground more quickly, which they took to reflect a conservative approach to balance. However, the older people also made larger compensatory arm movements and were more likely to trip over the swinging foot as it returned to the walking surface.

Pavol et al. (2001) subjected a sample of people aged over 65 years to a trip. The participants were supported in a harnesss and walked along a track "at a self-selected, 'normal' speed" (p. M429). None had a history of repeated falls. They knew they would be tripped, but not exactly where on the track or on which trial. An obstacle was elevated about 5cm from the track in front of the swinging leg to impede its path. The apparatus recorded the amount of support required from the harness following the trip, and "falls" were recorded when full support was required. Kinematic analysis characterised three patterns of response to trips (for details, see Pavol et al.) and found, among other things, that for two of these, people who were walking faster were more likely to fall following a trip. This implies that slower or more conservative walking would be a rational defence against the potentially serious consequences of falling.

Cao et al. (1998) examined responses to a signal to stop walking or suddenly turn to investigate the process of avoiding collisions. The signal to stop was given as participants walked down a track at comfortable walking speed, reported to be within 10% of 1.3m/s for older (65–85, mean 73.8 years) and younger (18–30, mean 21.8 years) adults, male and female. They found that older adults took longer to begin to decrease forward velocity, although all groups reduced forward acceleration within 250ms. Older men then decelerated more quickly, and older women more slowly, than younger adults. Thus older men partly compensated for the initial delay. The magnitude of differences was of the order of tens of milliseconds. It is possibly surprising that the groups could be matched so closely for comfortable walking speed given the data on walking speed discussed above, and it is conceivable that differences on the task were an artifact of differences in the percentage of maximum effort being made to achieve that rate of progress. Nevertheless, as Cao et al. noted, the pattern of results is consistent with other findings that older adults' walking is affected by diminished muscle strength in the lower limbs.

Older people walk using more conservative patterns of movement, but are vulnerable to loss of balance. Sensory decline and reduced strength appear to be important factors in this higher rate of falling. Older people tend to respond to loss of balance differently to younger adults, and are less able to recover balance. Older people are less able to cope with a secondary task while walking. Some older people have particular problems with balance, and are at risk of repeated falls. The consequence of falling can be serious for older people.

2.3.3 Intervention and physical mobility

Shumway-Cook and Woollacott (2001) summarise in detail current approaches to rehabilitation for people with physical mobility difficulties, including assessment and training strategies. Tests such as the Performance Oriented Mobility Test (Tinetti, 1986) are available to screen older people for problems with physical mobility. There are also specific screening tests for older people with particular medical conditions (Shumway-Cook and Wollocott, 2001).

Muscle strength training has been shown to improve older people's walking speed by as much as 48% (Fiatrone et al., 1990), but this was with frail people aged over 90. With normally healthy older people, the benefits are less striking (Shumway-Cook and Woollacott, 2001). One exercise programme covering general fitness, strength, coordination and balance (twice a week for about five months) involving older women (mean age about 71 years) was shown to provide a statistically significant 6% improvement in walking speed from 1.12m/s to 1.18m/s, and found greater improvement for those who had larger improvements in measured muscle strength (Lord et al., 1996). Armstrong et al. (1996) reported a randomised controlled trial of hormone replacement therapy (HRT), and found it gave no improvement in muscle strength, walking speed, or number of falls over 48 weeks. Indeed, the control group showed a larger increase in muscle strength.

Shumway-Cook and Woollacott (2001) reviewed balance training programmes. Judge et al. (1994) gave older people (over 75) three sessions of balance training a week for three months and measured significant improvements. There is also some evidence that regular exercise can help. Gauchard et al. (2001) found that older people who regularly took a particular form of physical exercise (yoga) had better balance compared to controls whose only exercise was regular walking. They were also less reliant on vision, implying reduced impairment of vestibular function.

Several clinical studies have attempted to find ways of predicting who is likely to become a faller, with a view to prevention. Falling is linked to visual function. Lord and Dayhew (2001) screened a sample of older people for specific visual deficits and followed them for a year. Many (43%) reported falls, and 22% reported repeated falling. There were significant associations with several measures of visual deficit, especially depth perception, contrast sensitivity and low contrast acuity. Those with one good but one less good eye, which would affect binocular cues, also had greater risk. Poor depth perception identified those at risk of falls even after controlling for a measure of balance problems. Lord and Dayhew recommended that visual loss should be corrected in older people when feasible. The commentary by Tinetti (2001) on Lord and Dayhew (2001) identified intervention priorities such as an emphasis on offering cataract surgery or other appropriate correction, even for people who have had cataract surgery on the other eye already. Tinetti also recommended high contrast markings on obstacles on walkways, such as kerbs.

Brauer et al. (2000) administered a battery of tests to women aged 65–86 years, including clinical balance assessments and detailed measurement of a stepping task. Participants then kept a diary for six months recording any falls. Various tests and sets of tasks were then used to model fall risk. The clinical tests were not good predictors, but fallers did tend to have slower step times and to have slower onsets of muscle activity.

A large clinical study (n = 18,855) of nursing home residents found that a history of previous falling was the best predictor of future falling (Kiely et al., 1998). This has also been found in a UK study of people with PD living in the community (Ashburn et al., 2001). Kiely et al. examined a number of variables, and found evidence that some nursing homes had a particularly high rate of falls independent of the risk profile of their residents. This shows that environmental factors contribute to fall risk. Other variables associated with increased risk included unsteady gait, use of a walking aid, wandering behaviour, and dizziness/vertigo. Interestingly, male gender was also a risk factor in this study.

In conclusion, some older people have a higher risk of falling, and progress has been made in identifying screening tests to predict who is vulnerable. Moreover, researchers have successfully developed programmes that can help improve older people's physical mobility. These include strength and balance training, but there is also good evidence that the correction of visual problems is an important element in reducing the risk of falls.

2.3.4 Walking summary

As people get older, they walk more slowly. Estimates of average, or 15th percentile, walking speed at a given age vary greatly between studies. Women are generally found to walk more slowly than men, and older people's walking speed is, for example, slower when they are crossing with a "green" light at a signal-controlled crossing than when crossing against the signal. Illness leads to the largest reductions in walking speed, but loss of strength is likely to be a factor for normally ageing people. Changes in leg strength and, possibly, patterns of muscle activity also affect older people's ability to maintain balance and to cope with losing balance. Falls become more common from late middle age and can have serious, even fatal, consequences for older people. Visual impairment is known to increase fall risk. Training programmes have been shown to improve muscle strength, balance, and walking speed. Implications for the design of crossing facilities that allow for older people's slower movement, and for the maintenance of a high-quality walking surface are discussed in sections 7.3.1, 7.3.2, and 7.3.4.

2.4 Cognition

Some aspects of cognitive performance decline with age. There are, for example, age-related deficits in both speed and accuracy for memory, spatial processing (see 2.2.1 above), planning, and attention. There are several types of theoretical explanation for lower performance on specific tasks. For example, some theorists argue that the differences result from general slowing or some other general reduction in resources. Others believe that certain effects are best explained by reduction in some specific capacity, such as attention. As with sensory decline, individuals vary a great deal on many measures. Older people particularly show greater variability than younger adults on tests of memory and fluid intelligence, although they show no more variability on tests of crystallised intelligence. In some tasks, older groups also show greater response time variability than younger adults (Morse, 1993).

2.4.1 Cognitive performance

Performance on simple reaction time (SRT) and choice reaction time (CRT) tasks is often used as a measure. Older people tend to respond more slowly, and the mean difference is greater in absolute terms for the more complex CRT task. This "age-complexity effect" has been noted across a range of other cognitive tasks (Salthouse, 1991; Fisher et al., 2000). Although the absolute difference is greater in more complex situations, the proportional change is typically similar and so these results are consistent with explanations that attribute age-related change to a common or general process, such as generalised slowing. Cerella (1990) reviewed comparisons between older and younger people on cognitive tasks, and the slope of a linear model of the relationship was between 1.8 and 2.0 for tasks not using lexical materials. That is, older people take on average about twice as long as younger adults to perform a given cognitive task, and from a practical point of view the absolute difference in performance between older and younger people is greater in more complex tasks.

Error rates across various levels of task difficulty have been compared (Salthouse, 1991; Verhaeghen, 2000). There is a roughly linear relationship between the error rates of older and younger adults. That is, although the match is not as good as for reaction time, more complex tasks produce roughly proportional changes in error rate for younger and older adults. However, for some tasks such as a classic analysis of attention shifting data (Brinley, 1965), the slope of the line relating younger to older error performance is greater than one, but for others, such as list recall, the slope is less than one. This means that the absolute difference between younger and older people's performance increases in more difficult conditions for some tasks, but decreases at greater levels of task difficulty in tasks like list recall. Verhaeghen (2000) provides a detailed discussion of more precise models of the relationship between younger and older adults' error rates. The relationship between the error rates of different age groups in the context of the pedestrian task remains to be discovered, but analysis of the task suggests that it would have little in common with episodic memory tasks like list recall and, speculatively, that performance would pattern in ways more similar to Brinley's data. This would be an interesting area for research.

One specific recent approach that advocates a general explanation for reduced cognitive performance in older people is termed the common cause hypothesis (Baltes and Lindenberger, 1997; Lindenberger and Baltes, 1994). This approach postulates a general physiological decline in the brain, although the details are not specified precisely, and hypothesises that this common cause links decline in sensory, motor, and cognitive domains. The principal evidence used to support the common cause explanation is the finding that cognitive performance correlates with a range of measures including visual acuity and other sensory measures, and balance. Schneider and Pichora-Fuller (2000) reviewed evidence of this relationship. A study by Marsiske et al. (1997), which explored relationships among visual acuity, balance–gait scores, and activities of daily living scores, is reviewed in section 2.2.1 above.

It has been shown that artificially reducing the visual acuity or hearing of younger adults to match older people does not produce similar cognitive deficits (Lindenberger et al., 2001), and that the strength of the relationship increases with age (Baltes and Lindenberger, 1997). These findings are consistent with the common cause explanation, although it does not necessarily follow from them (Salthouse, 1991). It is worth noting, however, that these studies have generally used visual acuity as a proxy measure for visual function, but that visual acuity does not correlate especially strongly with some other measures of visual function such as contrast sensitivity. It is conceivable that relationships between vision and cognitive decline are specific to visual acuity. Students of vision have long been aware that intelligence affects performance on tests of visual acuity (Weale, 1963), and have considered this in explaining why visual acuity increases during childhood and adolescence. Other experimental research does suggest that differences between older and younger adults on tests of attention and memory can be reduced or eliminated when visual acuity or contrast sensitivity are controlled (for a review, see Schneider and Pichora-Fuller, 2000).

Many of the studies discussed in relation to the common cause hypothesis have used cross-sectional methods. A recent longitudinal study found a link between greater decline in visual acuity and greater decline in memory, but not with processing speed or a measure of verbal ability (Anstey et al., 2001). No association was found between decline in hearing and cognitive function. Anstey et al. speculated that a rapid decline in visual function may be an indication of incipient dementia rather than normal age-related cognitive decline.

Hall et al. (2001) reviewed studies showing that people who exercise more have smaller age-related declines in cognitive function. Giving emphasis to recent randomised studies that manipulated aerobic fitness with exercise programmes, they concluded that the effect on cognition is in fact specific to executive function, and occurs because exercise maintains blood flow to the frontal cortex. Damage to the frontal cortex is associated with impairment on executive tasks. Furthermore, age is associated with lower cerebral blood flow. Arking (1998) reported that 70 different studies found that metabolic processes in the brain either stay the same or reduce with age, with a tendency for cerebral blood flow to be less for older people than younger people during cognitive tasks.

Older people show bigger disadvantages on more complex tasks, but because average performance is a constant proportion of younger people's across a range of levels of task complexity, this could be explained by a single mechanism of impairment. Possible candidate mechanisms include general neural deterioration or reduced cerebral blood flow. For some cognitive tasks, there is evidence that improved blood flow to the frontal cortex resulting from physical fitness improves performance. However, further work using appropriate research designs is needed to investigate these points.

2.4.2 Attention

Attention is important to pedestrians in a number of ways. They need to be able to switch attention between tasks, to focus attention in particular locations, and to carry out visual search. They will sometimes also need to manage a division of attention between tasks when, for example, they are walking and talking at the same time. There is some evidence linking attention to the pedestrian task and to accidents. Most pedestrians who are struck by cars do not see the vehicle that hits them at all, and many report that they looked but did not see it (Wilson and Grayson, 1980). Dunbar et al. (2001) showed that children who did better on a laboratory task related to executive function were more likely to look at approaching traffic as they began to cross a road with their parent. Clinical assessments believed to tap executive processes, such as the Trails B test, have been shown to be related to accident risk in drivers (Janke, 2001).

It is also known that older road users, both drivers (Moore et al., 1982) and pedestrians, have a heightened accident risk at intersections, and it is believed that this is because of the greater complexity of road junctions compared to other situations (Hauer, 1988; Staplin et al., 2001). Hakamies-Blomqvist and Henriksson (1999) looked at data for at-fault intersection accidents involving older drivers in Finland between 1987 and 1995. They found that, comparing younger old drivers at each point in time, the relative rate of intersection accidents decreased. However, for the oldest drivers the excess remained and, indeed, rose, at least for men. They concluded that, although the precise relationship with age might vary between cohorts, older people did tend to have more accidents of this type.

Bailey et al. (1992) found that 62% of older pedestrians aged over 56 years, in a sample from Orlando, Florida, reported anxiety when crossing at a busy intersection. Snyder (1972, p. 27) pointed out that many interventions to reduce pedestrian accidents at intersections involve simplifying the situation: "It would be expected that the fewer directions from which threatening traffic can arrive, the more likely it is the pedestrian will be able to handle the situation." Laboratory studies of attention support this general view that complex situations are more difficult for older people. Furthermore, some tasks that were once automatic, such as walking, come to require cognitive control with age. That is, they come to show performance decrements when combined with a second task. This has been shown for both walking (Lindenberger et al., 2000) and avoiding obstacles (Chen et al., 1996), as well as in the studies of balance control discussed in section 2.3.2 above. Older pedestrians are therefore likely to find complex situations such as intersections difficult to cope with.

Aspects of attention and executive processing decline with age, and these skills are important for the control of perception and action. Indeed, one general account of cognitive ageing would be that reduced cognitive performance results from the single general effect of declining attentional resources (Salthouse, 1991) or declining ability to inhibit irrelevant information (Hasher and Zacks, 1988). Mayr and Kliegl (1993) found that whereas the slope of the line relating older to younger adults' speed of performance (measured as response time) was 1.95 for a cognitive task, consistent with the figure indicated above, for a task requiring executive control the slope was 3.91. That is, there is a proportional relationship between younger and older people's performance on tasks requiring executive control, but increases in task difficulty cause more rapid divergence between absolute levels of performance than on other cognitive tasks.

There is a variety of specific attentional functions. For example, selective attention brings target information into focus, disregarding other information, and divided attention shares the focus between more than one task or source of information. Most investigators currently believe that general slowing explains some but perhaps not all of the age differences in divided and selective attention, and switching (McDowd and Shaw, 2000). It has been suggested that older people perform more poorly on cognitive tasks in part because they more frequently produce very slow responses, or lapses, and that this is true for executive tasks specifically (West, 2001), although further work is needed to test that view. In the following paragraphs we briefly characterise the relationship between specific aspects of attention and ageing.

Selective attention requires attention to the desired target and inhibition or filtering of attention to alternative information. Typical laboratory tasks require participants to find an item that meets some criterion in an array of items. If the search criterion is simple or the target location is known in advance, then age differences are slight, but on more complex tasks older people do less well (Rogers and Fisk, 2001). In a typical experiment, targets are defined by one feature (e.g. find the pink item – a simple task showing little variation with age) or by a conjunction of features (find a small pink item among distractors that are also pink, or small). Older people perform relatively less well on searches for items defined by a conjunction of features (Plude and Doussard-Roosevelt, 1989).

Older people use cues to switch attention to another spatial location as effectively as younger people, including in three-dimensional space (Atchley and Kramer, 1998), when the cues are physically related to the target location. For example, luminance changes or abrupt onset cues at the target location produce similar responses from older and younger people. These cues are believed to induce an involuntary attention switch (McDowd and Shaw, 2000). However, people over 75 years show poorer ability to re-orient after an invalid cue of this sort, i.e. when the target appears in a different location to the one cued (Greenwood and Parasuraman, 1994). For symbolic cues, such as an arrow in the centre of the visual field pointing to the target location, older adults can actually perform more slowly than when no cue is given (Folk and Hoyer, 1992), in contrast to younger adults who benefit from the cue. Greenwood et al. (1997) found that participants in a 75–81-year-old group were less able than 63–74 year olds to use spatial cues that indicated the rough location of the target in a visual search task.

In some experiments, participants are asked to switch from one task to another, as opposed to switching attention to a new location. For example, they may begin by responding on the basis of the numerical value of a target digit and then, on a signal, switch to responding on the basis of the number of digits displayed. Older adults show a greater amount of slowing on the first trial after a switch, the switching cost, than younger adults, but the cost has been found to be smaller among physically fit older people (Hawkins et al., 1992) and after extended practice (Kramer et al., 1999).

Divided attention studies typically ask subjects to perform two tasks that require cognitive control, and interest centres on comparing the standard of performance to conditions in which each task is performed alone. Tasks may not show age differences if the memory requirements are low, but otherwise consistent reductions in performance are found for older people (Rogers and Fisk, 2001). One study compared pilots and non-pilots aged 20–79 years on a series of dual tasks (Tsang and Shaner, 1998). Tasks included tracking a moving target and spatial orientation, and in some trials participants were to emphasise one task at the expense of the other. Tsang and Shaner concluded that older people were less able to combine tasks, and were less able to vary the relative priority of the tasks. The pilots – representing dual-task experts – showed better dual-task performance. This suggests that experience leads to better dual-task performance by older and younger people.

In some attention tasks, older people and younger people perform similarly. Sustained attention requires ongoing monitoring of a source of information for a target event. Whether differences between older and younger adults are found depends on the testing procedure used and aspects of the individual such as their motivation or visual function. In general, however, there is little evidence for substantial differences between older and younger people unless task demands are high (McDowd and Shaw, 2000). For example, one study found no significant differences between healthy older (mean age 67 years) and middle-aged or younger adults on a range of sustained attention performance measures, including hit rate and response time, for a relatively difficult task lasting over two hours (Berardi et al., 2001). Age differences in sensitivity approached statistical significance, but there was no age difference in the rate of decline in performance during the experiment. Older people's vigilance fell away at the same rate as younger adults' across the period of the experiment.

Another type of experiment uses the distractor from one trial as a target on the next. In general, people respond more slowly to a target that was the distractor on the preceding trial. There can be a similar effect if the target appears in a location that was used by a distractor on the preceding trial. This has usually been interpreted as a carry-over from processes that inhibited response to the item when it was the distractor on the initial trial, although this interpretation is controversial. The effect is termed negative priming. Across studies, the magnitude of the effect with older participants is similar to younger adults for negative priming of both location (McDowd and Shaw, 2000) and identity (Gamboz et al., 2002).

Similarly, in the visual attention literature, there is a phenomenon known as 'inhibition of return', whereby responses are slowed to targets appearing at locations to which attention has recently been directed in comparison with responses to targets at new locations (Maylor and Hockey, 1985; Posner and Cohen, 1984). Like negative priming, inhibition of return has been shown to be unimpaired by normal ageing (see Faust and Balota, 1997; Hartley and Kieley, 1995).

We would also expect a recently identified process termed ‘visual marking’ (Watson and Humphreys, 1997) to be relevant to the pedestrian task. In brief, visual marking refers to the ability to select or prioritise new information in the visual field by suppressing old information already present. This is a top-down capacity-limited inhibitory process that is thought to be required in many circumstances in everyday life. Watson and Humphreys (1997) give the example of an air traffic control task but note that “in general terms, visual marking provides valuable survival advantages for observers in relatively complex environments that require monitoring for changes that indicate danger” (p. 90). Initial studies found that older adults showed evidence of visual marking to exactly the same degree as young adults (Kramer and Atchley, 2000; Watson and Maylor, 2002, experiment 1). However, in these simple cases, the stimuli were all stationary. Subsequent experiments with moving stimuli show no evidence at all of visual marking in older adults, whereas young adults continue to show visual marking (Watson and Maylor, 2002, experiments 2 and 3). Moreover, it seems likely, although not yet tested, that older adults will show impaired visual marking even with static displays under conditions of increased cognitive load (see Watson and Humphreys, 1997).

Cognitive performance varies with time of day, and recent evidence indicates that, cross-culturally, there is a tendency for a larger proportion of older people to be “morning people” (Yoon et al., 2000). “Morning” people tend to be more active and more alert in the morning. Relationships have been demonstrated between time of day and cognitive tasks, particularly for tasks that can be characterised as requiring inhibitory processes. For example, in one experiment older and younger adults were asked to make category judgements (“Is a chair a piece of furniture?”), but to hold back their response on a few trials, which were indicated by a “stop” signal (May and Hasher, 1998). Older people were less able to hold back in the evening than in the morning, whereas younger adults were better later in the day. A variety of tasks requiring careful and deliberate processing have been shown to be subject to these effects. On the other hand, very familiar and routine tasks do not appear to be affected by time of day.

In conclusion, older people do less well on a range of tasks that require the control and allocation of cognitive resources, although they do not do worse than younger adults on some tasks such as sustained attention tasks. There is good evidence that these problems make driving more difficult, and there is evidence linking attention to pedestrian behaviour. It is now known that older people need to employ greater attentional control even for tasks like walking, which are relatively automatic for younger adults. If any aspect of the road environment places additional demands on attention, this will be particularly difficult for older people, and it is quite plausible that this could explain the over-representation of older pedestrians in accidents at junctions.

2.4.3 UFOV – a composite measure

One composite measure of cognitive function that is of particular relevance is the Useful Field of View, currently operationalised as a standardised test called UFOV®. Functional tests of field of view evaluate the detection and localisation of targets well above the sensitivity threshold, whereas tests of visual field discussed earlier evaluate the threshold for single-target detection. UFOV scores are a composite of more than one task, including peripheral localisation of a static target with and without a concurrent task of identifying a centrally presented target, with the position and, in current versions, the duration of the peripheral target varied systematically. Performance is affected by the conspicuity and duration of the peripheral target, and the difficulty of the central task. People with poorer UFOV scores are assumed to need more, time consuming, eye fixations to take in information from a complex visual scene (Ball et al., 1988).

Scores on this test tend to fall with increasing age, but there is a great deal of variation at a given age. Ball et al. (1990) found that differences in variables such as speed of processing, divided attention performance and ability to ignore distractors could explain a large proportion (91%) of individual variation in UFOV scores. A decline in UFOV could therefore reflect a decline in one or more of these functions. Further work on the construct validation of UFOV would be useful from both a theoretical and practical point of view (see e.g. Owsley et al.,1998; Sekuler et al., 2000).

Owsley et al., (1991) found a significant correlation ($r = 0.36$) between UFOV and accident risk among a sample of 53 older drivers. Subsequently, in a series of analyses of data from a stratified random sample of 294 older drivers from Alabama, the Jefferson sample, Ball, Owsley, Roenker and colleagues (e.g. Ball et al., 1993; Goode et al., 1998; Owsley et al., 1998) have examined the relationship between accident risk for drivers and a range of variables, including measures of UFOV. They found that UFOV could explain more variance in accident rates than other measures such as visual acuity, and that the relationship is stronger for accidents in which the older person was held to be at fault, for accidents leading to injury, and for accidents at intersections. The association with accidents at intersections is particularly interesting because of the evidence that older people's greater risk at intersections also generalises to pedestrian accidents. However, we believe no-one has yet investigated the relationship between UFOV and pedestrian accidents.

Sims et al. (1998) invited the Jefferson sample of older drivers to return in 1991 for a further battery of tests, including self-reported difficulty with everyday tasks and physical examinations. Slightly over half were tested (59%), and UFOV was found to be associated with accident history. Measures of walking were included, but unfortunately relationships with other tests were not reported, except that those who had had an at-fault crash in the previous six years were more likely to report having fallen in the last two years. Sims et al. (2000) reported a marginally significant relationship between fall risk and subsequent driving accidents in the following five years, but no significant relationships between subsequent driving accidents and walking speed, use of walking aids, or self-reported difficulty walking indoors or outdoors.

Other investigators have replicated aspects of these findings using accident records or driving performance in a simulator or on the road as outcome measures. However, some have found a rather lower strength of effect linking UFOV to accidents (e.g. Hennessy, 1995).

2.4.4 Cognition summary

Some attentional functions, such as sustained attention, are not impaired in older people. In addition, people's ability to cope with simple search tasks or familiar, routine, and well-learned tasks shows a smaller range of impairment in older age. However, in more complex situations there is a larger absolute difference between older and younger people's cognitive performance. Older people have greater difficulty with situations that require dividing attention between more than one task or piece of information, switching attention, complex visual search, and ignoring distracting information, particularly if it is moving. Analysis of the pedestrian task suggests that these difficulties would have a negative effect on performance, and there is some evidence for direct links with pedestrian behaviour. Research on driving has found links between cognitive impairment of various types and accident risk, particularly for the composite measure UFOV. Studies have found that relevant attentional skills can be improved by training, and this is discussed in section 7.1.2.

2.5 Summary

This section has focused on characterising the most relevant functional impairments experienced by older people, and indicating their relationship to the pedestrian task. Although older people as a group tend to perform less well on tests of vision, hearing, physical mobility, and cognitive performance, there is a great deal of variability, more than is found among younger people.

- With increasing age sensory function tends to be less good, and there is detailed knowledge about the pattern of decline for many of these functions. Less is known about their relative importance in the pedestrian task, particularly in the case of hearing.
- Although sensory, motor, and cognitive measures have face validity as predictors of accident involvement, there is at best weak evidence to implicate functional impairment directly as a cause of pedestrian accidents. The possibility that this is because people with impairment compensate is explored in section 6 below.
- Older people walk more slowly, and it has often been reported that they find it difficult to cross roads even at signal-controlled junctions. It is important that the

road environment is designed to accommodate these lower walking speeds (see section 7.3.1 below). There is variation in walking speed between individuals, and walking speed is also affected by the situation. For example, older people crossing against traffic signals walk slightly more quickly than those who comply. Very roughly, typical walking speeds when crossing roads of around 1.5m/s for middle-aged adults reduce to around 1.2m/s for older people. However, some people walk much more slowly. The largest falls in walking speed appear to be caused by medical conditions rather than ageing as such.

- Older people often have difficulty with balance, and are vulnerable to falls. It has been reported that, on average, about one in three people aged over 65 living in the community falls each year (Shumway-Cook and Woollacott, 2001). There is evidence that some older people are particularly likely to fall; people who have fallen before are more likely to fall again. Falls can have serious consequences for older people. A number of laboratory studies have looked at the way older people cope with losing balance, and we have described some of their findings in detail because of the importance of understanding how older people cope in such situations.
- Older people appear to need to use more deliberate control to accomplish physical tasks that are relatively automatic for younger people. This may reduce the cognitive resources available for other tasks at the same time, and has particular implications for older people's ability to respond to changes occurring rapidly.
- A number of controlled studies have demonstrated that exercise programmes can improve balance and walking speed. It is not yet possible to quantify the safety value of such improvements, but these results are encouraging and there are intrinsic benefits to increased physical fitness.
- In relation to driving, stronger relationships with accident rate have been found with composite measures involving higher order variables that include cognitive aspects than with simple measures of sensory performance. The possibility of developing such measures has not been explored in relation to pedestrian behaviour, probably because the issue of licensing does not apply to walking as it does to driving.

2.6 Research implications

To understand the role of functional impairment in accident causation, we need more precise models of the pedestrian task and the role of perceptual and cognitive functions in that task. Empirical studies looking at associations between specific impairments and accident involvement would complement this.

In particular, the role of hearing in pedestrian behaviour is not well understood, although there have been a few explorations of this issue.

It may be that screening measures can be developed, along the lines of UFOV® in relation to driving, and UFOV itself might make an interesting starting point for such research. Work on developing predictive tests for falling has already begun, and this too could be of assistance.

Not all of the functional impairments identified can be ameliorated by simple measures such as spectacles. On the other hand, there is clear evidence that regular exercise of various sorts can reduce the decline in physical mobility. Continuing research and development of interventions to maintain or improve functional performance will obviously benefit older people in general ways, as well as potentially helping them with pedestrian tasks.

3 MEDICAL STATUS OF OLDER PEDESTRIANS

Older people commonly suffer from medical conditions that may impair performance and increase accident risk. In addition, certain kinds of medication affect performance. Compounding these effects, many older people are suffering from more than one chronic illness and are often taking a variety of different medications. Methodologically, it could be difficult to determine the added risk to pedestrians of a specific illness, because people may change their pedestrian behaviour. For example, Waller (1987) found that drivers with severe heart disease were more likely than drivers with less severe or no heart disease to reduce annual mileage, driving in bad weather, at night, or at high speed. Such changes in exposure would lead to underestimates of risk based on population.

Most relevant previous research typically relates to driving, and reviews include Janke (1994), and Staplin et al. (1997). A recurrent conclusion of this research has been that net functional capability, rather than a specific medical diagnosis, often better predicts accident risk (e.g. Waller, 1965). For example, if an illness adds to existing cognitive, sensory or motor difficulties, then function on the roads could be significantly impaired. However, if a person has no existing problems, then the same illness may not be dangerous. Thus, it is important to consider the severity of combined effects (Wallace, 1989).

Langlois et al. (1997) examined the difficulties of older pedestrians in relation to their health status. They examined a large number (n = 1,249) of older people aged 72 to 105 years in terms of self-reported difficulties crossing the street, and examined several variables in relation to this, such as measured visual acuity, walking speed and cognitive status. The participants were also asked if they had been told by a doctor that they had had a stroke, a hip or other fracture, a heart attack, cancer or diabetes. They were assessed in terms of basic activities of daily living – their ability to bathe, dress, toilet and eat unaided and without special equipment. Excluding those who said that they could not walk across a room indoors unaided, 11.4% reported that they had difficulty crossing the street. Those aged 80 years or older and women were more likely to report difficulty crossing the street (e.g. 19.2% of the women over 80). Those reporting difficulty were more likely to have a very slow walking speed and were more likely to need help in daily living. They were also more likely to have histories of stroke, fracture (excluding hip) and diabetes, but there was no relationship with a history of heart attack or cancer. There was also an association with low visual acuity and a low mental status score, but these relationships were not statistically independent of other associations. This study is significant as it is one of the few to have examined these questions, although we should bear in mind that the criterion for classifying illness was potentially imprecise, and that, as the authors noted, there are limitations with generalising walking speed measured over a short distance indoors.

A prospective longitudinal study in the USA using otherwise similar methods confirmed that five medical conditions (heart problems, arthritis, diabetes, cancer, and stroke) were associated with functional impairment (Kiely et al., 1997), although the rate of further decline was not elevated. Impairment was measured by an index of self-reported coping with basic self-maintenance and other everyday activities such as walking. Those with more than one condition had greater impairment, but the effects were found to be additive. Expressing the cost of these impairments in terms of normal ageing, Kiely et al. found that arthritis and cancer were equivalent to about one year of normal ageing, heart problems and diabetes to two years, and stroke to five years.

Eye disease is discussed in an earlier section relating to perceptual decline.

3.1 Cardiovascular disease

Cardiovascular disease accounts for about half of all deaths in the UK (Taylor, 1995) and death from coronary heart disease (half of this) is commonly sudden. Driving studies have noted an almost twofold increase in crashes for those known by the vehicle licensing agency to have heart disease (Crancer and O'Neill, 1970), sometimes due to acute collapse. The influence of cardiovascular disease on pedestrian safety is more likely to be due to indirect effects, such as the effect of the illness on speed of walking and also on general oxygenation of the brain, resulting in less efficient processing of information.

The pedestrian group may include cardiovascular patients who have given up driving because of their condition, perhaps for a specified recovery period after heart surgery or after a heart attack. It is also a common reason for people being advised to walk more as rehabilitation exercise. This may put people on the roads as pedestrians more than they are used to at a time when their walking speed may have slowed due to their illness. Whereas the benefits of walking and restriction of driving are not debated, this may be a situation in which advice – for example, on avoiding crossing wide and busy roads – may be helpful in reducing risk.

Cardiovascular problems can cause hypotension, which can lead to fainting (syncopal episodes). This is relatively common for older people. Loss of consciousness would obviously be hazardous for an older pedestrian.

3.2 Cerebro-vascular accidents (strokes)

Cerebro-vascular accidents vary widely in severity, and the effect depends on the location and extent of damage to the brain. In some cases, repeated small strokes progress to vascular dementia (Gelder et al., 1996). A self-reported history of stroke has been associated with driving accident risk (Sims et al., 2000). Stroke patients commonly have lateral weaknesses, affecting their ability to walk. Cognitive changes could also affect performance, even if the patient is physically rehabilitated sufficiently to manage to walk and negotiate kerbs and other obstacles. Although about half regain independent living, stroke patients report more difficulty with everyday tasks (Kiely et al., 1997; Langlois et al., 1999). Kiely et al. found that of five conditions (heart problems, cancer, diabetes, arthritis, and stroke), stroke was the most functionally disabling. Langlois et al. (1997) found that people over the age of 72 with a history of stroke reported finding crossing roads a particular difficulty. Shumway-Cook and Woollacott (2001) reported an estimated mean walking speed of 0.65m/s, although of course there will be wide variations.

Some stroke patients experience lateral neglect, and do not attend to information from one side of the body. Robertson et al. (1994) found that patients with unilateral left neglect deviated to the right as they attempted to walk through a doorway. Failure to process information on one side would be an obvious hazard for a pedestrian. It would be important to consider this possible effect in the context of rehabilitation.

3.3 Diabetes mellitus

Diabetes becomes more common with age, and almost 40% of persons aged 75 or over develop some form of glucose intolerance (Adams and Collins, 1987). Langlois et al. (1997) found that older people with diabetes were more likely to report that crossing roads was difficult. Crash experience of diabetic drivers is generally higher than that of non-diabetic drivers. For example, Owsley et al. (1998) cited a study (Koepell et al., 1994) that showed a higher rate of injury accidents. The situation is improving as control and self-monitoring of glucose levels improves (e.g. Hansotia and Broste, 1991). However, control often becomes more difficult with increasing age, and any consequent fluctuations in awareness are obviously a risk factor for any road user.

Diabetes of long standing brings with it many associated difficulties. For example, arterial degeneration can cause blockages in blood vessels, leading to heart attacks and strokes. Such difficulties in old age contribute to generally poor health, which itself could lead to functional difficulty in the road environment. Vision is also affected if the blood supply to the retina becomes damaged (diabetic retinopathy). Browning (1998) cited a study by Tay et al. (1995) indicating poorer auditory signal–noise discrimination for diabetics. One specific difficulty is polyneuropathy – a peripheral sensorimotor deficit affecting nerves in the feet and hands. This results in loss of ankle reflexes. Diabetics with this symptom show disturbances of balance, and balance recovery problems (Boucher et al., 1995).

3.4 Epilepsy

In the UK, four to six per 1,000 of the population have epilepsy. Old age, as well as childhood, is a peak time for onset (Gelder et al., 1996). In a minority of cases, the condition is chronic. The rapid onset of seizure, with the resulting catastrophic temporary impairment, leaves a victim highly vulnerable in almost any situation. Cases of collapse in the roadway have been reported (Al-Qattan, 2000), but the incidence of pedestrian casualty is not known with certainty. It is likely that injuries from associated falls are more frequent than collisions with vehicles.

People with a recent history of seizure normally have to give up driving, because of the demonstrable risk. They are also unable to enter a number of occupations, such as the armed services, in which the potential consequences of a seizure are perceived to be too great. For a review of the relationship with driving, see O'Brien (1986). Although it used to be thought that epilepsy led to cognitive decline, it is now known that this is rare (Gelder et al., 1996).

Many forms of epilepsy can be managed by medication, but some drugs used can affect mood or behaviour (Gelder et al., 1996). In particular, some drugs cause drowsiness, at least at the start of treatment, which may affect skills involved in the pedestrian task as well as other activities. Nevertheless, greater risk can arise if a patient abstains from medication, which can occur, for example, in religious observance (Al-Qattan, 2000).

3.5 Sleep disorders

Sleep disorders can be very disturbing for people who experience them, and have been associated with an increased risk of injury (Morin and Edinger, 1999), although not specifically pedestrian–vehicle accidents. However, the relationship between fatigue and driving accidents is notorious. Some of the problems associated with lack of sleep may in fact result from the cause of the sleep disorder, such as depression, rather than being a consequence of a lack of sleep (Gelder et al., 1996). Primary insomnia is age-related in that it is more common among older and middle-aged people, who are also more likely than younger adults to have problems with sleep quality rather than with getting to sleep in the first place (Gelder et al., 1996; Morin and Edinger, 1999). Women report insomnia more often than men, but this could reflect a reporting bias rather than a true difference in prevalence (Morin and Edinger, 1999). Nowadays, long-term treatment with hypnotic drugs tends to be avoided because of problems with addiction, tolerance, and side-effects (Gelder et al., 1996). Obstructive breathing-related sleep disorders, such as sleep apnoea, are most common among men aged 30–60 years, but are also frequently experienced by older adults (Morin and Edinger, 1999). Alzheimer's disease (AD) is associated with serious disturbance of the sleep/wake cycle (Gelder et al., 1996; Morin and Edinger, 1999).

3.6 Arthritis

Although various conditions are termed arthritis, rheumatoid arthritis and osteoarthritis are the two most common forms in the older population. Arthritis leads to disability more often in older women than in older men, for reasons that are not well understood (Peek and Coward, 1999). Rheumatoid arthritis often begins between the ages of 25 and 54 years, but as it is a progressive disease, serious impact tends to occur later. It generally affects mobility more seriously than osteoarthritis, the onset of which is age-related. Most people over 70 have some form of degenerative joint disease (Tonna, 1987), but younger people are also affected. In terms of pedestrian behaviour, the slowed and restricted movement resulting from arthritis can affect not only speed of walking, but also ability to negotiate uneven pavements, steps, kerbs and slopes. In addition, the ability to move the head from side to side when checking for traffic could be impaired.

Arthritis can affect proprioception, which is used to balance, to correct position after a perturbation of balance (e.g. a trip), and to help control walking. Receptors in the joints provide proprioceptive information known as joint position sense (JPS), which is impaired by osteoarthritis (McChesney and Woollacott, 2000). McChesney and Woollacott demonstrated that arthritic participants with poor JPS depended on visual input to maintain balance more than did controls, in that they showed greater sway when standing still with their eyes closed.

3.7 Parkinson's disease

Parkinson's disease (PD) is typically, but not exclusively, diagnosed after the age of 50, and affects about 1.6% of the population over 65 (Pentland, 1999). It is a progressive neurological pathology involving the loss of dopamine production. Movement is affected in various ways, such as delayed initiation, and slowing. Postural reflexes can be impaired, making balance recovery difficult. Falls are frequent, and there is particular difficulty in busy streets (Pentland, 1999). Specific symptoms vary between patients. Gait can be affected, with turning movements becoming especially difficult. Hesitation and "freezing", especially in confined spaces or crowds, are common events (Lee et al., 2001). Rigidity of movement may affect the ability to look around for traffic (Lincoln and Radford, 1999). In later stages, patients may be unable to walk.

PD is associated with a higher incidence of depression and, by some estimates, also dementia than would be expected in non-Parkinson's age-matched populations. Even in the absence of dementia, more subtle cognitive impairment is frequently, but by no means invariably, associated with PD (Pentland, 1999). Lincoln and Radford (1999) describe a study by Dubinsky et al. (1991), which suggested that, although disease severity correlated with accident risk per mile for drivers with PD, those with cognitive impairment had a higher accident rate than those without. Heikkila et al. (1998; cited by Lincoln and Radford, 1999) found that tests of choice reaction time, visual memory, and speed of information processing correlated with ratings of competence by a driving instructor. People with PD often give up driving voluntarily (Campbell et al., 1993; cited by Lincoln and Radford, 1999).

In PD, walking speed is sensitive to disease progression, effects of medication and other factors (Shumway-Cook and Woollacott, 2001). Blin et al. (1990; cited in Shumway-Cook and Woollacott) reported a mean of 0.44m/s. Ashburn et al. (2001), noting earlier findings that people with PD had a higher risk of falling, found that laboratory measures of gait and sway were not good predictors of fall risk. However, frequency of falls in the past year and subjective anxiety about falling were good predictors of falls and near falls over the subsequent three months.

3.8 Medication

Psychotropic drugs have been found to affect performance in ways relevant to the pedestrian task. Mustard and Mayer (1997) reported an increased risk of falling among nursing home residents who had been prescribed antipsychotic or sedative drugs. This study used a sophisticated case–control methodology, and considered only instances in which the person experienced a fall requiring hospital treatment for the first time. Similar results were reported by Thapa et al. (1998; cited by Colenda et al., 2000). A large study of nursing home residents in the USA found significant bivariate relations between both antipsychotic and anti-anxiety medication and fall risk (Kiely et al., 1998). However, they did not predict risk independently of other variables included in a multivariate analysis. The other variables included measures of fall history, physical mobility, mood and cognitive ability. Kiely at al. found each type of drug was being taken by 14% of their sample, aged 65–110, median 87 years.

Owsley et al. (1998) cited a Tennessee-based study (Leveille et al., 1994), which found higher accident risk among drivers taking cyclic antidepressants or opioid analgesics. A Canadian population-based study looked at links between medication and workplace injuries. Gilbert et al. (1996) found that antihistamines were associated with an increased risk, along with antibiotics and diabetes medication, but the design of this study did not allow for separation of the effects of the illness and the medication. The same study found no association with psychotropic drugs. A prospective study with the Jefferson sample of older drivers found increased accident risk for those taking hypnotic medication (Sims et al., 2000).

Horne and Barrett (2001) reviewed the classes of over-the-counter medicines that can lead to unwanted sleepiness in drivers. This symptom would also affect pedestrians in certain situations. They identified three groups of medicine having this effect (antihistamines, opiods, and muscarinic antagonists), with particular formulations of one group found to impair performance more than the legal blood alcohol concentration limit in the UK (classical H_1 receptor antihistamines). Horne and Barrett pointed out that older people taking such medicines regularly would be more affected because poor renal performance could allow the drug to accumulate in the body. They recommended better monitoring of drug labelling, noting that many of these medicines came with no specific warning for older people.

3.9 Dementia

The term “dementia” covers a variety of diseases with the diagnostic criterion of a progressive, serious decline in cognition. The most prevalent types of dementia are Alzheimer’s disease (AD) and vascular dementia. The prevalence of such disorders is rising because of demographic changes. The prevalence of moderate and severe dementia, for example, rises from 5% at 65 years or older, to 20% over 80 (Gelder et al., 1996). A diagnosis of dementia can bring pressure to give up driving, perhaps putting people into the pedestrian situation more than they are used to at a time when they could be more vulnerable anyway. Drivers with dementia have, on average, twice the crash frequency of age-matched controls (e.g. Cooper et al., 1993; Kaszniak et al., 1990; Waller et al., 1993). Whereas this is lower than young men or alcohol-impaired drivers, it nonetheless represents a substantial risk to those with AD. According to Johansson et al. (1997), half of all older driver fatalities in their sample had neurological evidence of AD.

Dementia is a progressive disease and a diagnosis of AD may not mean that a person has serious difficulties yet. Drachman and Swearer (1993) and Waller et al. (1993) reported that during the early stages of AD, driving accident risk is no higher than that for the general population of that age group. On the other hand, Rizzo et al., (unpublished) show that a group of older people with probable AD, most of whom were still driving or had stopped only in the previous six months, who were living at home, were able to cope with personal daily needs, and had only mild or moderate impairment as assessed by a neuropsychological battery, nevertheless showed a significant UFOV loss compared to controls matched on age and visual acuity (69.7% and 32.4%, respectively). UFOV loss correlated with the degree of neuropsychological impairment, and has been found to correlate with accident risk among older drivers. This suggests that older people suffering from dementia may be at increased risk in the road environment even at relatively early stages of the disease. In the later stages impairment is more global and severe and there is little disagreement that negotiating traffic would pose a considerable risk (Lundberg et al., 1997).

Vision can be impaired in AD, especially contrast sensitivity, (e.g. Gilmore and Levy, 1991). Gilmore (1995) reported that improving the contrast of stimuli improved performance of AD patients on certain linguistic tasks in the laboratory. By improving lighting carefully, the road environment could possibly be made safer for people with AD. Trick and Silverman (1991) found that AD patients had higher thresholds for motion detection than age-matched controls, and that the increase was greater for those with worse symptoms. On average, the threshold was approximately doubled, and many in the AD group (seven out of 20) could not detect motion at all within the range tested.

Other researchers have examined AD patients in terms of their risk of falls and balance. AD patients have three times as many falls as healthy older people (Morris et al., 1987). To investigate the role of sensory information, Chong et al. (1999) varied the sensory information available to a person with AD whose task was to maintain balance while standing on a platform. In one condition, participants were simply blindfolded. Healthy older people increased their body sway, but AD patients did not. This implies that AD patients actually found loss of visual information did not increase difficulty so much. In contrast, there was a trend ($P = 0.07$) for them to sway more when ankle somatosensory information was upset by sway-referencing the platform, which suggests relatively greater reliance on somatosensory input for AD patients. When misleading ankle information was combined with a blindfold, AD patients found it hard to cope (about half fell) and hard to adapt with practice. In another condition, the visual surround was rotated (in proportion to body sway) while accurate ankle feedback was given. With misleading visual information but accurate somatosensory feedback, although two of the 11 AD patients fell on the first trial, compared to none of the healthy older adults, none fell on the second or third trial, showing some ability to learn to ignore misleading visual information. When both ankle somatosensory information and visual information were misleading, over half the controls but all of the AD patients fell on the first trial. Although both groups showed some improvement on subsequent trials, over 60% of AD patients still fell. Thus, when participants had to rely on vestibular cues, all did poorly, but the AD patients were especially disadvantaged. Nevertheless, Chong et al. note that they were able to maintain balance for a period before falling in these conditions, unlike patients with vestibular loss who would fall immediately. The AD patients also had normal vestibular reflexes. Chong et al. concluded that the problem lay in coordinating and if necessary suppressing information from different senses. Overall, these results suggest that somatosensory information is particularly important for AD patients' balance.

3.10 Psychiatric illness: depression and anxiety

Depressive symptoms are commonly associated with old age. Onset is often related to bereavements and loneliness, but also to ill health. Depression varies greatly in severity, and because different studies have used different diagnostic criteria it can be difficult to compare results. Beekman et al. (1999) reviewed 34 epidemiological studies of depression in people aged 55 years and older who were living in the community. The studies were mainly from OECD countries. Weighting findings by sample size, average prevalence rates were 1.8% for major depression and 10.2% for minor depression (clinically significant depressive symptoms). There is, however, great variation between studies, including variation within the UK (Copeland et al., 1999; Simon et al., 2002). Copeland et al. (1999) found that the prevalence of depressive illness among people in the community aged 65 years or over ranged from 8.8% to 23.6% between the European cities studied. Depression is relatively frequent among older people with conditions that affect mobility, such as PD or arthritis, and has an especially high prevalence among those living in institutional settings (Colenda et al., 2000). At all ages, women and socio-economically disadvantaged groups have higher prevalence rates (Beekman et al., 1999).

Depression in all age groups is associated with symptoms such as slowed responsivity, inattention, poor judgement, confusion, pessimistic thoughts, reduced energy, and sleep disturbance, especially early-morning waking. Psychomotor activity can be affected, resulting for instance in slower walking (Gelder et al., 1996). However, research is needed to provide direct evidence of any increase in pedestrian accident risk. Although a prospective study with the Jefferson sample of older drivers found increased accident risk for people with high scores on the Geriatric Depression Scale (Sims et al., 2000), a larger study of older women drivers found that depression was not significantly associated with accident risk, and so the possibility of a link between depression and driving risk remains an open question (Margolis et al., 2002).

Margolis et al. (2002) did find an association between depression and fall risk, and this had been reported in earlier studies. For example, Whooley et al. (1999) carried out a prospective study of several thousand older women in four areas of the USA. Controlling statistically for a number of associated variables, including age, bone mineral density at the start of the study, use of medication, arthritis, diabetes, history of falling, and a measure of cognitive function, they found that older women with depression had a higher risk of falling (40% increased odds).

There have been suggestions that occasionally older people use traffic in deliberate suicide attempts, or are at best indifferent to the possibility of being killed (Lawton and Azar, 1964). Lawton and Azar said that "many elderly persons have passed their anticipated life span and have run out of life programmes and, essentially, of any will to live. . .. If they were not killed, the change of life pattern and the welcome attention produced by the mishap would at least bring some meaning to their otherwise valueless lives" (p. 72), a statement that seems astonishing now. Yaksich (1965) indicated that there was no evidence of suicidal behaviour by older pedestrians, but Sjögren et al. (1993, 1977–86 data) found that two (about 2%) of the older pedestrians (over 60 years) in their study of traffic fatalities in northern Sweden had committed suicide.

3.11 Vulnerability to the consequences of an accident

Older people are more likely to suffer serious injury or die as a result of an accident as a pedestrian, probably because of their increased frailty (see section 1.3.4 above). Older people are also likely to require longer hospital treatment (OECD, 1985, based on 1979 data from the Netherlands). A number of age-related changes contribute to this. For example, lower bone density (osteoporosis), particularly common in older women, increases the likelihood of fractures.

A number of studies have examined the patterns of injury sustained by pedestrians of different ages, and the consequences of physical injury for older people (e.g. Hardy, 2000; Harruff et al., 1998; Kong et al., 1996). We have not reviewed this work systematically, but it has implications for the design of interventions to moderate injury, such as aspects of vehicle design.

Victims of traffic accidents quite often go on to experience psychological disturbance. Mayou (1997) reviewed the most common consequences of traffic accidents. Some victims experience anxiety about travelling, particularly in the same way as at the time of the accident, which can have negative effects on mobility. Mayou and Bryant (2002) reported an incidence of travel anxiety of 16% (after one year) and 13% (after three years) for adults (17−69 years) whose physical injuries had been no greater than bruises and lacerations or minor fractures. These levels were not significantly different to those found among adults with more severe injuries. Mayou and Bryant did find that long-term depression was more prevalent for people with more severe injuries.

Post-traumatic stress disorder (PTSD) is also common, and can have severe effects. PTSD is a collection of psychological and somatic symptoms that can develop following situations in which someone's own life is threatened or they witness trauma to another person. Symptoms include unwanted re-experiencing of the event (flashbacks), avoidance, emotional numbing, and insomnia. Hickling et al. (1997) reviewed studies of the prevalence of PTSD among road accident victims (about 10% for young adults) but did not report data for older people, and there does not appear to have been research on pedestrians specifically. Averill and Beck (2000) recently reviewed issues specifically relevant to older people. Reviewing studies of survivors of events including the Lockerbie disaster and a dam collapse in the USA, they concluded that older people who experience trauma have about the same likelihood as younger adults of developing PTSD.

3.12 Summary

In summary, the key points of this section are:

- Chronic illness is more common in older people, who often have more than one condition as well as age-related functional impairment.
- Older people's reactions to some medications are different to younger people's, and these can sometimes combine with pre-existing age-related deficits (e.g. in cognition) in a way that could increase risk for pedestrians.
- Conditions such as stroke and diabetes, as well as physical problems affecting movement, are linked to self-reported difficulties crossing the street.
- Objective evidence relating specific illnesses or functional measures to pedestrian skill or risk is rare in the literature, but we expect that conditions affecting spatial judgement, level of consciousness, cognitive resources, and balance and speed of movement would increase accident risk. Such conditions include certain prevalent psychopathologies.

- Older accident victims are more likely to be seriously injured or die as a result of an accident, and tend to spend longer in hospital. The psychological consequences are largely unexplored.

3.13 Research implications

Little research appears to have been done on the psychological consequences of pedestrian injury, but studies with road accident victims suggest that these will be significant. A better understanding is important for the development of proper care, and estimation of the true cost of accidents.

There has been little research on the antecedent mental health of pedestrian accident victims. Various conditions have been found to increase risk among drivers, but these studies either excluded pedestrians or did not report separate data for them. Such investigations should include consideration of the effects of age, sex, and medication in their analysis.

Little research has been done to evaluate direct links between pedestrian behaviour or accidents and specific conditions or levels of impairment. In contrast, some research of this kind has been carried out with older drivers. Such studies will need to differentiate sub-populations where relevant.

Longitudinal research to examine the contribution made by relative physical mobility and fitness, and by compensatory mechanisms (section 6) in the context of different conditions would be likely to have important implications for advice given to patients.

Research to identify links with other illnesses that may be related to pedestrian safety would be useful. Illnesses that affect balance, proprioception and risk of falls would be likely to be significant.

4 RISK FACTORS FOR OLDER PEDESTRIAN CASUALTIES

In this section, we identify some features that are associated with accident risk other than the effects of particular illnesses or medication, dealt with in the preceding section. There is no one causal process underlying all accidents, but a plurality of mechanisms and influences that combine in different ways on different occasions. In particular, the causally relevant factors may vary substantially with age. The pedestrian task is complex, especially high-risk aspects such as crossing a road (e.g. Firth, 1982; Fontaine and Gourlet, 1997; Thomson et al., 1996). It demands a variety of cognitive skills, such as visual search, gap judgement, and understanding the behaviour of other road users. In addition, it requires the adoption of responsible attitudes. At different ages, or in different situations, variance in different capacities may be key to explaining accident risk. For example, among teenagers and young adults motivational differences may be important, whereas among older adults these may play little role in accident causation. Similarly, functions such as visual acuity may be comfortably within the limits required by the task for the great majority of young adults, so that individual differences are irrelevant to the chance of successful performance. However, as acuity declines towards the threshold of task requirements with age, equivalent individual differences could come to differentiate successful and unsuccessful performance. In addition, functional differences that were not significant could become so if compensating mechanisms decline. As a simple example, a pedestrian who might have been able to compensate for attentional errors by reacting quickly would become compromised if the ability to react also declined.

For some factors, existing accident data can be used to demonstrate increased risk. For others, we have inferred risk on assumptions about things such as the role of a particular ability in the pedestrian task. In most cases, however, there is no experimental evidence demonstrating a cause and effect connection. Furthermore, we have focused primarily on aspects of the pedestrian, such as their behaviour or their capabilities, when of course in many accidents the pedestrian only contributes to the event, or is entirely faultless. We discuss the contribution of other participants in the section on intervention. The identification of groups at high risk of falling is discussed in section 2.3.3 above.

4.1 High-risk situations

The characteristic features of pedestrian accidents involving older people were summarised in section 1.3.5 above. A number of studies based on accident records have examined where and when older people are most likely to experience accidents.

4.1.1 Crossing the road

Crossing roads is dangerous, and a number of studies have reported higher accident or casualty rates for older people (Fildes et al., 1994; Fontaine and Gourlet, 1997; Todd and Walker, 1980). For example, Todd and Walker reported casualty rates of 15 and 41 per hundred million roads crossed for younger adults and adults 60 years and older, respectively. In this subsection, we review reports on the risk to older adults crossing roads.

Fontaine and Gourlet (1997) analysed pedestrian fatalities in France over a one-year period (1990–91). Using data from police accident reports, they classified 1,289 fatalities by the age of the victim, the time of the accident, and other relevant variables. One of the four high-risk groups identified was the older pedestrian crossing an urban road. Among the over 65s, 73% of pedestrian fatalities were killed crossing the road. Older pedestrians were more likely to be hit in the middle or latter part of the crossing, with 56% hit by a car in the far lane, in contrast to children who were most likely to be struck at the beginning or in the middle of the crossing. Fontaine and Gourlet attributed this to the slower speed of the older pedestrian. However, the difference between older and middle-aged pedestrians was greater in the middle of the crossing, 47% and 35% of fatal accidents, respectively, than at the end, 27% and 26% (Fontaine and Gourlet, 1997, Table 1, p. 306). In characterising this type of accident, Fontaine and Gourlet noted that it typically occurred during the day, apart from lunchtime, and that more fatalities were women than would be expected on a per capita basis. The victim had often gone out alone to do some shopping. They emphasised that conclusions about causal relationships among these variables cannot be drawn, given the correlational method of their project.

Several investigators have considered whether older people are more likely to be involved in accidents in the far lane during a road crossing (e.g. Grime, 1987; Carthy et al., 1995). There are three relevant studies based on UK data. The first was a joint project between the Transport Research Laboratory and Hampshire Constabulary (TRRL, 1972), and was based on pedestrian accidents in Hampshire in the first half of 1970. This study reported that the ratio of nearside to farside accidents was 3.6 (i.e. 3.6 nearside: one farside) for 15–60 year olds, 2.1 for 60–70 year olds, and 1.5 for those over 70. Nearside accidents were more common for all ages, but the proportion of farside accidents increased with age. Grayson (1980) supplemented these data with additional cases from the same study, giving nearside to farside ratios of 2.0 for people under 60, and 1.7 for older casualties. Considering these and other differences in accident circumstances, Grayson concluded that "in general the accidents to the elderly and to other adults were very similar" (p. 408).

The second study covered pedestrian casualties in Great Britain, excluding London, in 1980. This reported ratios of 1.57 for 16–69 year olds, and 1.51 for over 70 year olds. The over 70s had more of their accidents overall while crossing the road. The main differences between older and younger casualties were higher proportions of accidents walking along the carriageway or standing stationary on the highway among younger adults. These types of accident are sometimes associated with alcohol intoxication.

The third considered accidents in Newcastle for the years 1991–93 (Carthy et al., 1995). Among other aspects of road location, they considered the relative proportions of collisions occurring in which the pedestrian came from the driver's nearside (i.e. typically in lane 1) or offside (lane 2). The frequencies they reported are shown in Table 12. No comparative figures for younger pedestrians were given. We have calculated population rates based on the population data given by Carthy et al. Overall, there were 85 nearside and 67 offside incidents. For nearside accidents, there was a similar rise in rate per population with age for men and women. For women, but not men, there was a large increase in offside accident rates. We note that the mean age in the 75+ groups was probably greater for women than men, which makes it difficult to be certain that any difference is a function of sex rather than age. Ratios for nearside to farside accidents varied between men and women. For men, the 65–74 year olds had a ratio of 1.17, whereas the over 74 year olds had a higher ratio of 1.5. That is, the men over 74 years had a higher proportion of nearside accidents. Women showed the opposite pattern. For 65–74 year olds the ratio was 1.81 (almost twice as many nearside as offside accidents), but for women over 74 the rate for nearside and farside accidents was almost the same.

Table 12: Frequency and rate (per population) of nearside and offside pedestrian accidents in Newcastle 1991–93 by age and sex. Based on data from Carthy et al. (1995)

	Frequency		Rate per 1000	
	65–74 years	75+ years	65–74 years	75+ years
Nearside				
Men	20	15	0.89	1.20
Women	20	30	0.71	1.15
Offside				
Men	17	10	0.76	0.80
Women	11	29	0.39	1.12

Other data on the relationship between nearside and farside accident rates for older people have been reported from Australia. Oxley et al. (1997a) reported data from a study of pedestrian accident blackspots in Melbourne. They broke the casualty data down according to where in the road the accident happened. For both younger and older (over 65) pedestrians, almost half the accidents happened as they stepped off the kerb. The proportion of accidents in the far lane was similar for older and younger pedestrians, but older pedestrians tended to have a smaller proportion of accidents in the nearside lane. However, no tests of significance were reported, and the sample size for older pedestrians was small (n = 19). It is unlikely the difference was statistically significant. The Pedestrian Council of Australia (1999) reported that for pedestrians aged 60 or over in Victoria, 41% of accidents were on the nearside and 35% on the farside, a ratio of 1.17, but no comparative figures for younger adults were given.

Overall, it is clear that accidents are more common in the first half of road crossing, rather than the second. Some studies suggest that the difference is lower for older people, but some other data suggest no difference or the opposite pattern. However, two studies have suggested that there is a relative increase in farside accidents for older women only.

4.1.2 Road location

Older pedestrian accidents are more common in densely populated urban areas (e.g. TRRL, 1972). Ward et al. (1994) in a study of accidents in Northampton found that people who lived in pre-1914 terraced housing and local authority housing were at greater risk per capita of pedestrian accidents. Ward et al. suggested that the road layout of these areas was the relevant factor. Transport Canada (2001) reported that 85% of pedestrian fatalities aged over 64 were in urban areas.

Ossenbrugen et al. (2001) compared different kinds of location in New Hampshire. Out-of-town shopping sites were high-risk locations for pedestrians because of high traffic volumes and the lack of footpaths. Ossenbrugen et al. found that more built-up village centre locations could be safer, despite high traffic exposure, where there were pedestrian-friendly features such as high pedestrian numbers and pavements.

A study of police data for fatal pedestrian accidents on a particularly wide arterial road in New York (12 lanes, 175−225 feet wide) that was notorious for pedestrian accidents, found that all fatalities whose age was known (n = 20) were aged 60 or over (Retting et al., 1989). Zegeer et al. (1993a,b; 1994) examined several thousand pedestrian accidents in the USA, and found that older people were particularly at risk crossing wide roads, with four lanes or more. Others have observed that older people have difficulty crossing such roads in the time allowed by light controls (e.g. Hoxie and Rubenstein, 1994; see sections 2.3.1 above and 5.1 below).

Crossing roads at junctions is hazardous for older people. TRRL (1972, p. 2) mentioned that “most accidents occurred near junctions. . . particularly so for the elderly”. Händel (1981) gave crossing near major junctions as a significant source of fatalities among older pedestrians in Germany. In the USA, 38% of older pedestrian fatalities were at intersections (IIHS, 2000), and Yaksich (1965) observed that 70% of “older adult pedestrian accidents occurred at intersections while the pedestrian was crossing in a crosswalk” (p. 24), with half of those occurring with the signal on green. Fildes et al. (1994) reported a small excess in intersection accidents for older pedestrians in Victoria, confined mainly to ’cross’ intersections. Hauer (1988) found that 31% of older pedestrian fatalities, and 51% of injuries in the USA were at junctions. For adults aged 26−64, rates were roughly halved. Council and Zegeer (1992) reported that the young old were more likely to be struck by left-turning vehicles, the older old by right-turning vehicles. However, this was in the USA, and that particular detail may not generalise to all countries. Sjögren et al. (1993) found 32% of older pedestrian fatalities in a Swedish sample were killed at intersections, compared to 28% on a straight road and 26% on a crossing.

Zegeer et al. (1994) analysed fatal pedestrian accidents in the USA from 1980 to 1989, and all injury accidents to pedestrians in North Carolina from 1980 to 1990 (see Table 13). Zegeer et al. considered whether over-representation in intersection accidents could arise from an increased numbers of intersection crossings by older people, or from increased difficulty coping with the complex environment of an intersection. A third contributory factor could be the increased frailty of older people. The rate of increase is greater in the national fatality data than in the North Carolina data, which includes injury accidents as well as fatalities. Intersection accidents tend to be at relatively low speeds compared to mid-block collisions, particularly turning vehicle accidents. They would therefore be proportionately more likely to lead to fatality in older people. Stutts et al. (1999), analysing a stratified sample of 5,000 pedestrian accidents from six states in the USA, reported that pedestrians over 65 years old were disproportionately likely to be involved in intersection-related accidents, apart from those involving a running pedestrian.

Table 13: Percentage of pedestrian accidents that were at intersections in the USA (1980–89) and North Carolina (1980–90) by age. Source: Zegeer et al. (1994, Figure 3).

	15–24 years	25–44 years	45–64 years	65–74 years	75+ years
USA fatal accidents	10.8	13.3	21.7	32.2	35.3

Increased risk at intersections has been noted for older drivers as well as older pedestrians. In section 2.4.2 above we considered the possibility of a link with cognitive changes.

Damage is caused by the force at impact, which is increased by the speed or mass of the objects colliding. Vehicles are overwhelmingly responsible for the force of collisions with pedestrians. Accidents that occur when vehicles are likely to be travelling faster, such as mid-block versus vehicle turning at an intersection or reversing accidents, cause more severe injuries (Stutts et al., 1999). However, it has often been reported that older people are over-represented in accidents with reversing vehicles (e.g. Stutts et al., 1999; Zegeer et al., 1994). Zegeer et al. found 9.5% of injury accidents to older pedestrians involved reversing vehicles, compared to 3.9% for those under 45 years. Fildes et al. (1994) reported that older pedestrians were more at risk of accidents in driveways (5.4% of their accidents, compared to 2.4% for all ages). This could reflect poor anticipation of unexpected vehicle movement by older people. Alternatively, it could reflect a reporting bias. Older people are quite likely to be injured by even a small impact at low speed, whereas a younger adult might simply walk away.

An Australian report examined the location of older pedestrian accidents in urban areas (where most accidents occurred), and found differences between cities in the proportions of accidents on main roads and local roads (Federal Office of Road Safety, 1987). For example, in major urban areas in Victoria, about 8% of fatalities among over 60s were on local roads, but 38% in New South Wales (Sydney, Newcastle, and Wollongong) were on local roads. Comparative figures for younger people were, however, not reported.

Ward et al. (1994) reported data on the types of road where accidents occurred over a five-year period in Northampton. Some caution should be applied in interpreting these results, because the overall sample size was relatively small (108 accidents involving older people). Casualties on "primary distributors" – dual carriageways with speed limits of 50mph or greater – were most likely to be fatal or serious (80% across all ages) but were also rare. During the five-year period there were no fatal or serious accidents involving people aged over 60 years on these roads. People aged over 65 most frequently suffered a pedestrian accident on "district distributors" – other main A or B roads. About 65% of all their accidents, and the same proportion of those involving death or serious injury, were on these roads. These percentages were similar to those for 35–49 year olds (58% and 64%, for accidents and fatalities, respectively). "Local distributors" – other principal through roads within local areas that typically had bus routes along them – accounted for 19% of over 65 year olds' accidents, but 24% of their fatal or serious pedestrian injuries (compared to about 20% for 25–49 year olds). A higher proportion of middle-aged and older people's accidents on local distributors resulted in serious injury or fatality. For pedestrians aged 50 and over, 58% of accidents on local distributors had these more serious outcomes, compared to 30% for those aged 20–49 years.

Is there still a difference between type of road after controlling for reported frequency of crossing each type of road? In general, despite the fact that only 34% of roads crossed by the over 65s (on a selected day during the survey) were busy roads (primary, district and local distributor roads, as compared to residential roads), 89% of this age group's injury accidents over the preceding five years were on district and local distributor road classifications. The casualty rates per 100 million roads crossed reported by Ward et al. (1994) are shown in Table 14. The risk rises substantially for the over 65s on all types of road, more than doubling compared to adults aged 35–49 years, but showing the smallest rise on residential roads.

Table 14: Casualty rates per 100 million roads crossed for different types of road by age. Source: Ward et al. (1994).

Type of road	35–49 years	50–59 years	60–64 years	65 years and over
Primary and district distributors	115	259	117	318
Local distributors	48	43	59	124
Residential roads	10	15	10	21

It is possible, then, that older people have more accidents on main roads in particular, compared to younger people. For example, the older group had 92 accidents over five years on main roads, but this age group in the survey only crossed them an average of 0.88 times per average day. The group who crossed these roads the most was the 16–19 year olds (average 3.35 times per day) and they had only 61 accidents on them in the same five-year period. The casualty rate per population was, however, greater on main roads, three times greater than on local distributors, for the 16–19 year olds than older people. Furthermore, from Table 14 we can calculate that the rate of accidents on primary and district distributors as a proportion of the rate of accidents on all roads was approximately equal across the four age groups from middle-aged (over 35) to older (over 65) adults at about 0.65 (0.82 for 50–59 year olds). Given the small sample size, it would not be justified to draw a strong conclusion that older people face a higher risk on main roads than middle-aged adults from this study. New research addressing this question based on a larger sample of accidents would be valuable.

Ward et al. (1994) also found that older pedestrians, like children, tend to be injured on roads close to home – 73% of the older pedestrians were injured less than 1km from their home and 42% within 400 metres of their home. In comparison, only 40% of 16–19 year olds were killed within a kilometre of home.

Thus, older people who live in urban areas, who cross at junctions, and whose everyday pedestrian activity involves crossing main roads locally, will be at higher risk of accident and fatality in the road environment. However, in several respects the pattern of accident location is similar to the pattern for younger people, and it may be that differences can be partly explained by the greater frailty of older people.

4.1.3 Time of accident

Older pedestrian fatalities are more common in daylight hours (e.g. Fildes et al., 1994; Fontaine and Gourlet, 1997; OECD, 1970; TRRL, 1972; Zegeer et al., 1994). For example, Fildes et al. reported that 84% of older pedestrian accidents were in daylight (67% in the period 9am–3pm), compared to 70% (48% 9am–3pm) of all pedestrian accidents. This is largely a reflection of the times when older people go out walking. Jonah and Engel, in Canada, found 88.4% of older people's pedestrian activity was between 9am and 6pm, 84.4% while it was light.

Ward et al. (1994) estimated that about one third of all pedestrian casualties occur in darkness. Todd and Walker (1982) found that, by number of roads crossed, the risk when walking in darkness was three times greater for pedestrians of all ages. Interestingly, the multiple was lower for older than younger (18–59) adults at 2.6 and 3.3, respectively. Counter-intuitively, given the problems of vision and visibility discussed in section 2, the relative risk for older versus younger pedestrians decreased in darkness. The casualty rate per roads crossed for older pedestrians in darkness was 2.1 times larger than that for younger pedestrians, but 2.7 times larger in daylight. A possible explanation is that for younger adults risk is increased more by alcohol in the hours of darkness. In places where there are fewer hours of daylight, accidents in darkness are more common. Sjögren et al. (1993) reported that in northern Sweden about half of the fatal pedestrian accidents involving people over 60 occurred in darkness, with the percentage rising to 63% in November. An Australian report found an increase in older pedestrian accidents between 4pm and 8pm in the winter (Federal Office of Road Safety, 1987).

Accidents to older pedestrians generally are more common in winter and on weekdays (OECD, 1970), although, overall, accidents and pedestrian activity are more common in good weather. Ward et al. (1994) reported that 81% of pedestrian casualties, among pedestrians of all ages, occurred in fine weather, and Jonah and Engel (1983) reported that 73.8% of older pedestrian activity took place in clear weather. Sjögren et al. (1993) found that 65% of older fatalities were killed in the period from October to March. Sjögren et al. estimated that ice or snow was a contributory factor in 13% of all older pedestrian fatalities in their sample, with visibility problems caused by snowfall or fog another important factor. Zegeer et al. (1993a,b) found that, in the USA, pedestrians aged 65 or over were over-represented in crashes on weekdays and in winter (see also Zegeer et al., 1994). Ward et al. (1994) found most older pedestrian accidents were on weekdays (75%), whereas in contrast 20–34 year olds had more accidents on Saturday than any other day. Fildes et al. (1994) reported a slight excess of accidents to older pedestrians on weekdays in Victoria (83%, versus 78% for all ages). Sjögren et al. (1993) found that in northern Sweden more older pedestrians were killed on weekdays, and Björnstig et al. (1997) reported that women slipped on weekdays more often than men.

Older pedestrians are more likely to be injured in accidents in good weather, in daylight, on a weekday, and in winter. These accidents tend to happen in urban areas, close to home, when they are crossing the road, particularly at junctions or crossing wide streets, and there may be a tendency for an age-related increase in the proportion of accidents in the second half of the road for older women. Older pedestrians are usually familiar with the location of any accident. Older people are also more likely to be involved in accidents with reversing vehicles, which are common in car parks or on driveways.

4.2 Older old pedestrians

Statistics indicate that the oldest pedestrians are most at risk. Mitchell (2000) concluded that most of the over-representation of older people in UK accident statistics was due to the older old. Although both the over 60s and over 80s were over-represented among pedestrian fatalities, the percentage of injuries that are fatal increases steeply with increasing age, more than doubling between 70–79 and 80+. Per capita, 80 year olds were more than 10 times as likely to be killed as 40-year-old pedestrians. Table 15 shows the percentage of fatal casualties in each age group. Figures adjusted for exposure rates showed similar patterns. Casualty rates per distance travelled, for all severities of injury, indicate a large increase for older old pedestrians, with those over 80 having more than double the risk of those in their 70s. Goodwin and Hutchinson (1977) found that the casualty rate for older pedestrians sharply increased among those over 70 years. This difference may reflect a cohort effect.

Table 15: Percentage of all pedestrian casualties dying as a result of their injuries (adapted from Road Accidents Great Britain, 1999).

Age	0–29	30–49	50–59	60–69	70–79	80+
% killed	<2.0	<3.0	3.3	3.8	6.0	9.4

Keall (1995, Fig. 6) found that, in New Zealand, the over 69s had a higher risk of injury, with risk (per population, per hours walked, or per roads crossed) rising steadily from the age of 65. Using the formula given by Evans (1991), which describes the relationship between frailty and age, Keall extrapolated the number of severe impacts occurring from fatality rates. Controlling for frailty in this way, Keall argued that a marked increase in severe impacts, as opposed to fatalities, is only seen for those over 80. In his study, the over 80s had a five times higher risk of experiencing a collision of a given severity than 25–69 year olds.

Although currently less than 5%, the proportion of people aged over 80 in the UK is expected to increase in the next 20 years. Accident statistics indicate that although pedestrian accident rates are reducing, this decline in accident rates is lowest for those over the age of 80. This age group currently travels the least by car of all age groups, and has the lowest rate of living in households with a car (Noble, 2000). The household survey reported by Atkins (2001) found that people over 80 were more likely than others to attribute reduced mobility to their own problems with physical movement and sensory decline. The older old are more likely to depend on walking for transport.

More of the older old are likely to be experiencing age-related declines in vision, hearing, cognition and physical mobility, and the extent of decline is more often severe. Such declines would affect the ability to perform the pedestrian task safely, although little is known specifically about the nature of the effects. Functional decline also means that they have to devote more attentional resources to maintaining performance levels on basic tasks like walking (e.g. Lindenberger et al., 2001). A mild loss of visual acuity might cause little difficulty for a younger old person, but because of reduced central attentional resources, the same acuity loss could cause greater problems for the older old person. The older old will therefore experience more difficulty with everyday tasks, and have less spare capacity to adjust to unexpected events. Failure to compensate is not well understood, but appears in part to result from a reduction in awareness that errors are being made or that function has deteriorated. A further component may be a decline in strategy formation or planning. These issues are discussed in section 6.

The older old are also more likely to be affected by age-related pathologies such as dementia, and to be taking medication that could affect performance. The prevalence of dementia, for example, doubles every five years over 65 (see section 3.9 above). Links between various medical conditions and pedestrian accident risk were discussed in section 3.

To summarise, older old pedestrians may be at high risk because functional decline is more common and more severe, and because the capacity to compensate for specific changes is reduced as limited attentional resources are absorbed running peripheral perceptual and motor functions. In this context, it is interesting to note that later cohorts may become functionally "old" at later ages (Hakamies-Blomqvist and Henriksson, 1999).

4.3 Older men and women

Younger men are involved in more pedestrian accidents than women but, in the UK, by their 60s as many women are killed or seriously injured as men, and at older ages more women are casualties (Road Accidents Great Britain, 2000, Tables 6a and 6b). To explain the higher risk among younger men, factors like impulsive behaviour and exposure differences have been considered, but research is inconclusive. In this subsection, we explore the evidence for sex differences in accident risk and road behaviour among older pedestrians, the greater risk of falling among older women, and briefly review specific relevant differences in patterns of functional impairment.

4.3.1 Sex differences in pedestrian accident rates and road behaviour

The different numbers of men and women killed or seriously injured are shown in Table 16, based on the 1999 statistics from Road Accidents Great Britain (2000). A survey of blunt trauma injuries in pedestrian versus motor vehicle collisions in a Californian hospital found that males outnumbered females in all age groups except the over 59s, in whom the pattern was reversed (Kong et al., 1996). However, Australian data show more male than female pedestrian casualties in all age groups (ATSB, 2000).

Whereas these statistics illustrate that, in some countries, more older women have serious accidents than older men, they do not allow for the greater number of older women than men in the population. Foot et al. (1982) looked at UK data from 1975 to 1978. In each year, the absolute number of injuries or fatalities was as great or greater for women over 60 than for men. However, when figures were standardised per population, the risk for males was actually greater. This was true for all severities, serious injuries, and fatalities. For fatalities the ratio of male to female risk was roughly 1.4. Foot et al. concluded that the larger number of female casualties was a function of the greater number of older women in the population. Broughton (1997, p. 25) also reported higher per population fatality and injury rates for older male pedestrians in the UK in 1993, with an apparent narrowing of the difference in casualty rates between younger old men and women.

Table 16: UK pedestrian casualties killed or seriously injured, by age and sex. Source: Road Accidents Great Britain (2000).

	Men		Women	
Age group	1981–1985	1999	1981–1985	1999
60–64	409	166	390	122
65–69	371	143	450	142
70–74	447	151	667	216
75–79	394	194	611	258
80+	396	266	669	421
Older casualties as a % of total for all ages	18.1%	15.4%	35.2%	30.1%

Carthy et al. (1995) analysed older pedestrian casualty data from Newcastle, England, for the three calendar years 1991–93, and indicated that, compared to men, there was a doubled risk per population for women over 75 years, particularly for serious accidents. However, their data do not support this conclusion. Estimating population data from their Figure 1.1, p.2, and calculating per population accident rates from the absolute numbers of casualties given in Table 1.3, p. 6, gives the per population (roughly per 1,000) accident rates shown here in Table 17. Men had a higher risk of any kind of injury accident between 65 and 74 years. Over 75, men and women had similar risks of more serious accidents. Indeed, there were in absolute terms almost twice as many male fatalities (nine men, five women) for all over 65s, whereas the population of older women was, of course, rather larger. Women over 75 had a higher rate of recorded slight injuries (1.19 versus 1.04). Wouters (1991) calculated a frailty index for male and female pedestrians (fatalities per injury accident) and found that, although it rose with age from young adulthood for both men and women, men's frailty was greater at all ages. Women's frailty as pedestrians was lower than their frailty as car drivers up to 65 years. A possible explanation would be that more slight injuries were recorded for women. Carthy et al. interviewed a sample of 215 older pedestrians in Newcastle in their homes. The sample was roughly weighted to reflect population sex differences. One of the questions concerned accidents in the previous three years. For those aged 65–74, 2.3% of men and no women reported being hit by a vehicle. For those aged 75–84, 3.5% of men and 1.7% of women reported such an accident. Both data sets consistently indicate a higher prevalence of accidents for men.

Data from other countries tend to give a similar picture. Typically, the per-population accident rate is higher for men than women, although the rate for women sometimes increases more rapidly with age. Fontaine and Gourlet (1997) presented data showing that the pedestrian fatality rate was higher for men than women of all ages in France in 1991. Between 60 and 80, the difference in rate appeared to narrow a little (the male–female ratio estimated from Figure 2, p.305, is 1.8 for 60–69, and 1.4 for 70–80 year olds), but widened again for those over 80. For casualties, women and men had approximately the same risk per capita between 60 and 80, but the rate for men was again higher among those aged over 80.

Table 17: Older pedestrian casualty rates (approximately per 1,000 population) for Newcastle 1991–93 by sex and severity, estimated from data in Carthy et al. (1995).

	Men	Women
Injury accidents of all severities		
65–74 years	1.78	1.29
Over 75 years	2.24	2.42
Killed or seriously injured		
65–74 years	0.71	0.46
Over 75 years	1.20	1.23

Holubowycz (1995) gave fatality ratios (per population) for older male and female pedestrians in South Australia between 1981 and 1992. For the three age groups from 56–65, 66–75, and 76–84, the ratios were 4.1, 0.9, and 1.5, respectively. That is, men had higher fatality rates than women except for 66–75 year olds, although for those over 75-year-old women more nearly had as many fatalities as men than women did at younger ages. For all over 80s, the male: female ratio was 1.9. USA data also show male fatality rates higher than female rates (NHTSA, 1998, 2000, 2001b). For all age groups older than 65, more than twice as many men per population were killed as pedestrians, except that in 2000 the ratio was only 1.7. The pattern of higher risk for males also holds if injury rates are considered, except in the age band 70–79 in 1997 and 2000, and 80+ in 1999.

Transport Canada (2001) reported a higher fatality rate per population for older men than women between 1988 and 1997. As the fatality rates for both groups fell, by almost 50%, the male: female ratio rose slightly from 1.6 to 1.8. These international studies show a remarkably consistent relationship between older male and female fatality rates. Although the gap is smaller than in younger populations, women still experience a lower risk per capita. OECD (1970) reached a similar conclusion based on a review of earlier data. However, and this is important, these data do not take into account possible differences in exposure (cf. section 1.3.4 above).

Noble (2000) reported the average distance walked and the number of trips on foot each year for people in the UK. For both figures, in all age groups from 60 onwards, men walk more than women. For men but not women, there was an increase in distance walked between 60–64 and 65–69, but in later years the amount of pedestrian activity reduced for both. Ward et al. (1994) also found that women over 65 walked less than half the distance men do, and Carp (1971) found that one third of retired men but only 13% of retired women made daily trips on foot. Ward et al. projected risk for older people using casualty rates over five years in Northampton and their survey data on walking patterns. They estimated that female pedestrians over 65 were about four times more at risk of injury, including all severities of injury and fatalities, than males of the same age for the same distance walked or the number of roads crossed (Ward et al., 1994, Table 2, p 83). However, as noted in section 1, the survey by Ward et al. may have underestimated the distance walked by women over 65 quite substantially. Their particular sample also shows a higher risk per population for women over 65, which conflicts with national statistics. Given the relatively small size of both their travel survey and casualty samples, it would be unwise to regard their estimates of risk per distance travelled as definitive.

Goodwin and Hutchinson (1977) related 1972–73 UK National Travel Survey data on time spent walking to national police-reported accident data for the same 12-month period. They calculated accident rate as the percentage of accidents (of any severity) involving a given age group to the percentage of all walking done by that age group. For example, women over 70 accounted for 3.1% of all walking time recorded nationally, but were involved in 6.1% of all reported pedestrian accidents. Goodwin and Hutchinson found that the ratio of male to female accident rates fell smoothly from 2.5 at 20–29 years (men having more than twice as many reported accidents per self-reported unit of time walking) to 1.16 at 60–64, 0.93 at 65–69, and 0.66 for those aged 70 years or over. Between the age groups 60–64 and 65–69, a small fall in the percentage of walking by men was tracked by a similar fall in the percentage of accidents. However, a larger fall in the amount of walking by women across the corresponding ages did not see a change in their percentage of accidents, which was slightly higher than the percentage involving men (2.2% versus 2.0% for 60–69 years). For both men and women, there was a sharp increase in the accident rate over 70, but the increase was greater for women. Relative to men of the same age, these older women showed a greater increase in accident involvement and a greater decrease in mean time spent walking (Goodwin and Hutchinson, 1977, Table 1).

Using UK national statistics on casualty rates per population for calendar year 1972 (Road Accidents Great Britain, 1973), which overlaps with the first nine months of the period examined by Goodwin and Hutchinson (1977), gives some context to their findings. For adults 50 years or over, men had higher rates of pedestrian fatality and serious injury than women. This was true for all age groups, with the exception of the rate of serious injury between 70 and 79 years, which was 63 and 64 per 100,000 for men and women, respectively. The proportional increase between 50–59 and 60–69 years was larger for women for both fatalities and serious injuries, but the rates of fatality and serious injury were still lower than for men. For those aged 80 and over, the fatality rates were 52 and 24.2 for men and women, respectively. It appears likely that the increase in accident representation for women aged 70 and over found by Goodwin and Hutchinson must be largely attributable to differences in reported slight injuries.

Todd and Walker (1980) carried out a survey of walking activity with adults in the UK and looked at casualty rates (accidents involving personal injury) in relation to a variety of exposure measures, including distance walked, time spent walking, and number of roads crossed. Respondents estimated the time they had spent walking on the designated survey day (usually the previous day, but up to four days earlier than the interview) and described where they had walked. Jonah and Engel (1983) found that conducting interviews more than one day after the target day tended to produce lower estimates for the number of trips made, suggesting some forgetting. Todd and Walker's interviewers subsequently walked the route, counting the number of roads crossed and noting other features such as the class of road, whether crossings were made near junctions, and so on. Distance was estimated from the time the interviewer took to walk the route, with uniform allowance for interviewer walking speed and time to record information. Casualty rates were estimated from national figures for the two months during which the survey was conducted (September and October 1975) and risk was projected from these, although of course none of the respondents actually were casualties on the survey day. This survey provided some of the most detailed information we have on relative risk for older pedestrians in different situations.

Male and female accident risk varies with age, and slightly different patterns are found according to which measures of exposure are used (Table 18). In the study by Todd and Walker (1980), for older people (60 years and over), the absolute number of casualties, which we assume includes injuries of all severities, was greater for women than men, but per population the rates were the same between 60 and 79 years, with men having a higher risk over 80. If the population was defined to exclude those who could not go out on foot or those who did not actually walk on the survey day, the pattern was similar except that women aged 70–79 years had a slightly greater risk than men. By distance or time walking, older women (60 years and over) had a higher risk than men, except that men aged 60–69 had a slightly higher risk than women of the same age per hour walked. However, these measures of time and distance were based on self-report and a complex projection from the time the interviewer took to re-walk the route, and so may have limited validity. As noted in section 2.3.1, estimates of walking speed based on these data are broadly in line with expectation, but are anomalous in certain details. Perhaps more reliable, and more directly relevant (Fontaine and Gourlet, 1997), was the measure of casualties per road crossed. This showed equal risk at 60–69, greater risk for women at 70–79, and greater risk for men over 80.

At younger ages men had a higher risk than women on all measures, and Todd and Walker (1980) noted that this difference was most marked in darkness, especially between 10pm and midnight. At the time of the survey, these were the hours when pubs closed in the UK, and drinking in pubs was a predominantly male activity. It may be that the narrowing of the difference between male and female accident rates seen in the younger old reflected a reduction in walking after dark by men and a reduction in their exposure to alcohol.

Table 18: Number of pedestrian casualties for older men and women in 1975 by different measures of exposure, UK data. Source: Todd and Walker (1980).

Exposure	50–59 years	60–69 years	70–79 years	80+ years
Per 100 000 population in 1975				
Male	81	100	171	
Female	67	94	143	
Per 100 million hours walked				
Male	587	496	803	1,271
Female	253	380	991	1,665
Per 100 million roads crossed				
Male	36	32	56	167

Jacobs and Wilson (1967, see section 1.3.4 above) estimated pedestrian accident risk by comparing pedestrian flow at a number of different crossing sites of different types (e.g. zebra, signal-controlled, near junctions, far from junctions) with 30-month injury accident data. For those over 60 years, they found a non-significant trend for greater accident risk among men.

Wouters (1991) reported rates of death and injury per distance travelled for pedestrians, cyclists and car drivers in the Netherlands. Taking data for 1983 and 1984, he found a rise in risk beginning at about the same age for all modes, but the steep rise began earlier for women (about 60 years) than for men (about 70, ages estimated from Figure 3, p. 327). Up to 60 years, women's risk was lower than men's, but by 70 it was about double men's. Wouters noted a paradoxical relationship between distance travelled and casualty rates in the data. Taking adults as a whole, those who travelled further had fewer casualties per unit of distance travelled. As pedestrians, men's walking increased between 60 and 70 years, whereas women's decreased. Men's declined from 70, the age at which their casualty rate per distance increased. In other words, the patterns of increase in casualty rates could be accounted for by decreases in distance walked. We noted a similar pattern in data reported by Goodwin and Hutchinson (1977) earlier in this section. Wouters suggested that those who travelled further were able to maintain the relevant skills better, and advocated encouraging older people to keep up walking levels. However, we have to bear in mind that distance travelled is the denominator of this particular risk index. Hakamies-Blomqvist (1998) points to the difficulty this raises in regard to the interpretation of casualty rates per distance travelled for older drivers. Groups who reduce their exposure by travelling less will, if the accident rate per population remains the same, appear to have increased their risk per distance travelled.

Sjögren et al. (1993) reported higher pedestrian fatality rates per population for older men than women (a ratio of 1.75). Using data from a Swedish national travel survey, they calculated that the risk per million km walked was quite similar, at 1.4 for men and 1.5 for women. Keall (1995) studied pedestrian accidents for 1988–91 in New Zealand, and reported similar casualty rates per hour walked for male and female pedestrians between 70 and 74, and higher rates for women over 80. At all other ages, including 75–79, males had a higher accident risk. At all ages, men had a higher risk per population.

The role of reporting factors for pedestrian accidents must be considered. Most of the statistics suggesting that older women have more accidents than older men are based on injury accidents. Pedestrian accidents that cause only minor injury or no injury may be rarely reported (Keall, 1995; Mitchell, 2000; NCC, 1987). If older women's accidents are more likely to lead to fractures, due to lower bone density or pain thresholds, then they are more likely to be reported, and women's risk of accident involvement would be overstated in comparison to that of other groups.

Evidence on accident rates for older pedestrians fairly consistently indicates that the rates per population for men and women are closer than they are for younger people, but that men are at higher risk of serious injury. However, by some measures of exposure, such as distance travelled or number of roads crossed, in some countries for some age groups, women have more accidents than men, and the rate of increase in the accident rate is greater for women. Furthermore, the absolute number of pedestrian accidents involving older women is greater in the UK, although not in all countries. Some of the observed increases in risk by exposure measures other than population may be due to increased experience of slight injuries for older women, reporting bias, problems with the reliability of exposure measures, or problems with distance walked as a measure of exposure.

There is some evidence that older women's road-crossing behaviour differs slightly from men's, and may be more dangerous. Silcock et al. (1998) conducted an observational study of road-crossing behaviour at nine locations in the UK. Using automated recording, they recorded 32,000 crossings, which included about 1,700 encounters (where at least one traffic participant changed course or speed) and 100 conflicts (involving a sudden evasion). Older women were involved in more of these events than would be expected. Older pedestrians generally, but especially women, were more likely than others to experience an encounter at a signal-controlled crossing, having started to cross during the green signal. Away from crossings, women and men differed in their response to an encounter. Whereas men maintained or increased speed, women tended to slow down. Identifying older women as one of four high-risk groups, Silcock et al. described potentially hazardous characteristics of their crossing behaviour. Older women often followed other groups into the road, which is not safe if you cannot keep up (see also Mathey, 1983a,b). They commonly appeared to fail to monitor or understand the traffic flow, and appeared many times to cross at first considering the nearside only, attending to the farside only when they reached the middle of the road.

On the other hand, Job et al. (1998) observed people crossing at two busy signal-controlled intersections in Sydney, and found that older men took more risks. For older men (over 60 years), 22% began crossing during the "red" phase, compared to 10% of older women. For younger people, the percentages were 34% and 25% for men and women, respectively. Older people's road crossing is considered in more detail in section 5, and the use of signal-controlled crossings is discussed in section 7.3.1 below.

4.3.2 Falls

Falls are known to be common for older people, and women are more susceptible than men (see sections 2.3.2 and 2.3.3 above). Some studies have reported data on falls in the road environment. Eilert-Petersson and Schelp (1998) studied all non-fatal pedestrian accidents, as opposed to fatalities or serious injuries, in Vastmanland, an area of Sweden. They found that older women had more pedestrian injury accidents per population than older men. The highest pedestrian injury incidence was for older women, and the largest jump in incidence was between women in their 40s (3.8/1,000) and those in their 50s (7.2/1,000), rising to a peak for older women aged 60–69 (8.7/1,000). The age course of the increase parallels the age course of menopausal hormonal changes in women. The critical feature of this study is that it includes all pedestrian accidents, not just pedestrian versus vehicle conflict accidents. Falls accounted for 82% of non-fatal injuries in "the traffic area", mostly from slipping or stumbling, and that the greatest risk of sustaining such an injury was faced by females aged over 50. Fractures were common in the over 50s group and sprains predominated in younger groups. Slipping, usually in poor weather conditions, tended to result in more serious injuries than stumbling, and was more likely to lead to hospitalisation. Wintry conditions were clearly associated with an increase in accidents. Some of the slipping accidents were attributed to inappropriate footwear.

Björnstig et al. (1997), in a study of slipping accidents in the Umea area, identified older women as one of two high-risk groups, with two-thirds of injuries being fractures. A larger proportion of women's injuries were more severe. Again, risk per population rose from the age of 50, ranging from 8.2 to 9.7 per 1,000 between 50 and 79. However, over 80 the rate dropped to 3.3, presumably because of reduced exposure. Björnstig et al. discussed the issue of osteoporosis and the potential role of HRT. Sjögren and Björnstig (1991; cited in Björnstig et al., 1997) earlier studied a sample of 297 injured pedestrians aged over 60. Only 44% involved any vehicle; 52% were falls, and women were more likely to be involved in falls than men. The excess of falls was largely due to slips. Björnstig et al. cited Ralis et al. (1988), who reported higher accident rates for UK pedestrians during a couple of days of severe winter weather: nine to 16 injuries per 100,000 people per day. When the walking surface affords a poor grip, pedestrians are at heightened risk of falling. Older pedestrians, particularly women over 50, experience many injuries in such circumstances. Sjögren and Björnstig estimated that ice and snow accounted for 37% of the cost of all injuries to older people in the traffic environment in Sweden.

Stutts and Hunter (1999) investigated pedestrian accidents in three disparate American states, and found that 64% of pedestrian accidents did not involve a vehicle. For those over 65, even if slips were discounted, the proportion of non-road injury accidents was higher than would be expected on the basis of demographics. They also found that such accidents were more common for women. This study, although it takes population into account, like many others does not allow for possible exposure differences, and it is therefore difficult to reach definitive conclusions.

Falls are also a problem for older people on buses. Leyland Vehicles Ltd (1980) reported that in the UK in 1976, 88% of accidents to bus passengers over 60 did not involve a vehicle collision, and two thirds of those involved falls inside the bus. A recent report indicated a broadly similar picture (Kirk et al., 2001). Kirk at al. found that the average age for women experiencing such accidents was 15 years older than for men, and identified problems with the walking surface within the bus as the main problem, but concluded that the rate of change of direction or speed was also a factor. Plasència et al. (1995) also noted a high incidence of falls in public transport for the elderly.

Carthy et al. (1995) interviewed a sample of older pedestrians living in four areas of Newcastle, and asked about accidents in the previous three years. The most common accident mentioned was falling. Falls in the street caused by a trip or collision with an obstacle were reported by 14.6% of women and 18.6% of men aged 65–74 years old. For those aged 75–84 years, the figures were 36.1% and 20.7%, respectively. Over 85, falls were more common for men, but the sample size was low (four men over 85) and so this detail may not be reliable. In general, several studies in various countries have shown that older people, but particularly older women, experience injuries caused by falls while walking in the road environment or on public transport.

4.3.3 Relevant functional differences between men and women

In the remainder of this section, we consider differences between men and women that could affect pedestrian accident risk. There are many differences between men and women that could contribute to different accident risk in older age, some of which (e.g. hearing) have been discussed in the section on functional impairment. There are two ways in which sex differences could lead to differential accident rates as performance is compromised by decline. The simplest is that some function declines to the same extent or at the same rate for both sexes, but falls below a safe threshold earlier for the group that had a lower starting point. For example, hypothetically, if a safe walking speed was 1.2m/s, and women and men lost 0.1m/s every five years from the age of 60, then if the average walking speed at 60 was 0.2m/s slower for women than men, women would fall below the safe walking speed 10 years earlier than men. This is the scenario that is believed to apply, for example, to the relationship between bone density and fracture risk (Gannon, 1999). Alternatively, the rate or extent of decline might be greater for one group than the other. In this case, even a function once performed with equivalent efficiency by younger men and women could come to contribute to different accident rates in older people.

In the next paragraphs, we consider several functional differences between men and women that may be relevant: differences in visual impairment, spatial cognition, speed of processing, and decline in physical movement and balance. We also consider possible differences in driving experience. Although these are plausible mechanisms, there is little direct evidence connecting them to accident rates, and their relative importance is a matter for future investigation.

Older men and women report different levels of visual impairment, which could affect pedestrian safety. Desai et al. (2001) found that 34% of a sample of women in the USA over the age of 85, but just 26% of men, reported having difficulties with basic self care activities because of visual impairment, defined as vision loss that could not be corrected by glasses or contact lens alone. The same survey found that visual impairments such as cataracts and AMD were much more common among older women than older men.

The literature on cognitive differences between men and women is dominated by sex differences in spatial cognition (male advantage) and verbal abilities (female advantage). Differences in spatial cognition and perception could affect risk (Lundberg and Hakamies-Blomqvist, 1998). Men do better on spatial tasks such as mental rotation, with a larger advantage on more complex tasks. In particular, on tasks that require the coordination of perception and motor skill, such as hitting a target or intercepting a moving target, men show the greatest advantage over women (Kimura, 1999). These are abilities with obvious possible relevance to road crossing. Although any link to cognitive differences is speculative, Khan et al. (1999) observed pedestrians crossing at a number of roads known from accident records to be particularly hazardous in Karachi. They found that women of all ages were more likely not to look left and right, and to cross one lane at a time, observations that suggest they are not dealing with information from different directions simultaneously.

Sex differences in cognition are believed to be laid down in the brain developmentally, largely effected by hormonal differences (Kimura, 1999). Despite this early differentiation, some of these abilities may vary as hormone levels change, for example during the menstrual cycle in women, or in response to hormone therapy (Kimura, 1999). Studies by Willis and Schaie (1988) and Robert and

Tanguay (1990) have shown that some of these differences persist to old age (e.g. spatial rotation), but comprehensive evidence is not available.

Meinz and Salthouse (1998) carried out a large meta-analysis of age and sex-difference studies, and found a slightly greater age-related decline among females than among males, showing that women decline earlier than men in terms of perceptual speed. In comparison, studies examining speed of movement (e.g. in finger-tapping studies) have found that men are generally faster than women, that there is an age-related decline, but that the sex difference does not change across the lifespan (e.g. Welford, 1988).

Older women are more likely to have physical mobility difficulties than older men. Carp (1971), in a survey of retired Americans, found that more women than men mentioned physical problems with walking, with concerns about falling and sore feet particular issues. Noble (2000) found that half of men but more than two-thirds of women in their 80s have some form of mobility difficulty. Women over 75 were twice as likely as men to have severe mobility problems. Older women also walk more slowly than older men, including when actually crossing roads (see 0 above).

Older people may walk more slowly and have more difficult stopping or turning quickly because of reduced muscle strength, and there is evidence, discussed in section 2.3, that older women are particularly affected by this (Cao et al., 1998; Kwon et al., 2001). HRT has been reported to reverse or prevent decline in women (Phillips et al., 1993), but other studies have not confirmed this (Armstrong et al., 1996).

Women are also more likely to suffer from balance difficulties than men. For example, women are more likely to suffer from vertigo (Sidebotham, 1988), from muscle weakness, and particularly from osteoporosis, which not only contributes to muscle weakness, but also increases the risk of any accident or fall being serious in terms of increasing the risk of bone fracture.

4.3.4 Summary

In summary, older men are generally found to have a higher risk of pedestrian accident or fatality than women in relation to their population size. However, there is some evidence that the gap is lower for people in their 60s compared to younger or older age groups. In the UK, for road accidents generally, it has been reported that the over 70s represent 11% of all male road deaths but 30% of all female road deaths (Brown, 1991). Studies that take exposure measures such as distance walked into account have produced mixed results. Some have suggested that women's risk by these measures is greater than men's, whereas others suggest the reverse. However, many studies have suggested that more of women's pedestrian accidents involve slips or falls, with no vehicle involved. Possible explanations for sex differences include cognitive differences, differences in strength, physical mobility and fitness, and road behaviour.

4.4 Slower pedestrians

Accident data do not directly indicate whether slow walking speed is associated with higher risk, but it is widely believed to increase risk (e.g. Keall, 1995; Mori and Mizohata, 1995; OECD, 1985). Normally, ageing older people show reductions of about 20% in stepping movement speed and stride length compared to young adults, with other changes in gait believed to result from these reductions (Elble et al., 1991). Slower walkers do find aspects of the road environment more challenging. It has long been realised that older pedestrians often cannot reach the walking speed required to cross roads in the time afforded by light signals. Lundgren-Lindquist et al. (1983) found that only about a third of women and three-quarters of men aged 70 could reach the 1.4m/s then allowed for in Sweden. Comfortable walking speed was 78% and 70% of their maximum for men and women, respectively. Older women are slower walkers than older men, and older old people also walk more slowly. These differences correlate substantially with differences in leg extension power (Rantanen and Avela, 1997).

Walking speed is discussed in detail in section 2.3.1 above, and here we briefly repeat descriptions of two studies. In a field observation in Los Angeles, Hoxie and Rubenstein (1994) found that over a quarter of nearly 600 older pedestrians could not cross a particular urban intersection before the signal changed to favour vehicles, with about one in 20 still being a considerable distance, as much as a traffic lane, from the pavement. Many of these older people reported that they felt unsafe. Langlois et al. (1997) reported that in a sample of pedestrians aged 72 or over living in another city in the USA, the slowest walkers were three times more likely to say they found road crossing difficult. Less than 1% of the sample had normal walking speeds at the 1.22m/s allowed for by the crossing design.

There are five ways in which slow walking speed could be an index of greater risk. First, it has been estimated that older people experience 29% extra exposure to traffic simply because they spend longer in the road making a given crossing (Wilson and Grayson, 1980; cited in Keall, 1995). Second, slow walking speed may partly explain the relatively higher risk of accidents in the middle and later parts of crossing sometimes reported for older pedestrians (e.g. Fontaine and Gourlet, 1997; Mori and Mizohata, 1995) or in crossing roads with more than two lanes (Mathey, 1983a,b). Third, reduced balance–gait performance has been reported to correlate with cognitive and other functional impairments that may be important in the pedestrian task (Baltes and Lindenberger, 1997). To the extent that these concomitant deficits affect safety, the slower old person is likely to be more vulnerable. Fourth, slow pedestrians who follow a group into the road are at heightened risk if they are not as quick as the others, and this pattern has been noted among older pedestrians (Mathey, 1983a,b; Silcock et al., 1998). Fifth, the slower walker, with lower physical strength and possibly reduced cognitive resources is likely to be less able to react quickly or effectively to an unanticipated hazard, which Wilson and Rennie (1981) regarded as the main deficit of the older pedestrian.

Finally, there is evidence suggesting that slowed walking, in the absence of disability, predicts future mobility problems. Fried et al. (2000) reported that older old women who had reduced walking speed were most likely to develop problems in ascending a flight of stairs or completing a half-mile walk. Pine et al. (2000) found that self-reports by older people that their walking had slowed in the preceding year or preceding 10 years were associated with a greater risk of developing new problems in walking over the subsequent year. In the survey by Spackman (1986) of older pedestrians in the UK, 30% reported problems walking, with about a quarter of those saying that this made road crossing difficult. The recent USA studies mentioned above suggest that more of those having difficulty walking would go on to develop mobility problems later.

4.5 The former driver

OECD (1970) considered the possibility that one reason older pedestrians may be more vulnerable was that fewer of them had learned to drive, and so some might have a poorer appreciation of the road environment. Those with driving experience may have such an advantage (see section 5.6 for discussion). However, for those drivers who have to give up driving, there may be specific problems that offset this advantage. Older people tend to reduce driving, and eventually cease to drive. This will affect their quality of life, but may also make them more vulnerable as pedestrians. We discuss the likely extent of the problem before considering the reasons why former drivers may be more vulnerable. We found little previous research specifically on the former driver as a pedestrian.

Older people who experience reduced mobility will find it harder to access resources and social contacts. People who reduce or give up driving may experience a substantial relative disutility. Carp (1971) reported that former drivers in a city in the USA made more trips on foot than people who had never driven.

Maycock (2000) examined the rate at which people in the UK give up driving as they get older, and projected these rates forward to the period 2020–25, using anticipated changes in population, increases in numbers of people who hold driving licences, and changes in life expectancy in the projection formula. Maycock found no difference between men and women in the rate at which licences were given up. He projected that by 2020–25 the percentage of younger old women driving will approximately double from 1995–99 rates to about 80%. More younger old men were also projected to be driving. At present little more than 6% of women over the age of 80 drive, and 34% of men. However, in 20 years time, over 30% of women aged over 80 will be drivers, and 50% of men. These projections are based on reasonable assumptions, but do not allow for changes in transport policy affecting, for example, the availability of public transport, or changes in the relationship between household income and the cost of motoring. The projections have two implications. First, more households will have access to a car for longer. Second, more households may eventually experience the mobility loss that occurs with driving cessation, because fewer households will have been used to depending on public transport as younger adults. In 1996–98, for example, 76% of women and 57% of men aged 80 years or older in the UK lived in households with no car (Noble, 2000).

Marottoli et al. (1997) carried out a longitudinal study in the USA, where many people depend on their car for transport. They found that driving cessation was strongly associated with the development of depression, or of the increase in symptoms of depression, in older people. Atkins (2001) found that people in the UK who give up driving often report symptoms of depression occurring as a consequence of lost independence and mobility. However, that report did not involve standardised diagnostic measures.

Many people give up driving because of increasing health or vision difficulties, and the same problems could also affect their safety as pedestrians, because the two tasks involve similar skills, and the most difficult situations for older drivers are like those that are difficult for pedestrians. As noted in section 5.1, many older pedestrian accidents occur at junctions, and accidents involving older drivers frequently occur at intersections. Staplin et al. (2001) noted that 63% of older driver fatalities in the USA were at intersections. Similar evidence was reported by Ball and Owsley (1993) who reported that most crashes involving the Jefferson sample of older drivers were at intersections, and that these were better predicted by a decline in the UFOV measure of visual attention than were crashes in general. OECD (2001) suggested that this elevated risk at intersections may be because the task of coping with a junction is not self-paced, and older people are less able to cope with increased time pressure in this situation. Van Wolffelaar (1988; cited in Hummel, 1999) also found an increased risk for older pedestrians in situations of greater traffic complexity and time pressure. Thus, people who have given up driving because of functional impairment are likely to have particular difficulty with this high-risk aspect of the pedestrian task.

Drivers who stop driving because of medical conditions may also be at increased risk as pedestrians. For example, the lack of insight and cognitive impairment that make those with AD high-risk drivers would also reduce their ability to perform safely as pedestrians. Similarly, the poor control of physical movement and sometimes accompanying cognitive impairment that might lead someone with PD to stop driving would also make the pedestrian task more difficult.

4.6 Alcohol-impaired pedestrians

A substantial proportion of adult pedestrian fatalities in OECD countries are found to have been intoxicated with alcohol. Fontaine and Gourlet (1997) studied over 1,200 pedestrian fatalities in France in the 12 months to February 1991. About half had been tested for blood alcohol concentration levels (BAC), and they found that 35% of those tested had a BAC >0.8g/l. Fontaine and Gourlet reported that 90% of alcohol-impaired fatalities occurred at night, and that pedestrians were more likely than drivers to have been drinking. La Scala et al. (2000) reported USA data indicating that in 1996 32% of pedestrian fatalities had a BAC >1.0g/l. Miles-Doan quoted 45% for Florida, and Holubowycz (1995) reported 38% for South Australia.

One of the features that most strongly distinguishes older pedestrian fatalities, especially older women (Holubowycz, 1995; Fontaine and Gourlet, 1997) and the older old (Miles-Doan, 1996; Öström and Eriksson, 2001; see also Road Accidents Great Britain, 2000, Table 2g), is the much lower incidence of alcohol involvement. Nevertheless, the incidence is non-trivial. Fontaine and Gourlet (1997) reported that 11% of the over 65-year-old fatalities tested had a BAC >0.8g/l. Händel (1981) mentioned debility arising from alcohol alongside physical and mental causes as one of four leading causes of older pedestrian accidents in Germany, and an earlier German study found alcohol to be frequently involved, even at low BAC levels (Böhm, 1966; cited in OECD, 1970). Mori and Mizohata (1995) reported alcohol intoxication to be a feature of the at-risk older pedestrian in Japan. Holubowycz (1995) reported 15.8% of older male pedestrian fatalities with BAC ⩾1g/l, although no older females. In the USA, Schiller et al. (1995) reported that 13% of all admissions over 60 years old to an urban trauma centre were intoxicated with alcohol. Zegeer et al. (1994) reported that 15.4% of pedestrian injury accidents in North Carolina for 1980–90 involved drinking, including 3.2% of the over 75s. Zegeer et al. reported similar rates for national fatal accidents in the same period, 14.8% and 5.5%, respectively. National Highway Transport Safety Administration (NHTSA) data from the USA indicate that around 9–10% of pedestrian fatalities over 65 were intoxicated (NHTSA 1998, 1999, 2000). NHTSA (2001a) reported that the figure for those over 70 was 7% in 2000. Sjögren et al. (1993) studied older traffic fatalities in northern Sweden (1977–86 data) and found that 15% of the older pedestrians who were dead on arrival at hospital had taken alcohol. Many of these had high BAC (⩾1.5g/l) and many had signs of liver disease, indicating a history of drinking. Data from the study by Öström and Eriksson (2001) of 286 fatalities in Umea, northern Sweden, between 1977 and 1995, have to be estimated from their chart (Figure 2, p175), but approximately 9% of all pedestrian fatalities 65–84 year olds tested positive for alcohol. UK data for the period 1985–1989 showed that about 26% of 70-year-old pedestrian fatalities for whom data were available had been drinking, with about 18% over 0.8g/l, and 2% over 3g/l (Everest, 1991).

It is possible that the rates of alcohol involvement for older people are biased by under-reporting, as some studies have shown lower rates of alcohol testing for older people than for, say, middle-aged men (e.g. Fontaine and Gourlet, 1995; Öström and Eriksson, 2001). Webb (1995) discusses this issue in detail. However, studies that test exhaustively have found similar rates. For example, the South Australian data were gathered in the context of mandatory testing of BAC for all injuries and fatalities. Rates for other age groups are highest at night and at weekends, and these are times when older pedestrians walk less frequently (Fontaine and Gourlet, 1997; Öström and Eriksson, 2001; Ward et al. 1994), which could partly explain the difference.

There is a good chance that older pedestrians will continue to have a relatively low incidence of alcohol involvement, but the picture could alter if social attitudes and patterns of activity change. There is evidence from European research that successive cohorts of drivers preserve their driving patterns as they age (Hjorthol and Sagberg, 1998), and changes in drinking, such as increased drinking by younger adult women in recent cohorts, could also persist. There is some evidence linking intoxication rates to attitudes in different countries. Within the UK, rates are higher in Scotland and Wales than in England (Everest, 1991, 1985–89 data; Sabey and Staughton, 1980, 1978 data). Öström and Eriksson (2001) reported lower rates of intoxication among pedestrians in Sweden than studies from the USA and Australia. They attributed this to social and cultural differences, and to Swedish public policy, which inhibits the availability and consumption of alcohol. Studies in the UK have shown an increase in the alcohol involvement for younger adult women pedestrian accident victims over the past 25 years (Clayton and Colgan, 2001). The possibility that patterns of alcohol use by older people may change in the future cannot be ruled out.

Attitude changes are also believed to have affected behaviour in relation to drink-driving. Although there has been a recent decline in the number of drivers found with excess alcohol, rates of impairment among pedestrians have not declined so markedly. For example, between 1982 and 1992 in the USA, rates among drivers fell from 20% to 12%, whereas among pedestrians they fell from 39% only to 36% (IIHS, 1997; cited in La Scala, Gerber and Grunewald, 2000). Holubowycz (1995) reported a similar pattern in South Australia over roughly the same period. There have been extensive campaigns against drink-driving in many countries, but not in relation to walking. The campaigns against drink-driving appear to have succeeded, and several researchers have recommended similar efforts should be made in relation to walking. There are difficulties. Most agree that it would be impractical, for instance, to impose a legal limit on BAC for pedestrians. Although many states can detain intoxicated pedestrians, this is typically reserved for the obviously drunk, and risk appears to increase at relatively low BACs. Another difficulty is that for some drinkers, especially at night when public transport is limited, walking may be the safest transport available. Nevertheless, researchers have recommended raising public awareness of the risks of walking in the road environment after drinking (e.g. Miles-Doan, 1996; Öström and Eriksson, 2001).

Intoxicated pedestrians are not always at fault in accidents (Öström and Eriksson, 2001). Still, that is little comfort to the pedestrian, and there is evidence that alcohol affects mortality rates. Evans and Frick (1993) estimated that a BAC >1.0g/l doubled the risk of death from a given impact for car occupants. Waller et al. (1997) found that, after allowing for the effects of crash severity as measured by the degree of vehicle crush, seat-belt usage, sex, and age, alcohol was associated with an increased risk of being admitted to hospital rather than being treated and released. This relationship was not present for those found to have taken other drugs, mainly cannabis. Miles-Doan (1996) studied pedestrian fatalities in Florida between 1988 and 1990, and found that alcohol increased the risk of fatality among pedestrians by about a factor of four, depending on the measure of intoxication used. Zajac and Ivan (in press) studied factors influencing injury severity for pedestrians crossing two-lane highways in rural Connecticut. They found that pedestrian alcohol use was one of the variables associated with more severe pedestrian injury. Bradbury (1991) reported that pedestrians under the influence of alcohol at an Edinburgh hospital had worse injuries and were more likely to have facial injuries than other injured pedestrians. Given that older people are in any case more vulnerable to the consequences of an accident, this ought to be a concern.

In relation to older drivers and pedestrians, it is sometimes argued that alcohol is a negligible issue. However, some reviewers have taken a different view. For example, Planek (1981) suggested that the effect of alcohol at low levels is greater for older people, and discussed findings that, although overall rates of involvement are lower than for younger drivers, at higher alcohol levels older drivers have a greater risk of accidents. He cited the conclusion of a 1980 NHTSA report that "for drivers of 65 and over, alcohol is the most serious single contributing factor in fatal crashes" (p. 175). Zegeer et al. (1994) pointed out that quite small amounts of alcohol can interact with medications often taken by older people to produce large effects on performance. Because of older pedestrians' existing functional problems, they argue that alcohol might present particular difficulties: "While not as great a problem for the older age groups, alcohol use nevertheless constitutes a serious pedestrian safety problem for which effective and immediate interventions are needed." (p. 62).

Because the rates of positive alcohol tests in older pedestrian accident victims are lower than those for younger adults, alcohol cannot explain why older pedestrians are at higher risk overall. Nevertheless, alcohol compromises the safety of any pedestrian, and a significant number of older pedestrian fatalities are over the legal limit for driving when they are killed. Those older pedestrians who do drink and walk increase their personal risk.

4.7 Summary

Certain situations are more commonly associated with accidents involving older people, and some groups of older people are more vulnerable than others in the road environment. Accident records include information about only some of the variables that may affect older people's risk. This means we cannot directly establish all relevant risk factors, and some of those we have described are therefore based on inference from general principles rather than casualty data. In addition, available measures of risk often incorporate only rough measures of exposure, such as population size. The part played by illness and the effects of medicines in explaining older people's risk as pedestrians, are discussed in section 3. The key points of this section are:

- Older pedestrians tend to have accidents crossing the road in good weather and daylight, on weekdays, and near to home. For example, in one UK study, 73% were within 1km of home and 75% were on weekdays (Ward et al., 1994). There is evidence for increased risk at junctions and with reversing vehicles, but this may partly reflect the greater likelihood that an accident of a given severity will injure an older pedestrian and so be reported. One study in the USA found that about 22% of both fatal and all injury accidents to 45–64-year-old pedestrians occurred at junctions, but for people aged 75 years or over, 27% of all injury accidents and 35% of fatalities were at junctions (Zegeer et al., 1994).
- Among the normally ageing, the older old have a substantially elevated accident risk and slow walkers are likely to be vulnerable. A study in New Zealand concluded that the risk of experiencing a collision of a given severity was five times greater for those over 79 compared to 25–69 year olds (Keall, 1995).
- Men have a higher risk per capita of pedestrian fatality at most ages, although the gap between men and women may attenuate among the younger old. For example, 1993 UK data showed that the rate of pedestrian fatalitiesper 100,000 people was 1.58 times greater for men compared to women aged 70–79 years (estimated from Broughton, 1997, Figure 2.6). South Australian data from the 1980s illustrate a narrowing of the gap between men and women: for the three age groups from 56–65, 66–75, and 76–84, the ratios were 4.1, 0.9, and 1.5, respectively. The relative risk varies between countries as well as between precise age groups. Women appear to be at higher risk of injury from falls, even from late middle-age. By some measures of exposure, women have been found to have a higher accident risk in some age groups. An understanding of the reasons for sex differences is limited.
- There are reasons to think that older people who have recently given up driving are at higher risk, in part because they are likely to belong to other high-risk groups. For example, they may have stopped driving because of poor vision.
- Alcohol is associated with accident risk for pedestrians. Older pedestrians are less likely to have been drinking than younger adult pedestrians, and the evidence suggests that, at present, among older people this problem is largely confined to younger old men. In France, 9% of all older pedestrian fatalities tested had blood alcohol concentrations over 0.8g/l (Fontaine and Gourlet, 1997).

4.8 Research implications

European research on older drivers has in recent years shifted focus towards studying specific groups, rather than attempting to treat older people as a homogenous category (Hakamies-Blomqvist and Peters, 2000). Pedestrian research could develop fruitfully along similar lines.

We have been able to make direct links to accident or injury risk only when a factor is routinely recorded (e.g. age or sex) or epidemiological studies have been done. Specific research would be useful to establish whether, for example, slow walkers and former drivers do have measurably greater risk. As indicated in the introduction, the measurement of risk depends on using appropriate measures of exposure, and studies would need to take that into account. The investigations by Fontaine and Gourlet (1995) and Keall (1995) provide good examples of appropriate research methods.

Other factors, such as socio-economic status, are sometimes mentioned in relation to accident risk, but there have not been sufficient data to justify a conclusion. For example, pedestrians from lower income groups appear to be at higher risk, but there are few data specifically on older people, and differences may be explained by collinear variables such as the different road layout of urban and suburban residential areas. Understanding the effects of road layout and road situations on accident risk, particularly the apparent increase in risk for older people at junctions and from reversing vehicles, is itself an important area for continuing investigation. These would be interesting topics for new research.

Beyond establishing the characteristics of high-risk older people, there is speculation but little clear understanding of the mechanisms by which particular factors increase risk, except perhaps in simple cases like alcohol impairment. Because some of the factors are not as readily modified as, say, alcohol consumption, understanding these mechanisms may be necessary to understand how the most effective intervention might be made.

5 ROAD-CROSSING BEHAVIOUR

In sections 1.3.5 and 4.1, we considered characteristic features of older pedestrian accidents. The most serious accidents, and most pedestrian–vehicle accidents, occur when the pedestrian is crossing the road. In this section, we review studies that have investigated the way older people behave in the road environment. These studies have used observation of road crossing, and laboratory studies of simulated road-crossing behaviour. They have looked for characteristic patterns that might help explain accident data. Interest has focussed on four aspects of road crossing that older people may execute differently: looking behaviour; behaviour at the kerb; gap judgement; and behaviour during crossing. All of these can provide information about three key issues: whether older people's behaviour or judgement becomes less effective; whether older people behave less safely; and whether older people are more cautious.

5.1 How older people feel about road crossing

Most studies have been observational or experimental studies of behaviour, but one relatively early study explored older people's subjective experience of road crossing. Carp (1971) gathered qualitative data from a sample of 709 retired residents of San Antonio, Texas. They were shown drawings of two road-crossing situations. The first depicted a busy road, and was labelled "fast traffic". They were asked how they would cross and how they would feel in that situation. Some, particularly those who walked often, said they would never cross such a road, and "would simply go back home" (p. 115). Others said they would detour to a crossing or signal-controlled crossing. Those who normally travelled on foot were also more likely to associate feelings of anxiety with the situation. The second drawing showed a signal-controlled crossing at a busy intersection. Contrary to the intention of the researcher, participants focused almost exclusively on the presence of a car in the crosswalk, obstructing the crossing. They emphasised the problems this frequent event presented such as the increased likelihood of falling, and the time cost as they walked around it. They were concerned that any time penalty might make it difficult to cross in time, and were anxious about their safety although "they 'know' cars will not run over them" (p. 115). Some went on to say that cars parking on the sidewalk presented similar problems and dangers. Carp characterised these responses in relation to a concept of territoriality: pedestrian and vehicle territories were separate, and intrusion was deprecated strongly by these older people. Similar responses were found in a subsequent study in San Francisco using slightly different materials (Carp, 1972).

Langlois et al. (1997) studied the road-crossing difficulties of older old people in the USA (see section 3). They interviewed 1,249 older old people about their experiences. Their analysis excluded those with serious mobility difficulties, defined as being unable to walk across a room unaided. They found that 11.4% of the remainder reported that crossing roads was difficult. Of those who reported difficulty, 81% said that there was insufficient time to cross at signalled crossings, and 78% said they needed help to cross. At some junctions in the USA, vehicles can turn right against a red signal. In effect, the red light is treated as a "give way" signal for vehicles not crossing a moving traffic lane. This was reported to be difficult to cope with by 63% of the older pedestrians. From the point of view of a pedestrian, this arrangement means that they have to consider an extra source of approaching vehicles.

An Australian report asked pedestrians to say whether each of a number of issues presented a problem for road crossing (Job et al., 1994). They found that 82% of 20–59 year olds said that their walking speed was no problem, and also that 82% said estimating vehicle speeds was no problem. However, only 59% and 41%, respectively, of over 65 year olds were as sanguine. Older people were also more likely to be concerned about crossing roads at peak times (64% of 20–59 year olds saying it was no problem compared to 50% of people over 65). Perhaps surprisingly, older people were more likely to regard parked vehicles blocking their view as no problem (23% for 20–59 year olds versus 59% for older people).

Wilson and Rennie (1981) summarised the results of three pedestrian surveys carried out in the UK, including the study by Todd and Walker (1980). Older pedestrians expressed particular concern about fast traffic and busy roads compared to younger pedestrians. They were concerned about crossing "where several roads meet" (p. 146), wanted more crossing facilities, more time to cross at signal-controlled crossings, and wanted drivers to be more willing to stop at zebra crossings. A very similar set of results was found in a more recent survey in Wareham. Savill and Chinn found over half their respondents, who included disabled people, felt that crossing roads in the town centre was difficult because of the speed and volume of traffic, especially at places without pedestrian signals.

We consider marked crossings in more detail in section 7. In the remainder of the current section, we focus on the different phases of pedestrian road-crossing behaviour. Later in the section, we will also examine older people's knowledge and understanding of the road environment.

5.2 Looking behaviour

Like other pedestrian accident victims, and as we have noted already, a large proportion of older pedestrians say they did not see the vehicle that hit them (Sheppard and Pattinson, 1986). It is possible that this results from deficits in looking behaviour. Older people's capacity to look may be compromised by physical problems turning their head (Isler et al., 1997), by impaired vision (section 2.1), and by declining visual attention skills (section 2.3). It is difficult to measure these aspects of looking behaviour directly, and studies have tended to use the number of head turns pedestrians make as an indication.

Some studies have reported differences in older people's looking behaviour. Perhaps the most interesting analysis was made by Wilson and Grayson (1980). They observed younger and older adults crossing roads at three sites in the UK. These were urban roads, and about 10,000 crossings were recorded. They reported that older pedestrians made a smaller proportion of their head movements while approaching the kerb, and speculated that younger pedestrians, who were also less likely to pause at the kerb, were better able to assess the traffic on the move. There was, however, a significant tendency for the absolute number of head movements to increase with age, both before and during crossing. The mean total number of head movements was 6.5 for the oldest, 80 years old, and 5.5 for the youngest, 18 years old (data estimated from Wilson and Grayson, Figure 5). They also found that the proportion of pedestrians looking both ways increased with age (to 69% of those over 70). Although we have no data on what older people detect when they look at traffic, the available information implies that they do look at traffic at least as much as younger people.

To put this in context, slightly larger differences were found in the overall average number of head movements between the three crossing sites where data were recorded than were found between the youngest and oldest pedestrians. Wilson and Grayson emphasised that although they did find differences between older and younger pedestrians, the differences tended to be small.

Harrell (1996) recorded the looking behaviour of pedestrians at four signal-controlled crossings at intersections in Edmonton, Canada. Looking was defined as a head movement made at the moment the signal to cross came on. This may slightly bias age comparisons if older people are more likely to turn their head to make a given check (cf. section 2). Harrell found that, in general, pedestrians judged to be over 51 years, the oldest group defined, looked 50% of the time. That was more than young adults but very similar to those aged 31–51 years (49%). People, particularly older people, tended to look more when streets were less busy, probably in part because traffic flowing more freely would be moving faster. There was also an overall tendency to look more when there were fewer other pedestrians at low or medium traffic volumes. However, for over 51s this tendency was not significant at medium traffic volumes, although the size of the difference was large (87.5% looking with low numbers of other pedestrians versus 40%), and the direction was actually reversed at low traffic volumes. Harrell concluded that older people were not less safe than younger adults when checking traffic at a signal-controlled intersection crossing. Interestingly, he found that although men overall checked more often than women (47.1% versus 40.9%) women over 51 years tended to check more than older men at medium and high traffic volumes.

An earlier study by Harrell (1991b) using similar methods and the same criterion for looking, also found that 50% of older pedestrians (over 50 years) looked, and 48.9% of 31–51 year olds. It is perhaps surprising that the figures agree so closely, given that at least half the observations in the later paper were at different locations. Data for both studies were gathered in 1987, but data for the 1996 paper were also gathered in 1986. Sample size was good in both cases, with 1,489 usable observations in the 1991 paper, and 1,662 in the 1996 paper. Harrell (1991b) found more checking by over 50s when traffic volumes were at low or medium levels, but the difference was only large at medium traffic volumes. In treacherous conditions, when roads were snow covered, women increased looking but men did not, and this effect was strongest for older women who checked 48.7% of the time in dry conditions, but 83.3% of the time in snow. Older men actually decreased their looking when there was snow, down to 20% from 47.9% in the dry. However, although the overall gender interaction with weather was significant, these pairwise comparisons were not. Harrell suggested that older women may be especially concerned about the hazard of slipping.

Job et al. (1998) observed pedestrians crossing at two signal-controlled intersections in Sydney that had had high numbers of pedestrian accidents in the past. Older people were more likely than younger people to not look at traffic at all when crossing (28.8% versus 18.5% at one site, 44.1% versus 40.2% at the other). The difference between older and younger people was small compared to the difference between sites and, as Job et al. noted, no information was recorded on whether they looked before beginning to walk. It could be that older people tend to place more faith in the 'system', and believe that once they are on a crossing, the crossing will protect them. On the other hand, they may have judged accurately that they happened not to need to check on those particular crossing occasions. At one site, a larger percentage of older people looked three or more times than did not look at all. At the site where looking was less frequent, mean walking speeds for older people were 13% slower, indicating less concern about traffic (see section 2.3.1 above). Older people were also more likely to begin walking during the 'green' phase. A further possibility is that there are distinct subgroups of older pedestrians with different patterns of looking behaviour. Some older people crossed away from the crossing or at different phases of the signal, and the data on looking behaviour were not broken down by these categories.

Most studies indicate that the looking behaviour of younger and older pedestrians is rather similar. Older people look slightly more than younger people, and their looking behaviour appears to be sensitive to environmental conditions in ways that are prudent. However, one study has found that at some busy signal-controlled crossings, many older people do not look at all. Differences between older and younger people are small compared to differences between locations.

5.3 Kerb delay

Harrell (1990) carried out observations of pedestrians at an intersection in Edmonton. He found that older people waiting to cross stood a little further back from the kerb than younger people. When comparing daytime and night time positions, he found that older people adjusted their position further after dark, whereas younger people did not. He interpreted these results as showing that older people are more cautious, and more sensitive to changing levels of risk. In a similar later study at four sites in Edmonton he derived a composite score for caution from estimates of distance back from the kerb (one point per 30cm) and number of directions checked visually (Harrell, 1991a). In an analysis of covariance, age was one covariate and older people were found to be significantly more cautious. It would perhaps have been better to analyse looking and kerb standing separately, and the report gives no information on how age was assessed.

As noted earlier in this section, Wilson and Grayson (1980) observed that a larger proportion of older pedestrians paused at the kerb, and they linked this to looking behaviour, suggesting that younger adults were better able to weigh crossing opportunities as they approached the roadside. Wilson and Grayson also reported that, among those who waited, the mean delay at the kerb was not different for younger and older pedestrians. However, they timed delay from stopping at the kerb to beginning to cross, and so delay included time spent waiting for passing traffic to leave a gap. Wilson and Rennie (1981) summarised findings from three observational studies, including Wilson and Grayson (1980), with the conclusion that differences between older and younger pedestrians in terms of mean kerb delay time were largely due to differences in proportions not stopping at the kerb at all. At that time in the UK older pedestrian road training typically included the Green Cross Code advice to stop at the edge of the road (Sheppard and Valentine, 1979, 1980).

Oxley et al. (1997a) compared 80 older and 80 younger pedestrians making a mid-block crossing on two-lane arterial roads in Melbourne, using covert observation. They also observed crossings on one-way roads (with 40 older and 40 younger pedestrians). They found that in the one-way street both older and younger pedestrians stepped from the kerb immediately the last vehicle passed. The younger pedestrians also did this on busy two-way streets, but in this more complex situation there was a mean delay for older pedestrians of about 0.9s. Oxley et al. suggested that in the more complex situation older people have more difficulty responding quickly. Wilson and Rennie (1981) cited data of their own showing that when crossing from a refuge older pedestrians actually were more likely to anticipate a gap by stepping before the car has passed (27% versus 13% for younger pedestrians) and had slightly shorter mean response time (3.8s versus 4.8s). A refuge effectively turns a two-way street into two one-way streets for a pedestrian. Jacobs and Wilson (1967, see section 1.3.4 above) calculated a lower pedestrian accident risk for one-way than two-way roads in each of the three towns they studied that had both types of road. However, they did not calculate estimates separately for older and younger people, and presented evidence that the difference was actually due to differences in vehicle flow. They suggested that higher risks found in their earlier study of crossing in London could also be attributed to the greater volume of traffic there.

Studies of older people's approach towards the road suggest that they tend, if anything, to be more cautious than younger adults. For example, they are more likely to pause at the kerb. There is some evidence that their kerb delay is less when they have one direction of traffic to cross.

5.4 Gap judgement

A critical skill for a pedestrian crossing a busy road is judging which gaps between vehicles afford an opportunity for crossing. Many researchers have explored this question, noting that children or older people may be less proficient at making speed and distance judgements. When judging a gap, a pedestrian has to take into account their own walking speed. Older people tend to be slower walkers, and an interesting question is whether they make adequate allowance for this.

Several studies have looked at speed, distance, and time to arrival (T_a) judgements by older people in the road environment. There has been particular interest in patterns of error. If speeds are consistently underestimated, or T_a is consistently overestimated, judgements would tend to be risky. For example, if someone overestimates T_a, the approaching vehicle will arrive earlier than anticipated. It turns out that older people tend to make conservative judgements in most relevant situations. A second key issue is the way judgement is tested. Researchers have sometimes asked participants to articulate estimates of quantities like speed or distance in a verbal judgement. Others have used direct behavioural measures. These methods yield conflicting results in some circumstances, with direct measures probably having greater behavioural relevance.

Two relevant studies examined verbal reports by older drivers of the speed of approaching vehicles. Hills and Johnson (unpublished, cited by Hills 1980) looked at drivers finding a crossing gap in a high-speed road, and asked the drivers to say what speed they thought each approaching vehicle was doing. Higher speeds tended to be underestimated, lower speeds overestimated. In other words, the participants reports of speed occupied a narrower range of values than the objective speeds of the cars. Furthermore, older drivers used a narrower range than younger ones. Overestimating speed is conservative, because it implies that the car will arrive later than expected. For drivers over 60 years old, marked underestimation occurred for speeds higher than about 50mph, and speeds were underestimated by about 10% up to 70mph. The speed limit was 60mph, and Hills noted that beliefs about plausible speeds could have affected these verbal judgements. At a second site, with a lower speed limit, underestimation began at lower speeds, which supports the view that expectation played a role in these reports.

Hills and Johnson carried out their tests on open roads with real traffic. To exert more experimental control, a subsequent study in the USA used a closed test track (Scialfa et al., 1991). Ten older participants (55–74, mean age 65 years) were screened for visual health difficulties. Participants observed from the passenger seat of a car parked at a right angle to the track, while the target car approached from the side at 15–55mph. They wrote down their estimate of speed in mph. Scialfa et al. obtained similar results to Hills and Johnson, in that older people offered a narrower range of estimates than younger people. However, in the test-track environment the range of verbal estimates was slightly wider than the objective range of speeds. At 55mph, older people slightly overestimated actual speed (estimated from Scialfa et al., Figure 1), but there was no significant difference between older and younger people. At 15mph, older people slightly underestimated speeds, but to a significantly smaller extent than younger people. These two studies indicate that, although there are some differences between older and younger people, older people tend to make conservative verbal judgements in most circumstances. When they do underestimate speed, their underestimates are more conservative than younger adults' (low speeds on a test track) or occur only at relatively high speeds (over 50mph at a dual carriageway).

However, some investigators have questioned whether quantitative verbal estimates of speed actually play a role in behaviour. Schiff et al. (1992) argued that estimates of T_a give more direct information about the key judgement to be made. In addition, they argued that a behavioural response would match the gap acceptance task better than verbal judgements of speed and distance. They edited film of a car driving along a rural road so that at a predetermined distance from the camera position the car disappeared from the film. Participants were asked either for verbal judgements of speed and distance, from which their subjective estimate of T_a was projected, or were asked to press a button at the moment they felt the car would have passed them. For T_a estimates projected from verbal judgements, age-related differences in judgement of speed, which was overestimated to a greater extent by older women particularly, did not lead to corresponding differences in T_a. This led Schiff et al. to conclude that their data "did not seem to imply that velocity overestimation would result in decreased (more conservative) arrival-time estimates" (p. 522). For behavioural estimates, based on a button-push, Schiff et al. found that people of all ages tended to anticipate earlier arrival times than would have occurred objectively, with a tendency for older women to make the most conservative estimates. Estimates also tended to be slightly less conservative, and therefore in fact more accurate, at 20mph than 10mph, the reverse of the pattern with verbal judgements. Schiff et al. concluded that "our present results do not implicate low velocity estimates, high distance estimates, or high arrival-time estimates in age- or gender-related accident risk" (p. 525). Indeed, earlier accident analyses conducted in the UK suggested that such errors are involved in a minority of driving accidents. Hills (1980) reported TRRL data indicating that, of accidents in which drivers were judged to have been at fault in an accident and had made a perceptual error, only 5% involved a misjudgement of speed and distance.

Wilson and Grayson (1980) made an observational study of road crossing. They reported a relatively small percentage of pedestrians leaving short gaps, and for farside gaps this actually decreased slightly with age, from about 5% at 45 years old to 4% at 75. Short gaps were defined as gaps less than 2s, with the interval being measured from the time the pedestrian reached a given point to the time the next vehicle passed that point. There were fewer short gaps as the first half of the crossing was completed, and this stayed fairly steady at 2–3% for all ages. As with looking behaviour, they reported a larger variation in the proportion of nearside and farside risky crossings between the three sites where observations were made than between younger and older groups. Wilson and Rennie (1981), summarising data from this and two other observational studies at several different types of site, reported no differences between older and younger pedestrians in safety margins. Younger pedestrians were prepared to accept shorter gaps when traffic was heavy.

Harrell and Bereska (1992b) also defined risky gaps using a 2s criterion. However, they measured from initiation of the crossing to the passing of the next car. They observed 75 groups, some consisting of a single pedestrian, crossing a busy four-lane intersection in a Canadian city. Age was estimated by observers, and there was no validation for these estimates. They reported that older pedestrian groups tended to cross during longer gaps, and that risky gaps were more frequent for younger pedestrians. However, it is difficult to interpret these results because it appears that a car travelling in either direction stopped the clock. Because the crossing was 38 feet wide, some of the farside risky gaps must have closed before the pedestrian reached the middle of the road. That is, they were not gaps the pedestrian intended to enter. It is also a little difficult to disentangle effects of age and group size. Thus, these data are no more than indicative.

The observational study of Oxley et al. (1977a) assessed gap acceptance using two measures. The average distance to the next nearside vehicle when the pedestrian "first step[ped] forward to cross the road" (p. 842) was 69.1m for older pedestrians but only 51.3m for younger ones. The second measure compared the time pedestrians took to reach the centre of the road with the time it took the next vehicle to pass in the nearside lane at the crossing point. Oxley et al. constructed regression lines fitting crossing times to vehicle passing times. There was a positive relationship for all age groups, such that people took longer to cross when the gap was longer. However, Oxley et al. argued that for older pedestrians the line tended to converge with the minimum safe gap. That is, the longest crossing times were tight fits for older people, whereas for younger people the safety margin tended, if anything, to increase in longer gaps. This relationship was especially clear, they argued, for those older pedestrians taking longest to cross, who they labelled slower old pedestrians. However, there are qualifications that should be made to this conclusion. First, there was no independent measurement of walking speed. Slower old pedestrians were defined circularly as those taking longer than 6s to cross, but they almost always did this in longer gaps. They may have simply made full use of the available gap. Second, there is an outlying value in the slower old data, which anyway has only 11 data points. A line fitted without this value does not have a less steep slope than the theoretical safety margin line (data estimated from Oxley et al., 1997a, Figure 4). Third, although vehicle flow rate was well matched between age groups, the mean vehicle speed, at 27.3km/h, was a little over 4km/h higher when the older people were crossing. An alternative explanation for tight safety margins is considered later in this subsection.

On one-way roads, older and younger pedestrians matched crossing time to vehicle arrival in a similar way, with no evidence of convergence towards tighter fits at longer times. However, it should be noted that both vehicle speeds (about 45km/h) and the distance accepted (134m and 119m for older and younger pedestrians, respectively) were much greater on these roads.

Oxley et al. (1997a,b; 1999) used a simulated road crossing task to investigate gap acceptance more systematically, and the results help to address some of our concerns about the interpretation of the observational study. Pedestrians watched a computer-generated moving image of a road scene, and judged when a safe gap had appeared. The length of gap and vehicle speed were varied. Participants sat, and looked at the scene from the viewpoint of a pedestrian about to cross. Two cars passed in sequence, and the participant pressed a key to indicate whether they would accept the gap if they began to cross immediately after the first vehicle passed. Oxley et al. looked at willingness to accept different sizes of gap, decision times, and ratings by participants of how safe they felt a given crossing would have been. Older people took longer to decide, and their decision times were more variable. They were generally less likely to accept any given gap than younger adults, and tended to accept only reasonably generous gaps when the time to arrival was as short as 4s, as gauged by the average walking speed of their own age group. However, for 7s and 10s gaps, the older old, although still less likely than others to accept a given gap, accepted more gaps than would have been expected given their walking speed. Younger old and young adult pedestrians did not do this. The older old were compensating, but not enough at these longer distances to guarantee safe crossing.

Oxley et al. (1997a) calculated theoretical safety margins left by these virtual crossings. The margin allowed for decision time and a hurried walk (the mean of the person's normal and fast walking speeds). Data were presented for the 4s and 7s conditions. Young adults did sometimes leave tight fits, and this was more likely for slower walkers. However, decision times showed so little variation in this group, and were so short compared to the other variables, that calculated safety margins were almost entirely determined by walking speed and the independent variable time to arrival (inferred from Oxley et al., 1997a, Figure 3). For older people, individual variability was greater. Nevertheless, there was a clear relationship, with slower walkers tending to accept shorter margins. For the younger old, these margins remained large enough to imply completion before the vehicle arrived, except for trials in which particularly long decision times occurred. For the older old, almost all of the 18 participants accepted some crossings that could not have been completed without accommodation by the driver. Indeed, those with an estimated crossing time over 6s never accepted a safe gap. Again, of course, this practically follows analytically from walking speed and the values of the independent variable time to arrival. It is difficult to know how to interpret these findings. For example, it is unclear whether decision time ought to be included in the calculation of safety margins, as task instructions were to decide "as if [you] were to cross. . . immediately". To a large extent, these results do simply express the truism that if your walking speed is lower than needed to clear a given gap, you will not clear it. The puzzle is really why the slow walking older old accepted any of these gaps.

Part of the answer may lie in the demands of a laboratory situation. It is well known that human participants, especially volunteers, like those in this study, try to please the investigator, and try to respond to the experimental situation cooperatively. The older people may simply have felt, perhaps unconsciously, unwilling to give consistent "no" responses to all gaps in a given time interval. They, like the other groups, only did that for the 1s condition. They may have felt they should distinguish among the gaps. Although the order in which scenes were presented was counterbalanced, the nine trials in each time-to-arrival condition consisted of three scenes replicated three times. For pragmatic reasons, people tend to interpret a repetition of a question as implying either that the first answer was incorrect, or that a different question is now intended. Either way, they may feel a different answer is now expected. It would be interesting to know whether older people varied responses on trials that were repetitions.

A second possibility is that older people may actually be poor at calibrating perceptual judgement to their own walking speed. If this is correct, the question is whether poor laboratory performance would generalise to the road environment. For the slower older old, their judgements at 4s and 7s gaps implied complete dependence on drivers. However, the 69.1m gap Oxley et al. (1997a) found that older pedestrians accepted when crossing two-way streets implies an average time gap acceptance of about 9s. That is, in natural conditions, older people tended not to accept such short gaps. The participants in the two studies were different, and methodological differences, such as procedures for determining age, preclude direct comparison, but this does suggest that laboratory performance might not generalise, at least for this laboratory task. Demetre et al. (1992) reviewed the different patterns of results found for children's gap acceptance judgements in simulation studies compared to more realistic "pretend road" tasks. The simulation-based research they reviewed tended to underestimate children's ability to judge gaps.

Oxley et al. (1997a) also collected data on how safe people felt about the gaps they had selected in their simulator study. Older adults felt less safe overall, and although younger old people's ratings fitted predictions based on the difference in their walking speed, the older old indicated that they felt safer than would have been expected. No further information was reported on why they felt safe. Oxley et al. concluded that older old pedestrians behaved in a comparatively risky way and, although they were less likely to accept any given gap, they did not make full allowance for their slower walking speed and decision time. The younger old, on the other hand, tuned their behaviour to reduced walking speed rather better. These are interesting conclusions, and the questions of awareness and compensation are discussed more in section 6. However, given the qualifications raised, we cannot be entirely confident that they hold. It may be that these findings are partly a function of certain peculiarities of the specific laboratory set-up used.

In a second simulation experiment, Oxley et al. (1997a) allowed participants either a short (1s) or long (5s) time to inspect the simulated road scene. They concluded from this study that older pedestrians relied on distance information rather than speed. The older participants were happier to accept gaps when T_a was longer, irrespective of speed. As a consequence, on average they actually preferred gaps when the approaching car was travelling at a higher speed (80km/h rather than 40km/h) and was therefore on average further away, because the design balanced T_a. At short inspection times, the older participants, paradoxically, were more likely to accept gaps for faster vehicles, implying that in these rapid judgements the decision was based on distance rather than speed. This effect was reported to be greater for older old people. As in their first experiment, Oxley et al. also found that the older old reported greater feelings of safety than was predicted on the basis of their slower walking. They concluded that, unlike younger pedestrians, older people are unable to process distance and speed information simultaneously and rapidly. Instead, their judgement is initially distance based, with allowance for speed being made only subsequently. All age groups rated high vehicle speed trials as more safe at short and long inspection times, suggesting that these ratings were distance based. Once more, however, it is important to be cautious about whether the demands of this laboratory task, with limited inspection times, are a good model for crossing in the road environment.

An important implication of the data in the studies reported by Oxley and colleagues is that, if the results are valid, older old people and slow older people make inaccurate judgements about safe gaps, and accept gaps that are objectively risky. However, they also report feeling more safe than they ought to, and so they do not appear to be being less cautious. In absolute terms, their behaviour is more conservative than younger pedestrians' but the adjustments they make are not large enough to compensate fully for slower walking speed and decision time.

Although the studies reviewed have assumed that gap judgement is a valid indication of pedestrian skill, there is an alternative view. Wilson and Grayson (1980) suggested that in fact gap judgement might not be a good measure of skill because a tight fit, in which the gap between completion and vehicle arrival is short, could reflect low skill or high skill on the part of the pedestrian. In addition, pedestrians may well expect approaching vehicles to adjust their speed or direction to accommodate them (Sheppard and Pattinson, 1986). Indeed, Harrell (1993) showed that drivers in Edmonton were more likely to yield to an assertive pedestrian who stepped onto a crosswalk.

Expectations about what drivers will do could play a role in gap judgement. That is, the task might not be to judge whether a vehicle is far enough away that one can cross before it arrives, assuming constant velocity. Rather, the task might be to judge whether the vehicle is far enough away to avoid a collision. These different versions of the gap judgement task might, indeed, both be used but in different traffic situations. When large gaps are frequent, an autonomously safe crossing could be selected, using a gap large enough for crossing to be completed in less than the vehicle's time to arrival. On the other hand, if gaps large enough for autonomous safety are hard to come by, pedestrians may negotiate a crossing with the traffic stream, anticipating that drivers will slow down if needed. Moore (1953) observed that some pedestrians at a marked crossing accepted time gaps shorter than the time they took to cross the first lane. In these instances, the drivers must have slowed down once the pedestrian began to cross. In these instances, also, pedestrians tended to walk more quickly (see also section 2.3.1 above). For this type of judgement, simple distance would be a reasonable guide except in the wet, on ice, or in fast traffic, when braking distance increases greatly, or at night when a pedestrian may see a vehicle much sooner than the driver spots them (Allen et al., 1996; cited by Oxley et al., in preparation).

The Road Research Laboratory (1963) analysed gap acceptance judgements by younger adults in an artificial task, and concluded that they did incorporate an estimate of vehicle speed plus a separate distance criterion. Participants appeared to look for a gap of 2.9s plus 45 feet (about 14m). These people could cross the artificial carriageway in about 2.6s. Similarly, Moore (1953) observed pedestrian crossing behaviour at a marked crossing with a refuge. The probability of a pedestrian attempting to cross when a vehicle was a given distance away was lower when speeds were higher. Moore's analysis suggested that pedestrians tried to keep a constant time gap for crossing rather than a constant distance, and Moore argued that this was a rational preference in terms of economy of time given traffic flow at the crossing studied. For crossings in which the pedestrian's crossing time was less than the vehicle's time to arrival at the start of crossing, pedestrians walked more quickly.

More recently, however, Connelly et al. (1998) cited a study by Parsonson et al. (1996), which found that drivers' judgements of the last safe moment to cross a gap were made at an almost constant distance irrespective of the speed of the approaching vehicle. Connelly et al. found that children crossing roads behaved in a similar way. In addition to the speed judgement task described earlier in this subsection, Hills and Johnson (unpublished; cited by Hills, 1980) asked drivers to estimate the "last safe moment to cross". According to Hills, older drivers (possibly just older male drivers, Hills' paper is a little ambiguous) left a "virtually constant distance (approximately 150m)" (p. 206), whereas younger drivers were nearer to leaving a constant time margin. Carthy et al. (1995) described an experiment in which older people had to guess the arrival time of an approaching car shown on videotape. Their analysis was that older people compensated for distance well, but made poor allowance for speed, even though their relative speed judgement sensitivity was good. It is therefore not implausible that older pedestrians might use this kind of strategy.

Engaging in a cooperative crossing, relying on other road users to adjust, is something we might expect to be more common among young men, say, who might be assertive and be more willing to take risks that are contingent on the response of others, and it seems at first surprising to consider that old people may do it. However, if it were correct, it would completely change the interpretation of certain results. For example, Oxley et al. (1997a) showed that older pedestrians who took longer to complete their crossing left a tighter fit between completion and the vehicle passing them. This meant that the safety margin reduced. Their interpretation of this result was that slower-walking older people are worse at judging the gap. The alternative interpretation would be that these tight fits are as much a reflection of the driver's judgement and, in accordance with Wilson and Grayson's suggestion, they might be a sign of high, not low, skill. Data supporting the alternative account come from interviews with older people. Sheppard and Pattinson (1986) reported that 71 of their sample of 473 older pedestrian accident victims said the vehicle did something unusual that took them by surprise. Of the 71, 20% said they had expected the driver to stop or alter course. Job et al. (1994b) in a survey found that 78.9% of pedestrians and 64.2% of drivers of all ages thought that older pedestrians relied more on cars stopping for them than younger people did. We will see in the next subsection that older people have been observed to engage in what has been called "interactive" road-crossing behaviour.

Some evidence reviewed in this subsection suggests that older people, particularly the older old, are less capable of accurately judging safe crossing gaps. In simulated crossing tasks, the older old accept shorter gaps, and rate their safety more highly than their walking speed should allow. On the other hand, the proportion accepting unsafe gaps implies a far higher accident rate than is observed. As others have noted, drivers must be helping to create a safe gap after crossing begins. We do not know whether older pedestrians, consciously or unconsciously, rely on this in certain circumstances.

In all kinds of task, older pedestrians prefer approaching cars to be further away when they start to cross. If distance is the criterion they use, then their judgements are becoming relatively more cautious. Whether the distance adjustment is enough to maintain safety is a separate question. More cautious behaviour may not reduce objective risk. Oxley et al.'s finding that none of the tight fitting slower old pedestrians suffered a collision indicates that it is often sufficient. However, if older pedestrians do sometimes depend on the driver when they cross, then they will naturally be at greater risk when a driver does not anticipate or observe their behaviour. The finding of Harrell and Bereska (1992a) that drivers who had recently been frustrated by a delay are less likely to yield to a pedestrian indicates a particular situation in which that strategy might not work, although the effect size in their study was small. A UK study observed, similarly, that drivers who had been delayed longer by crossing pedestrians at a zebra crossing became more "aggressive" in entering pedestrian crossings during gaps in pedestrian flow, but no quantitative findings were reported (Griffiths et al., 1984). Griffiths et al. also noted that many pedestrians, especially older ones, tended to wait until it was clear that any approaching driver was going to let them cross.

5.5 Crossing the road

Some of the difficulties older people report they have crossing the road were summarised in section 2.3.1. They have often been found to say they have difficulty or experience anxiety crossing in the time allowed by light-controlled crossings (e.g. Bailey et al., 1992). We return to that issue in section 7. In this subsection, we focus on studies that have described the way older people cross the road.

Wilson and Grayson (1980) reported on delays or pauses pedestrians made during the road crossing. Most pedestrians (68%) were not delayed in the road, and this figure did not increase with age. The typical length of delay (about 9s) also did not change with age, except that it rose to 11s for those over 70. Delays during crossing imply that a pedestrian did not complete the crossing in a single movement, having to stop in the middle, for example. They found greater road delay at sites with higher traffic flow or parked vehicles on one side of the road. In their road observation, Oxley et al. (1997a) classified road crossing as non-interactive when a pedestrian waited for a gap in both directions and crossed in one movement, or as interactive otherwise. Interactive crossers negotiated their crossing, perhaps pausing in the middle or weaving through the traffic stream. More of the older people were interactive (75% versus 51% for younger adults), and the difference was largely due to more interactive crossing on the far side of the road by older pedestrians. This suggests, counter-intuitively, that older people behave in a way that is objectively more risky. Nevertheless, it is also consistent with a view that older people may be trying to manage their risk by negotiating a difficult road in stages, or that on a busy road some older people adopt a strategy of cooperative crossing, relying on help from drivers.

Carthy et al. (1995) observed older people crossing at two sites in Newcastle that survey respondents had indicated caused problems for pedestrians. Carthy et al. reported that potentially unsafe crossings often occurred when an older pedestrian had begun to cross without considering the second half of the crossing. However, they did not record data on adults under 65 years to provide a comparison. Data on relative accident risk in the first and second lanes during road crossing were reviewed in section 4.1 above.

Silcock et al. (1998) observed a large number of crossings at nine urban sites in the UK. They defined "encounters" between pedestrians and vehicles as situations in which either a pedestrian or vehicle changed course or speed during the crossing. "Conflicts" involved a sudden evasive manoeuvre. Silcock et al. looked at the way pedestrians responded to such events. They found that, on formal crossings, pedestrians of all ages were less likely, and cars were more likely, to slow down or give way. Elsewhere, pedestrians were more likely to change direction to avoid collision with a car, but men and women altered their speed in different ways. Although men increased or maintained speed, women were more likely to slow down. Cars were more likely to slow for women. This difference is intriguing.

Silcock et al. (1998) identified certain groups with a high risk of encounters, one of which was older women (see section 4.3 above). They reported that older women were more likely than other pedestrians to appear only to take nearside traffic into account at first, attending to the farside once they reached the middle. Overall, across all ages, they found that whereas more events took place in the far side of the road, conflicts occurred more often at the near side. They suggested that nearside incidents leave less of a margin for successful evasive action.

Howarth and Lightburn (1981) and Howarth (1986) have argued that drivers do not take sufficient responsibility for the safety of pedestrians trying to cross, a view endorsed by Chapman et al. (1981). Howarth and Lightburn (1980) reported observations of children crossing roads on the way home from school, and found that, if a car was approaching, children more often than drivers did something relevant, like waiting at the kerb. Thompson et al. (1985) observed vehicles passing schools in the UK, and found that their speed (passing about 1mph slower) and road position (4cm further from the kerb) made on average negligible concessions to the presence of children standing close to the kerb. When the pedestrians were adult, the average speed of passing cars was 2mph higher than when no pedestrians were present. However, Van der Molen (1986) reported that at least some drivers in a study in the Netherlands did adjust speed when confronted with potential hazards such as a ball rolling into the road or a child running erratically on the sidewalk. Mackie and Jacobs (1965) found that 72% of drivers approaching a zebra crossing failed to stop for a pedestrian who had stepped on to the nearside of the crossing. The motorist should give way when the pedestrian steps onto such a crossing.

Other studies have made similar observations. Katz et al. (1975) found that motorists at four sites on urban streets in Israel did tend to reduce speed when a pedestrian ahead of them stepped into the road as if to cross, with greater average reductions at the two marked crossings. About 15% actually stopped at the marked crossings. However, many motorists, 28–59% at the different locations, maintained or increased speed as they approached. Drivers slowed more if the pedestrian stepped into the road when the car was further away. A linear relationship with time to contact fitted these observations well. The shorter the time until the car would pass, the higher its passing velocity. Várhelyi (1998) studied the reactions of drivers to pedestrians trying to cross at zebra crossings on an arterial road in Lund. Várhelyi (1998) defined interactive situations as ones in which a pedestrian was at the crossing and a vehicle approached within 70m. Vehicles passed through the crossing before the pedestrian in 95% of these cases. In "encounters" pedestrian and vehicle could have collided given the initial speed of the vehicle. In 73% of these situations drivers maintained or increased speed. Várhelyi concluded that drivers were using speed to tell pedestrians to let them pass. A case study of an accident to a 73-year-old woman described by OECD (1985, case 1, p. 118) shows how this can lead to accidents. The driver assumed the pedestrian would stop midway, but she was not monitoring the approaching car, which she had seen, and carried on. The driver was going too fast to stop.

Sometimes older people also have difficulty leaving the road at the end of a crossing. This can result from difficulty with taking a high step at the kerb (FEPA, 1995; Savill and Chinn, 1993), but at least one case has been reported in which the problem was finding space on a crowded pavement (Sheppard et al., 1988: case 2). Gallon et al. (1995) found that one third of their visually impaired survey respondents reported having had an accident involving steps, but mostly these were steps at entrances to public buildings.

5.6 Knowledge of the road environment

There has been relatively little research on the extent to which older pedestrians understand the road environment. There is indirect evidence that some may not have a good understanding. Silcock et al. (1998) reported that older women commonly appeared not to assess traffic adequately when they were crossing a road. However, their paper did not provide detailed data relating to this observation.

Jonah and Engel (1983) speculated that perhaps older people were less aware of risks in the traffic environment. They based this on a lower average reported level of "fear of being struck by a vehicle" on the target day, the day before the exposure survey interview. Only 7.1% of the 65+ group said yes, compared to about 14.8% for younger adults (18–65 years). However, as Jonah and Engel pointed out, it could have been that the objective risk was lower, because older people walked at different times and places, made fewer trips, for shorter distances and less time, and were less likely to have been drinking.

Writers sometimes suggest that non-drivers will have a poorer understanding of traffic than drivers (OECD, 1970). Sadler (1972) compared the road safety advice given to young children by mothers with and without driving licences. There were some small specific differences. Mothers with licences were a little more likely to say they offered a given piece of advice, and were more likely to advise stopping at the kerb and crossing quickly. However, the pattern of advice given and relative priorities were similar. Carsten et al. (1989) reported that, among their sample of urban road accident victims, pedestrians, who mostly did not have driving licences, had very similar views to drivers on which traffic movements were the most dangerous. For example, both thought speeding was dangerous. Similarly, Sheppard et al. (1988) found little difference between drivers and non-drivers in their understanding of pelican crossings. They found much misunderstanding about how to use such crossings among both groups. However, it should be noted that at the time of that study, such crossings may have been novel to some people. One particular area of difficulty appears to be in the understanding of the "flashing go" signal at pedestrian crossings. This signal is used in many countries, although the precise form varies. The intended meaning is typically "do not start to cross, but if you have started, complete the crossing". Sheppard et al.'s research was directed towards teaching older people how to use such crossings, but an alternative is to try to design the facility so that users can understand it more easily. We discuss these approaches further in section 7.

5.7 Summary

Older pedestrians cross roads in ways that they may perceive to be cautious. There are several changes to their crossing behaviour that are consistent with this. For example, they are more likely to stop at the kerb, stand further back from the edge, and they increase this distance at night. They also look for traffic at least as carefully as other pedestrians, and the gaps they accept are on average longer in terms of distance than those accepted by younger adults. They are also more likely to use marked crossings. Finally, they often break the crossing of two-way roads into parts, which may reflect an adaptation to the complexity of this particular task. Jacobs and Wilson (1967, see section 1.3.4 above, and section 7.3.1 below) concluded that "For both sexes, elderly people had the best crossing behaviour" (p. 4).

Paradoxically, these behaviours may not increase their safety. Kerb delay could mean that the full width of an available gap is not utilised. Although they cross when approaching vehicles are more distant, they may be less effective at allowing for vehicle speed, and the older old in particular may not make full allowance for the decline in their own walking speed. There is evidence that older pedestrians depend on drivers accommodating their crossing.

5.8 Research implications

Many of the observational and simulation studies have examined mid-block crossing, although some (e.g. Harrell and Bereska, 1992a) have looked at crossings near junctions. Ward et al. (1994) did report that older people made a higher proportion of mid-block crossings than younger adults (25% rather than 20%), but detailed studies examining crossing near junctions would be useful.

We found no observational studies of older pedestrians walking in the road environment other than those looking at road crossing. Of course, this reflects the fact that many of the worst accidents happen crossing roads. Nevertheless, a more complete understanding of older pedestrian behaviour would be possible if there were data for example on how they negotiate obstacles on the pavement. Studies on the kinds of route older people choose would also be helpful.

More work is needed to develop the methodology of laboratory simulations of road crossing. Previous research has found conflicting results for video-based simulations and practical simulations (Demetre et al., 1993). It would be interesting to see studies based on the pretend road method of Lee et al. (1984) with older people as participants. This would help determine the validity of simulation-based studies, which can allow more systematic and controlled investigation of behaviour.

Interviews similar to those conducted by Sheppard and Pattinson (1986) could be used to investigate whether older people accepting tight fits do so with a conscious expectation that drivers will accommodate them. Similar methods could help determine the reasons behind interactive crossing.

There is no information on what older pedestrians actually see when they look for traffic. The rate at which accident victims report the failure to detect the vehicle does not appear to vary with age (Sheppard and Pattinson, 1986). Nevertheless, it would be useful to examine this directly, given, for instance, the data on decline in UFOV discussed in section 2.4.3, and evidence of its relationship with accident risk among drivers. Such research would not necessarily need to use the UFOV measure.

Few studies have systematically contrasted road types. Oxley et al. (1997a) compared two-way and one-way roads, but there were other differences between these roads such as vehicle speed. Wilson and Grayson (1980) gathered data at three sites (and a fourth in their pilot work), and made some post hoc comparisons. These studies suggest that differences between roads have effects on behaviour that may be greater than differences between age groups. Systematic observational studies comparing different road types would address this gap in knowledge.

Work examining sub-groups of older pedestrians who adopt different strategies in various situations would be useful. Similarly, psychological research on the different responses of men and women to an approaching car would be interesting.

6. SELF-AWARENESS AND COMPENSATORY BEHAVIOUR

Older people often report that their vision, hearing, or other capacities are declining, and people who feel this is so may alter their behaviour. Older pedestrians may be able to sustain overall levels of task performance through compensatory behaviour. In the previous section, we noted differences in older pedestrians' road behaviour that may reflect increased caution or attempts to compensate. For example, they look for longer gaps before crossing, and appear to be more cautious or deliberate at the kerb before crossing. They also make more head turns while crossing.

As noted in section 1.3.3, older people travel less. Ward et al. (1994) reported that the number of trips, and distance walked were lower among older people. This could be because they feel that their functional impairments require conservative behaviour. Mukai (1992; cited in Mori and Mizohata, 1995) reported that older pedestrians in Japan reduced trips on foot as their awareness of their own functional impairment increased. The household survey reported by Atkins (2001) found that people over 80 were more likely than others to attribute reduced mobility to their own problems with physical movement and sensory decline. Alternatively, it could be simply due to different patterns of activity. Older people do make fewer work and education-related trips than younger adults (Maring, 1972; Noble, 2000).

Compensatory mechanisms are central to one theory of ageing, which emphasises that older people have a reserve capacity, giving them the potential to change patterns of behaviour (Baltes, 1997; Baltes and Baltes, 1990). The theory of selection, optimisation and compensation (SOC) endeavours to explain behavioural changes in ageing in general as the outcome of compensatory processes, which may be more or less successful. SOC claims that individuals maximise their potential gains and minimise potential losses by the adaptive selection of goals and optimisation of their route towards selected goals. According to the theory, when losses or declines occur (e.g. in illness, disability or old age) individuals search for ways to compensate and still maintain their goals. For example, the older person who finds that they can no longer walk to the shops looks for other ways to get there. Li et al. (2001), in a study discussed below, provided evidence of these processes at work in a walking task. The process by which people alter the priority of their goals is termed "loss-based selection", and occurs more as the ability to cope safely in an environment declines.

Mitchell (2000) argued that the increase in accidents to older road users is not as high as one might expect given their frailty. Holland (2001) suggested that older drivers compensate for impaired perceptuo-motor function by adapting their traffic behaviour, and also by using cognitive resources still available to them to maintain low risk. There are two reasons why older pedestrians might not be able to do the same. First, many older pedestrians may have given up driving because of eyesight, health or cognitive difficulties. Second, areas of competence that change with age may affect the pedestrian task to a greater extent, namely hearing, balance and walking difficulties. Thus, more compensation may be needed, and there may be fewer spare resources.

It is not always straightforward to interpret research on pedestrian behaviour in terms of awareness of impairment or strategies to compensate, for reasons we discussed in the last section. In this section, we review work that more directly addresses awareness and compensation. Three key issues are: first, whether older people's beliefs about changing capacity are accurate; second, whether they alter behaviour in response; and third, whether their attempts to compensate for reduced performance are successful. For example, the changes made by the older old, in particular, may not be large enough to maintain safety margins. In a simulation study, older old pedestrians accepted gaps more rarely, but still accepted gaps they could not have crossed at a hurried walking speed (Oxley et al., 1999).

6.1 Physical mobility and walking

Carthy et al. (1995) found in a survey that many older pedestrians reported when asked that their balance was substantially worse than when they were younger. For females, the proportion saying this was 29% for 65–74 year olds, and about 50% for the over 75s. For males, the figures were 17% and 41%, respectively.

Although there has been little research directly on older pedestrians, some work on the physical movement and propensity to fall of older people is relevant. Sometimes older people make adjustments to their movements that anticipate future problems. Fried et al. (2000) reported that older old women who reported making adjustments in the way they tackled walking tasks because of health problems were most likely to develop problems in completing those tasks 18 months later. The changes had occurred prior to the emergence of observed physical mobility difficulties. Hughes and Schenkman (1996) analysed changes in movement adopted by older people with moderate physical mobility problems. They found that, in rising from lower chairs, the older people altered their pattern of movement, giving priority to stability. This is analogous to the more conservative driving style of older drivers reported by Mori and Mizohata (1995).

Li et al. (2001) gave older adults both a cognitive (word list learning) and a tricky walking task at the same time. The walking task involved following a track and negotiating obstacles, and performance was measured in detail. Older people were able to maintain walking performance in the dual-task setting relatively well, but at the expense of the cognitive task. When they were offered aids, such as a hand rail for walking, or a tape loop for remembering, they prioritised walking and balance. For older people, performance on the cognitive task did decline more in the dual-task condition (i.e. the dual-task cost was greater). This pattern was in contrast to younger people, who seemed to prioritise the remembering task. Li et al.'s analysis was that, because the consequences of falling are greater for older people, and walking has become more difficult, more of their cognitive resources are devoted to this task, leaving fewer for other cognitive tasks. They interpreted their findings in terms of the SOC model described above.

There are, in addition, studies showing that older people's assessment of their risk of falling is realistic. Deery et al. (2000) found that participants (all over 60 years old) who reported that they were concerned about the likelihood of falls over the next few years were three times more likely than their peers to have experienced a fall at follow-up 12 months later. This suggests that their beliefs were accurate. The researchers did not report any age difference in this relationship. Vellas et al. (1997) found that, of those older people who had falls during their two-year study, the ones who developed a fear of falling again had had the greatest problems with balance and gait at the start of the investigation. They had also experienced larger increases in such problems during the course of the study. That is, their fear corresponded with their degree of functional impairment.

These studies show that older people are at some level aware of declining mobility, and that their self-reports are valid indicators even of future problems. They do try to compensate, and the evidence is that they become more conservative in their movement patterns (see also section 2.3.2 above), giving priority to the goal of stability. To the extent that the SOC model is correct, some of this compensation draws on cognitive resources that are themselves limited.

6.2 Awareness of perceptual decline

Older drivers generally tend to avoid driving at night, in heavy traffic, in conditions of reduced visibility such as fog, and alone (Hennessy, 1995; Planek et al., 1968; Schlag, 1993). They can do this, in part, because they tend to have fewer constraints on when they must travel than younger adults (Ball et al., 1998; Noble, 2000). However, some studies have shown specific links with visual impairment. For example, as drivers' contrast sensitivity and difficulty adjusting to glare increases, they reduce night driving (Planek et al., 1968; Schlag, 1993). Nevertheless, older drivers with visual and cognitive impairment can still have a higher accident risk, even though they report modifying their behaviour (Ball et al., 1993; Owsley et al., 1991). Thus, even if people believe they have problems, and try to adjust for them, they may not succeed in compensating.

Holland and Rabbitt (1992) asked older people about their pedestrian activity, and looked for relationships with self-assessed vision and hearing. People who felt that their hearing had deteriorated in the past 10 years were more likely to say that they avoided walking along roads without pavements than other groups. Older pedestrians generally reported avoiding going out in the dark and in bad weather. Older people who felt their eyesight had deteriorated in the past 10 years reported that they had made no changes to their pedestrian behaviour because of it. However, in separate questions they did say that they avoided crossing busy roads at night. Similarly, although people who said they had difficulties seeing in the dark or at dusk did not say they avoided crossing the road at night, they were more likely to say they avoided crossing the road without pedestrian crossings and walking along roads that had no pavements, than other groups. Thus, the pedestrians did not consciously connect their behaviour to difficulties they might experience with vision or hearing. Bailey et al. (1992) reported survey results indicating that older pedestrians, aged over 56, in Orlando, Florida, avoided crossing roads at peak traffic times, at dusk, or at night.

Spackman (1986) surveyed 100 older people. Seven reported that their eyesight, and four that their hearing, made crossing roads difficult. More than half had spectacles for seeing at a distance, and 89% said they always wore them when crossing roads. Holland and Rabbitt (1992) found that many older people with poor visual acuity had distance spectacles, but were not aware that they ought to wear them for crossing roads or driving. Spackman's data were gathered in the context of a road safety survey rather than during vision testing, which may account for the different levels of appropriate behaviour reported.

Although Holland and Rabbitt (1992) found no age differences in self-reports of vision and hearing difficulties, and no significant correlation between self-reports and objective measures for vision, their research did contain some findings that suggest older people may have awareness of some perceptual problems. First, they found that there was a good correlation between self-reports of hearing problems and objectively measured difficulties. Second, the correlation for vision among pedestrians who did not drive ($r = -0.34$) was of a similar magnitude to the one for hearing. It may have not reached significance just because of the low sample size ($n = 14$). It is also possible that the method used for scoring problems with vision may have attenuated the correlation.

Kosnik et al. (1988) used a self-report questionnaire to ask older people questions about visual difficulties. A range of questions was asked to assess their experience of different kinds of problem with vision. For example, they asked people whether they had difficulty reading small print to assess their near vision. They used factor analysis to validate the questionnaire, and compared the scores derived from this for different age groups. Several aspects of visual function were associated with increasing awareness of problems among older people, although the rate of increase was not the same for all types of problem. Kosnik et al. argued that these were aspects independently known to show objective decline in older populations. Older people were therefore shown to be aware of visual impairments they would be expected to have. A key aspect of this result is that participants were not asked directly about the aspects of vision. Rather, they were asked about everyday experience of difficulties. For example, they were not asked "are you getting more short-sighted", but "do you have problems reading small print". This is not, therefore, evidence for transparent knowledge of their own visual capacity, but for a correspondence with their experience.

The participants in the study by Holland and Rabbitt (1992) received feedback from an expert on their peripheral vision and their visual acuity in various lighting conditions, and two-thirds reported then making changes to their road-use behaviour. For example, they reported reducing their driving at night, wearing their spectacles, and checking for road users in the periphery of their vision. Importantly, those who had made such adjustments to their driving on their own initiative were significantly less likely to have experienced an accident in the previous three years. Owsley et al. (1991) reported that older drivers in the Jefferson sample who had received an eye problem diagnosis were more likely to steer clear of difficult driving situations. Thus self-testing, or greater useful feedback in professional testing, could be helpful.

One possible explanation for a link between experience of visual difficulties and moderation of driving could lie in people's knowledge of minimum vision requirements for driver licensing. Some states in the USA, such as Illinois, issue daytime-only driving licences according to the severity of visual impairment (Staplin et al., 2001), and it could be that such schemes highlight particular hazards even to those with unrestricted licences.

Kline et al. (1992) found that older drivers who rated their visual ability as poor were more likely to report that they were sometimes "surprised" by other vehicles when merging with traffic, and that other vehicles appeared unexpectedly in their peripheral vision. As noted already, a large proportion of pedestrian casualties of all ages report that they did not see the vehicle that hit them (Sheppard and Pattinson, 1986), and so poorer detection of vehicles in peripheral vision is relevant to safety.

In summary, some evidence suggests that older people have reduced awareness of decreasing perceptual function. For example, Holland and Rabbitt (1992) found no difference in the level of self-report between older and younger participants, and Lutman (1989) reported paradoxically lower self-reports of deafness among older people. On the other hand, other studies have found close links between self-reported problems and problems older people would be expected to have (Kosnik et al., 1988), and several investigations have found that experience of difficulty with vision can contribute to people's decisions to alter driving activity. Awareness of visual problems does not imply an understanding of the biological or psychological mechanisms that are affected. It appears that, when relevant environmental feedback is available, older people can recognise at some level that they have perceptual problems. Kosnik et al.'s demonstration of awareness relied on questions about everyday activities, but feedback from other people, as well as everyday experience, can be effective (e.g. Holland and Rabbitt, 1992). However, there is no clear evidence that individual self-reports are veridical.

6.3 Awareness of cognitive processes

Many studies have examined older people's self-reports of problems with memory and other cognitive lapses, and the results suggest a complex relationship between their beliefs and their functional performance. In this subsection, we begin by reviewing studies that have looked at awareness of declining visual attention. Some of these examine both perceptual and attentional measures, allowing comparison with the findings of the previous subsection.

Ball et al. (1998) revisited the Jefferson sample to examine the relationship between objectively measured functional impairment and driving patterns. Because most older drivers reported avoiding driving at night, it was not possible to gauge any link to impairment. However, avoiding driving at speed or in busy traffic correlated with objectively measured impairment of vision, visual attention (UFOV), and a measure of general cognitive function. Those who were impaired also reported driving fewer times in a week. Drivers with cataract problems were more likely than those without eye disease to avoid busy or fast traffic, and driving in rain or alone (see also Marottoli et al., 1993). Older drivers with functional impairment were thus more likely to change driving behaviour, but as Ball et al. point out, given the design of the study, it is not possible to say that the impairment directly led to avoidance.

Ball et al. (1998) also looked at relationships with accidents. They looked at accident records for the five years prior to assessment, and three subsequent years. Those who had experienced crashes in the previous five years were more likely to avoid driving in the rain, or in rush hour, and to avoid turns that involved crossing a traffic stream (i.e. left turns). This last point is interesting in the light of data that intersections are especially risky for older drivers (section 4.1). It could reflect accurate awareness of increased vulnerability and judgement of a particular source of risk, or because the accident history would often have involved intersection collisions, it may arise from a simpler mechanism of avoiding the specific situation that caused a previous accident. For subsequent accidents, there was no relationship with avoidance. Ball et al. pointed out that of the many in their sample who stopped driving altogether before the end of the three years, most had substantial functional impairment. This would have made it harder to detect a statistical link. Nevertheless, this study provides no direct evidence that the adjustments made by older drivers were effective in reducing accident risk.

Ball et al. (1998) did find a weak indication that older drivers with general cognitive impairment did not have as much insight into their difficulty as those with more specifically visual problems, for whom there was a closer match between degree of impairment and level of avoidance. Dubinsky et al. (1992) linked a lack of awareness of driving impairment to cognitive decline. Cognitive impairment certainly does increase risk for drivers. AD is associated with an increased risk of fatality among older drivers (e.g. Johansson et al., 1997). Lundberg and Hakamies-Blomqvist (1998) compared older drivers with a history of at-fault crashes to other older drivers and found they did less well on tests of visuo-spatial memory, emphasising the relevance of subtle cognitive changes that may go unnoticed. Given that pedestrians have to deal with aspects of the same road environment as drivers, we would also expect cognitive decline to affect their safety.

In relation to cognitive problems, there is other evidence of a relative lack of insight. Rabbitt (1990) showed that whereas older people may be aware that reaction times slow with increasing age, they may not be aware of the extent to which their own reaction time has slowed, or of their errors in such reaction time tasks. Spackman (1986) reported that of the 27 older drivers in her survey, with an average age of 67 years, all believed they could concentrate on traffic as well as ever. Rabbitt et al. (1996) found that older drivers were typically unaware of problems identified by qualified instructors observing them, such as speed and distance judgements. In general, the evidence that visual attention problems (e.g. as measured by UFOV, see section 2) are associated with higher accident risk among drivers implies that drivers are either unaware of or unable to compensate for such deficiencies. Ball and Owsley (1993, Jefferson sample) looked at a subset (14 people) who had poor UFOV scores, yet few crashes, and so appeared to be successfully compensating. On further investigation, they found that 10 of them also had poor eye health. They also found that those with poor eye health reported greater avoidance of difficult driving situations. Ball and Owsley (1993) speculated that perhaps these older drivers did not pick up their problems with attention but were aware of eye problems, which led them to regulate their driving.

McGwinn et al. (1998) asked drivers about their accidents over the past five years, and found that those who failed to report accidents that were recorded in official accident records also tended to have lower functional levels of contrast sensitivity and peripheral field sensitivity.

Mori and Mizohata (1995), reviewing several Japanese studies, found that older people who had stopped driving did not give functional impairment as a reason. In fact, they were more likely to stop driving if they lost access to parking space near home. Atkins (2001) also reported that 52% of older drivers surveyed in the UK gave parking as a particular difficulty, more than speed of traffic (15%), restrictions in their own physical movement (5%), or slowed response speed (4%). However, Mori and Mizohata observed that older drivers drove more slowly, and adopted a lane position further from other cars, suggesting that their driving style was more conservative. Indeed, greater age was associated with cessation, and Mori and Mizohata interpreted age as a proxy for increased “uneasiness” (p. 398). They concluded that older drivers, who estimated a younger age to cease driving for others than themselves, tried to compensate but either did not recognise, or were unwilling to act fully on, functional changes, resulting in an elevated accident risk. Mathey (1983b), discussing older German drivers reported similar changes in driving style, and a recent UK survey found that four in five older drivers preferred to avoid driving long distances, at night, in bad weather, or in town centres (Atkins, 2001).

Lyman et al. (2001) studied driving habits among a large sample of older drivers in Mobile County, Alabama, and their relationship with the amount of driving and self-reported difficulty driving. For vision, cataracts and visual impairment were associated with less driving, but only poor near vision was associated with significantly more self-reported difficulty. This suggests that some drivers were compensating for problems they were not aware of, or at least did not report. Other medical conditions, like stroke or kidney problems, were also associated with more experience of difficulty. These particular conditions are likely to produce highly noticeable symptoms. For cognitive impairment, there was no link with reported difficulty, and only a non-significantly increased likelihood of having a low annual mileage. These data are consistent with the conclusion that normally ageing older people become aware of some functional changes, but perhaps not all.

Cognitive functions such as planning and executive control are obviously important in the road environment, and we would expect impairment to affect skill. A laboratory study by Brouwer et al. (1988) illustrated this. In a simulator, they found that older drivers could compensate for the effect of a sidewind, but could not adjust for such strong sidewinds as middle-aged drivers. Older drivers with better scores on laboratory measures of executive skills (e.g. planning and reasoning) and information processing speed adjusted best.

Tun and Wingfield (1995) gave older people (60–91 years) a questionnaire asking about experiences of difficulty carrying out different kinds of dual-task activity in everyday life, such as walking while doing housework. Reported difficulty increased with age, particularly for activities in which a sustained attention task had to be combined with another task, such as looking for a sign while driving. Unfortunately, there was no direct test of actual performance. Tun and Wingfield suggested that the self-ratings reflected participants' confidence in their ability to perform these tasks.

Some research on self-report of age-related changes in cognitive function has found that there is a peak of complaints in the 50s. People in their 60s and beyond, who one would expect to have more problems, paradoxically report fewer difficulties in their everyday absent-mindedness and memory lapses (Rabbitt and Abson, 1990). Rabbitt and Abson suggested that this is because the older old have fewer comparisons with the young and fewer opportunities for observing discrepancies between self-assessed and actual levels of competence. In addition, they may be making comparative judgements against their own performance in the remembered past, or with their beliefs about the capabilities of their contemporaries. In general, people can only make a relative judgement. Furthermore, information processing declines may make older people less able to monitor performance, less aware of mistakes, and less able to remember making them (Rabbitt, 1990).

Rabbitt et al. (1995) investigated the validity of older people's self-reports. They were particularly concerned with questionnaires designed to assess cognitive problems, such as the Cognitive Failures Questionnaire (CFQ). They concluded, having reviewed several reports showing moderate correlations between CFQ scores and measures of depression, that in fact CFQ scores reflected a mixture of effects. They speculated, consistent with a view attributed to Donald Broadbent, that poor CFQ responses were to a degree determined by feelings resulting from depression. According to this view, depression also directly affects cognitive performance, possibly because of its effect on selective attention. Thus, older people report cognitive difficulties because of feelings of depression rather than direct awareness of cognitive difficulties, but the reports may be valid because the depression also impairs cognition.

6.4 Summary

Changes that are obvious and have a transparent link with performance are more likely to be acted on appropriately. Explicit feedback from a professional, such as an eye specialist, prompts behaviour change in this way. Some adjustment to behaviour may occur without conscious awareness, there being some evidence for this in relation to the patterning of complex motor skills and driving style, and possibly in relation to night time travel. In general, older people say that they cut back on driving because of problems with vision, other health problems, discomfort, and loss of confidence (Lyman et al., 2001). However, even when the changes they do make should at face value reduce accident risk, there is little firm evidence that they are effective in doing so. Indeed, some changes in road-crossing strategy, such as taking a two-lane road one lane at a time, may increase the risk of an accident. Older people may not notice their own cognitive impairment, and evidence from research on driving accidents implies that older people with cognitive impairment are often victims.

According to the SOC model, age-related performance decrement results when the capacity to compensate is exhausted, and this capacity itself declines with age (Baltes and Baltes, 1990). The SOC model also emphasises the variability of individual older people's capacity to compensate, and the need, therefore, to provide support that is tuned to their differing needs. Indeed, even if older pedestrians did manage to compensate for functional impairment fully, and maintained the low accident rate of middle-aged pedestrians, they would still experience more fatalities and serious injuries because of their increasing fragility. We discuss intervention in the next section. Some key points from this section are:

- Research suggests that older people's beliefs about impaired abilities can be accurate when they have good environmental feedback. However, for cognitive changes especially, the evidence is that awareness of impairment is poor in many cases.

- Older people are relatively unlikely to have good insight into the abilities, particularly attentional and cognitive skills, most relevant to accident risk.
- Although older people do try to compensate for difficulties, there is no clear evidence that they successfully reduce accident risk.
- Some compensatory mechanisms operate without conscious awareness, and so would not in theory require executive resources. However, there is evidence that even tasks like walking absorb more of the available cognitive resources than in younger adults. Because of this, and a reduction in executive resources in older people, ability to compensate in acute situations is compromised.
- Specific high-risk groups would be expected to be particularly affected on theoretical grounds. Older people with abnormal cognitive impairment will have reduced insight into their own difficulties, compromising their ability to compensate. Also, slow walkers may be relying more heavily on cognitive resources to maintain balance, negotiate obstacles, and so on, reducing the availability of resources for compensation.
- Older people have been shown to be able to prioritise resources to optimise performance on key tasks such as balance. Nevertheless, for many older old people, capacity for compensation through planning or cognitive effort reduces at the same time as increasing functional decline creates greater demand for attentional control.

6.5 Research implications

It may be that drivers are more aware of impairment because the driving task provides clear feedback on performance difficulties. It would be useful to know whether the level of awareness differs between drivers and non-drivers.

Researchers have hypothesised that older people may not be aware of functional problems because they are less able to process or remember the errors or other sources of feedback that would create this awareness. It would be useful to have direct evidence for this. Similarly, evidence is lacking on the capacity of older people to make plans and strategic changes in response to information on functional impairment or road safety advice.

Further research is needed to evaluate the most effective sources of feedback found in the everyday environment, and to identify key skills for which good feedback is not usually available. Subsequently, interventions could be developed that help older people to gain awareness of these difficulties.

There is a complete lack of research on individual differences in relation to awareness of problems and decisions to modify behaviour. Lincoln and Radford (1999) pointed out that people with PD often give up driving voluntarily, but speculated that some may make over-conservative decisions, whereas others may continue driving for too long. People are not all the same. To optimise the mobility of older people, it may be important to be able to characterise individual differences of this kind.

Little is known about the prevalence of cognitive impairment among older pedestrian accident victims, although a good deal of work has been done on older drivers. Knowledge about these patterns is a prerequisite for identifying appropriate compensatory steps or other interventions.

An important area for further work is how older people respond to situations in which a rapid response to quickly changing circumstances becomes necessary. According to various accounts of cognitive ageing, the capacity to respond effectively is probably poorer for older people. Some relevant studies were reviewed in section 2.4, but we lack a clear understanding of how people with physical impairment and declining cognitive resources cope with crises. Keall (1995) also called for research on this issue.

7 INTERVENTION

Interventions can be made to improve mobility and to modify accident risk. In this section we review the literature to identify best current practice. As in previous sections, we have supplemented published work on older pedestrians with material from related topics such as child pedestrians when that has helped to complete the picture. We have also identified implications for intervention from the preceding reviews of functional impairment, awareness and compensation, and pedestrian risk. Oxley and Fildes (1999) provided a good earlier review of these issues.

Intervention takes many forms, and theorists have identified a number of types (Anderson and Menckel, 1995). In relation to traffic injury prevention, it is widely understood that intervention can involve the several elements participating in the system. These include the road user, the design of the road environment, and so on. One framework, provided by Haddon (1974), cross-classifies the elements in a situation, such as the pedestrian and the car, at each period in time, before, during, and after a possible accident. This matrix identifies points at which intervention could be made. Among other things, an approach like this, which distinguishes relevant phases of intervention, clarifies the distinction between preventing accidents and moderating consequences through injury prevention. Some other distinctions are relevant. Intervention can be active or passive (e.g. Andersson and Menckel, 1995; Haddon, 1974) from the point of view of a particular element. In the following discussion, active interventions are ones that require the older pedestrian to initiate action themselves, whereas passive ones do not. For example, re-engineering the road environment would be passive from the point of view of an older pedestrian. As noted by Andersson and Menckel (1995), this is a graded distinction because interventions can be active to varying degrees. A related distinction made by Andersson and Menckel identifies the agent or level of intervention, which can be individual, organisational or societal (or individual, community, and national). Finally, interventions can be top-down, with an authority taking responsibility and imposing a solution, or bottom-up, with individual citizens taking the lead. Of course, these are poles of a continuum.

The road environment is a system with human users. National policies to reduce death and injury on the roads implicitly or explicitly combine approaches addressing road users and the road environment through education campaigns, applying regulation, and setting standards for road engineering. Recently, some countries have made an effort to systematically articulate approaches exploring relationships between these elements. Here, we review the intervention literature using the conceptual distinctions outlined as an organising framework, distinguishing interventions addressed to the individual older person, other road users, and the road environment. We consider especially the appropriate balance between active and passive intervention. We go on to consider approaches to implementing intervention, giving special attention to community and bottom-up aspects. The section concludes with a brief discussion of evaluation.

Interventions generally require resources, and as resources are limited, proposals compete. Various factors affect allocation and, at least since the 1950s in the UK, some form of cost–benefit analysis has been used to clarify the relationship between alternatives and thereby assist decision-making (Elvik, 1995). Two important factors are the range of costs and benefits included, and the values given to items such as the loss of a life. Interventions have to justify their cost in the face of alternative opportunities for spending, and we now briefly summarise some of the key issues in relation to the older pedestrian.

Various methods exist for valuing a traffic fatality (Elvik, 1995). Older people, whose expected future economic contribution is lower because they retire, potentially fare badly in such analyses, especially those based on a human capital approach. Charness and Bosman (1992) made this point in relation to a hypothetical example of extending crossing time at signalled crossings by 3s. Making a similar point to Hauer (1988), they noted that the cost of delay to drivers may outweigh the economic cost of accidents. Even willingness-to-pay methods such as those currently used in the UK (Elvik, 1995), which tend to lead to higher valuations being placed on a life, may need to be tuned for older people. The requirements of the older old, or those suffering degenerative conditions, for example, might otherwise not be accorded sufficient weight. There are significant social, political and ethical issues involved, as well as bluntly economic ones. Elvik (1995) notes that differences in the value of a life across countries legitimately reflect different preferences as well as different levels of national wealth. One implication, however, is that interventions that also benefit other segments of the community, such as area speed restrictions or upgrading crossings, are likely to be easier to justify.

Elvik (2000) discusses the range of impacts of particular relevance to pedestrians that might be considered in a cost–benefit analysis. The generalised cost should include, he suggests, such things as changing levels of traffic noise, pollution, and feelings of security experienced by road users. On plausible assumptions about costs and benefits for illustrative examples, such as providing signals at pedestrian crossings, he shows that such factors could be critical in evaluating interventions. The difficulty, as Elvik points out, lies in attaching a value to a subjective impact like feelings of insecurity. Assessing this fairly is complicated by the observation that perceived security may not correlate well with objective safety. Elvik gives the roundabout as an example of an intervention that reduces accident frequency, for pedestrians as well as vehicles (see also Dijkstra and Bos, 1997), but which makes road users feel less secure.

One argument for focusing resources on helping older pedestrians is that their fatality risk in pedestrian accidents is relatively high. Foot et al. (1982, Table 1.2) presented data that give an interesting, and provocative, perspective on this risk.

Although older people are more likely to die in a given pedestrian accident, pedestrian fatalities are a small proportion of deaths from all causes in this age group. They reported that, as a proportion of all fatalities in a given age group, pedestrian deaths were 100 times greater for children between five and nine years old than for people over 60. For children, pedestrian fatalities accounted for one in five fatalities; for the over 60s, just one in 500. These UK data were from 1978, but there is a similar pattern in, for example, Austrian data for all accidental deaths in 1998 (Unfallstatistik, 1999, Table 1.1.3). Brown (1991) records that in the UK in 1990 road deaths formed 23% of accidental deaths and less than 1% of all deaths for the over 65s, compared to 69% and 28%, respectively, for those aged 20–24 years. This highlights the importance of relative priorities. For older people, pedestrian accidents account for a lower proportion of overall mortality.

Vision Zero is an alternative approach based on the ethical premise that no toll of human life ought to be exchanged for increased mobility (Tingvall, 1997). Tingvall and Haworth (1999) described the principles as implying a shared responsibility between the road user and the system designer. This framework aims to guarantee users of the transport system that if they comply with certain basic regulations, they will never be killed or seriously injured. Elvik (1999) questioned the validity of this position by costing the resources required to achieve the target, and arguing that the loss of those resources to other parts of the economy would lead to greater countervailing loss of life. Vision Zero has been adopted in Sweden (Tingvall, 1998) and Denmark (PROMISING, 2001). However, recent accident data from Sweden indicate that progress towards the ultimate goal is not good. The concept of sustainable safety developed in the Netherlands places similar emphasis on user-centred system design (PROMISING, 2001), and it may be this that is the most important aspect of Vision Zero.

When evaluating interventions, there are then two components that must be satisfied. The first is to establish practical effectiveness: the intervention works as intended, is acceptable to users, and produces measurable benefits. For the second component, however, it is necessary to weigh the cost of implementation against competing opportunities. The first component is a matter of science and engineering, and can be informed by a range of disciplines. The second can also be assisted technically, as illustrated in detail by the report of working group 5 in the PROMISING project (PROMISING, 2001). But this component involves judgements about values and value, to which the entire community can contribute. In what follows, we focus on the first component.

7.1 Older pedestrians

In the pre-accident phase, a number of interventions are possible. Mitchell (2000) argued that older people should be encouraged to drive, or be driven, for as long as possible, because this is safer than becoming full-time pedestrians. The more older people rely only on walking for mobility, the more limited and less safe their travel will be. Mathey (1983b) advocated developing car design to help this, a course also suggested by OECD (2001). Older people themselves often mention that better car parking facilities would be beneficial (Savill and Chinn, 1993; and see section 6.3 above). For older people who can no longer drive, public transport and special services like “dial-a-ride” and “shopmobility” in the UK can help reduce exposure to accident risk while maintaining mobility (Atkins, 2001). Car-sharing schemes are another option that may be attractive to those older people whose decision to stop driving is determined by financial considerations. A potential added advantage of communal schemes is that they offer social contact within themselves. Although costly, such services are desired by older people (Atkins, 2001).

Nearly every older person is a pedestrian, and part of most journeys takes place on foot, even when that is not the primary mode of transport. Interventions can prepare older people for the particular difficulties they may face as pedestrians, and can assist them to cope. These interventions are directed at increasing knowledge, at physical preparation, such as improving general fitness, and at practical training. The literature search found work with older people related to fall prevention, and as fall prevention is a component of pedestrian safety we have also looked at that.

7.1.1 Information for older pedestrians

A traditional approach to safety is to provide information to potential victims to improve their ability to cope with the hazard. Van Wolffelaar (1988; cited in Hummel, 1999) recommended that older pedestrians should be given information to improve their understanding of traffic and their own skills, but also information about the ageing process and ways to adapt to its effects. Preusser and Blomberg (1987) described a methodology for implementing public education programmes. They identified two key pieces of information for adult pedestrians relating to two characteristic accident scenarios. To avoid accidents in which the vehicle is turning, and so the driver has multiple demands on attention, pedestrians should “Look at the driver, not just the car. The car won’t stop unless the driver sees you” (pp. 121–122). To avoid accidents in which a vehicle in one lane has stopped to allow a pedestrian to cross, but a second vehicle passes it, pedestrians should “Stop at the outside edge of the stopped car and look for what might be coming in the next lane” (p. 122). This was tested using public service broadcasts in two cities in California, and Preusser and Blomberg report a degree of success in getting the message understood and reducing accidents. However, measured success was limited to the Spanish version of the campaign, and an estimate of an 18% reduction in vehicle turning accidents was based on accidents involving drivers or pedestrians who had “Spanish” surnames.

Sheppard and Valentine (1979) surveyed Road Safety Officers (RSOs) in the UK, who deliver road safety information within local areas, to find out what information or training was offered to older road users. In 1977, 80% had provided activities specifically for older pedestrians. Mostly this consisted of information disseminated through talks or leaflets, and often information focused on new facilities such as pelican crossings. RSOs said problems with vision and hearing, ability to assess speed and distance, cognitive declines such as lack of concentration, and lack of mobility were important issues for older pedestrians. However, over a third mentioned the capacity or willingness of older people to adapt to the traffic environment. About a quarter said it was difficult to communicate with older people for reasons such as lack of resources or a sense that older people did not respond to the message. Commitment of resources was strongest in areas with the highest casualty rates for older pedestrians.

A second survey examined the relative priority that should be given to different kinds of information (Sheppard and Valentine, 1980). Most of the 58 items on Sheppard and Valentine's checklist were rated by RSOs as being at least important. Items rated particularly highly included wearing spectacles if you need them, stopping before crossing, and monitoring the behaviour of vehicles before stepping out at zebra or pelican crossings, with at least 66% saying these were essential. In contrast, less than 50% thought it was essential to advise older people to check whether a nearby parked car might move off or reverse, and only 13% to avoid going out when snow and ice was about. Still, a further 64% thought that advising older pedestrians to avoid ice and snow was important or very important. Sheppard and Valentine also gathered RSOs' views on which advice was most likely to be adopted by older people, with the most typical response across items being "some older people will adopt this". Sheppard and Valentine pointed out the pragmatic value of selecting items for instruction that are likely to be adopted, but recognised that some items might be seen as so important extra effort might need to be made to convey them. In addition, of course, we cannot simply assume that RSOs' predictions would be correct. Sheppard and Valentine distilled an ordered list of 31 items that they recommended for instruction of older pedestrians. Their items were all related to the act of road crossing.

Sheppard et al. (1988) evaluated a range of training materials designed to help older people understand pelican crossings, from leaflets to a half-size model of a crossing that allowed an element of practical training. Different groups of older people were given presentations of each resource, and their knowledge of the crossing was tested by a short questionnaire given before and after training. There was no significant improvement. Sheppard et al. also described the development of a talk for older people illustrating several different pedestrian hazards encountered on a shopping trip. Knowledge was again assessed by a questionnaire, and scores were high, but there was no control group and so it is difficult to draw a conclusion from the data.

Katz (1991) described an evaluation of older people's response to two safety campaigns in Israel. The "Golden word for safety" campaign encouraged trained volunteers to approach pedestrians who behaved unsafely and give them appropriate advice. One aim was to establish a norm that pedestrians generally could advise one another in this way. Evaluation was done through a survey of over 1,000 pedestrians, 240 of whom were 65 years old or older. Overall, there was good memory for the campaign message several weeks later, and accidents fell by 10% during the campaign. However, accident reduction was not maintained. Older people were less likely than other adults to be aware of the campaign message (79% versus 89% for 16–60 year olds). Factual information about accident rates was broadcast throughout the month-long campaign. The correct figures for deaths and injuries were only remembered by 36% and 18%, respectively, of older people, but these levels were higher than for younger adults (26% for fatalities, 15% for injuries). Only 19% of older people (60+) expected that their own behaviour would improve as a result of the campaign, compared to 33% of younger people, but 66% of older people did think that others would improve their behaviour.

The second campaign reviewed by Katz (1991) was a scheme piloted in one town to encourage pedestrians to wave a flag towards motorists as they crossed. Although slightly better disposed to this than other age groups, a third of older people surveyed (65+ years, n = 94) indicated that they were not inclined to use the flag. Only 42% understood this part of the campaign, compared to 60% of 19–64 year olds. In practice, 10% of older people did use the flags, compared to 6% of other adults. Observations of crossing behaviour found no overall reduction in pedestrian–vehicle conflicts, although separate figures for older pedestrians were not reported. These evaluations suggest that older people may become aware of a campaign and broadly understand its themes. They may also be more prepared to acquiesce than younger adults, but a large proportion may not understand in detail specifically what they are expected to do. There was no evidence of a lasting effect on accident rates for any age group.

In the UK, a programme called “Defensive Walking” was published (HMSO, 1990), and in 1991 a Government campaign was launched. Defensive Walking gave information through video and flashcards on seven road safety principles, such as checking whether drivers are doing what is anticipated, and planning trips in advance to reduce the number of roads crossed. We found no formal evaluation, but the programme has been criticised for its emphasis on caution, for possibly creating anxiety, and for its focus on information rather than practical training (Carthy et al., 1995). Help the Aged produce a “Keeping Mobile” leaflet aimed at older people, with advice, mainly on fitness and related factors, and contact points for organisations providing services (e.g. on age or health-adapted fitness instruction), but with no safety advice for older people as pedestrians. A survey of overseas information (English language) yielded a similar pattern, with the exception of sources from the USA, where there was much more available.

A useful resource is the FHWA Pedestrian Safety Toolkit, a catalogue of materials to support interventions, covering phases such as initiation, gathering support, implementation, and law enforcement strategies (NHTSA, 1999). These materials include a booklet and video targeted at older pedestrians that identifies risks and suggests strategies to avoid accidents, including hazards in car parks. Another video aimed at older pedestrians includes information about coping in different traffic situations, improving visibility, and problems with medicine or alcohol affecting judgement.

An interesting example of these materials is the “Walk Alert Pedestrian Safety Program” (National Safety Council, 1989) and described by Zegeer et al. (1994). Instead of concentrating on mobility issues such as fitness and preventing falls, this programme focused on specific messages for improving pedestrian behaviour among older people with printed leaflets, presentations at senior centres, public service announcements and other media outlets. The key advice came under six headings:

1. Proper search behaviour: always stop at the kerb, look left, then right, then left again (USA), keep looking and listening.
2. Being seen: bright clothing in daylight, retroreflective or white items at night.
3. Traffic signals: behaviour at crossings, meaning of flashing green man, use of button, checking for moving traffic even when green man is showing. Not stepping into road until traffic has stopped (e.g. on zebra crossings).
4. Vehicle breakdown: getting out carefully, pull off roadway, walk facing traffic, be seen.
5. Intersection crossing: check for turning vehicles, look for indicators.
6. Visual screens: crossing near parked cars, move forwards until a good view is available. Be aware vehicles may not see you.

Although there are many leaflet type campaigns, notably in the USA, few combine fitness and safety information. “Walking is for you” (Florida) does this, and appears well adapted for an older audience (e.g. emphasising the use of appropriate spectacles and hearing aids, watching out for reversing vehicles, taking care when taking certain medications). This leaflet emphasises benefits such as maintaining balance and mobility, and keeping in touch with neighbours. It also highlights the importance of walking for cardiac rehabilitation. However, evaluation is important.

OECD (1985) described evaluations of a number of information programmes in various countries for older road users, including some for pedestrians. Although in some cases there was evidence of improved knowledge, there was no evidence of an effect on safety.

Materials designed for children are easier to find, as are evaluations of the children’s understanding of them (Cohen and Preston, 1968). With materials designed for children, studies have shown that five to seven year olds do not understand verbal material completely (Groos, 1977) and can even have difficulty understanding posters (Colborne and Sheppard, 1966). Although, of course, one would not expect older pedestrians in general to have difficulty with everyday vocabulary, any materials being developed for educational interventions should be evaluated with representative groups during design (Sheppard and Valentine, 1979).

Deery et al. (2000) found that older people who attended presentations by peer educators on fall-related attitudes, knowledge and prevention behaviour, maintained greater knowledge of factors that can prevent falls 12 months later than a control group. They had also made more changes at home to prevent falls. However, a higher proportion of the trained group suffered falls themselves in the year following training. Interpretation of the results is difficult because the intervention group was self-selected and so may have had, on average, more reason to be concerned about falling than the control group at the outset, but there was no baseline difference in the self-reported number of falls or actions to prevent falling, and so this study suggests that increasing knowledge about prevention may not be effective.

Interestingly, Deery et al. (2000) found that of over 55s in their intervention group who were concerned about falling in the future, it was the younger ones who were more likely to improve safety in their home. This may be because they were more concerned, but perhaps because younger old people retain the energy or enthusiasm to make changes such as fitting a handrail. Changes made early, perhaps before there is a serious need for them, will be well learned by the time they are really needed in old age.

Information campaigns with older people should consider the application of psychological theory on the relationship between beliefs and actions. Social learning theory has been applied to the design of practical training for children (Thomson et al., 1997) and the Theory of Planned Behaviour has been applied to road safety information (Parker and Stradling, 2001). Evaluations have been carried out for some of these interventions, and some have been successful. However, not all have even shown improved knowledge compared to a control group (Evans and Norman, 2002). Further research is required to develop these approaches.

A particular issue for older people is whether they believe accidents can be prevented. A large telephone survey in the USA found that older people were less likely to believe that accidents were preventable (Girasek, 2001). According to psychological theory, this would tend to make them impervious to safety advice. Girasek noted that the current generation of older people may be objectively correct to believe accidents were less preventable. For example, they may have been more likely to have experienced war, during which individual people may have less control over aspects of personal safety. In addition, technological aids to safety have tended to increase preventability over time.

An interesting programme to persuade pedestrians to cross rail tracks using a footbridge at a suburban station in Auckland was described by Lobb et al. (2001). Local people were taught about crossing safety through talks at nearby factories and schools and a leaflet distribution. They were also reminded of the legal penalties. In addition, passive changes were made, making access to the track more difficult, and creating larger warning signs. Subsequent behaviour was observed, and surveys were carried out. Results were similar for older and younger adults. Self-reports indicated less track walking, but no change in awareness of safety or legal penalties. Observation confirmed that a larger proportion of adults used the bridge. In this study, there were improved outcomes without a change in knowledge.

Often conventional approaches (e.g. the Green Cross Code in the UK) emphasise strategies for simplifying the pedestrian task. For example, children are advised to avoid parked cars. Some more recent developments have recognised that children eventually do have to deal with complex situations, such as crossing at junctions and between parked cars (e.g. van Schagen and Rothengatter, 1986; Thomson et al., 1996) and have set out to teach children how to cope with difficulty rather than emphasising only how to avoid it. Some older people, perhaps living in urban areas, or visiting an unfamiliar town centre, may not be able to avoid complex situations. If that is the case, they will need ways to handle complex situations.

Owsley et al. (in press) describe the initial evaluation of a targeted intervention with older drivers known to have an accident risk because of visual impairment. Their work could provide an interesting model. In two one-to-one sessions with a health professional, the nature of their impairment and its impact on driving were discussed, and eight specimen dangerous driving situations were reviewed. In addition, strategies to cope with such situations were discussed. Although these drivers were more likely than controls to rate their eyesight as poor six months later, their ratings had not changed (self-ratings for the control group improved over the six-month period). However, self-regulatory behaviour, such as reducing driving, did increase in the experimental group only. This project is continuing, and the large sample size and randomised design mean that it has the potential to evaluate whether there is a direct link between the intervention and longer term crash risk.

The reviews in earlier sections have implications for advice that might be given to older pedestrians. We will not repeat the earlier material at length here, merely summarising key points. We develop ideas about training in the next section. Advice for older people with relevant medical conditions is dealt with in section 3.

There are some general considerations. First, different advice may be appropriate for different groups of older people. For example, a pedestrian in a high-risk group may need specific information and guidance (section 4), and different advice may be appropriate for different age groups. Second, aspects of advice may be difficult to follow in individual cases, and materials should allow for this. For example, older people living in cities may not be able to avoid complex junctions. Third, a balance must be struck between making people usefully aware of any difficulties they have, and increasing the insecurity they feel to the extent that they substantially reduce their mobility. Fourth, some items might be worked into more general advice for successfully adapting to older age, rather than necessarily being seen as relevant to pedestrian safety only. Fifth, importantly, because the connection with accident risk is not well established for some items, in those cases further research is needed before the advice can be regarded as definitive.

Here are specific pieces of advice that our review indicates would be useful to older pedestrians:

1. Information about specific functional declines that can occur, and their potential relevance to pedestrian behaviour, including the risk of falling, with advice on monitoring current performance levels (section 2).
2. Advice to garner explicit feedback on perceptual, cognitive, and motor performance, with information on understanding the difficulty of doing so, especially in relation to cognitive changes (section 6).
3. Advice on the importance of vision and hearing checks, along with an explanation of aspects that may not be evaluated in standard tests, such as dynamic acuity, with information that poor vision may compromise visual attention (section 2.2). MAVIS (1997) details contacts for older and disabled driver safety evaluation and screening which may be useful.
4. Advice to use appropriate spectacles and hearing aids in the road environment (sections 2.2, 6). Many older people have spectacles for reading as well as distance spectacles. Even simple strategies like labelling one pair for crossing roads and the other for reading may help.
5. Advice that they may be able to maintain performance through functional compensation, but compensation that engages their capacity for cognitive control may eventually compromise their ability to respond quickly to unexpected events.
6. Information on the role of physical well being and mobility in pedestrian safety, and the benefits of walking for health (section 2.3, 3, 4.4).
7. Guidance on ways to modify pedestrian activity to increase safety, highlighting situations that tend to be more difficult for older people, and suggesting strategies for coping with each. For example:
   - avoid complex road situations (section 2.1, 2.3) such as junctions (section 2.1, 2.2);
   - avoid high-speed roads (sections 4.1, 5.4);
   - use central refuges and crossings if available (sections 2.4, 5.4);
   - take special care on two-way roads (sections 2.3, 2.4, 5.4);
   - be conservative in gap judgements (section 5.4);
   - prefer crossing points where traffic movements are easily anticipated

(section 2.4), and where demands on peripheral vision are kept low, i.e. at places with long sight distances, away from junctions and drives (section 4.1);

- be deliberate and thorough in visual search, using head, neck and body movements, especially in poor lighting conditions (sections 2.2, 2.4.2);
- when crossing from a position that may make you less easy to see, for example between parked cars, walk to the edge of the obstacle and then check for traffic again;
- be aware of situations in which vehicles may make unusual movements, like changes of direction or reversing, especially when crossing or walking near driveways or parked cars (section 4.1);
- respect the right of way of vehicles in the roadway, and do not assume that they will slow down or avoid you (section 5.5).

8. Advice on when to seek additional support. For example, if an older person perceives that their walking speed is beginning to slow, or they are beginning to alter the way they tackle certain everyday movement tasks (sections 4.3, 6).
9. Advice on the effects of alcohol, medication, and specific medical conditions. On alcohol, we note that intervention aimed at younger people, among whom the problem is clearly serious, could be expected eventually to carry through to older people. Medical advice is probably most effectively disseminated by health professionals and specialist organisations like the Alzheimer's Society or Epilepsy Association in the UK.
10. Make yourself conspicuous.

Sheppard et al. (1988) presented 12 case studies of older pedestrians who had injury accidents. They asked these people to suggest advice they could give to others to help them avoid a similar accident. Although in some cases the advice was, naturally, relatively specific (e.g. "watch out for motorcycles", but see Road Research Laboratory (1963), Grime (1987) and McLean and Mackay (1972) for evidence that even this may be good general advice for older people), in fact it is striking how similar their list was to this one (Sheppard et al., 1988, Appendix D, p.18).

7.1.2 Training for older pedestrians

Training interventions concerned with balance, strength, and walking speed were reviewed in section 2.3.3 above. Training of attentional processes is discussed later in this section.

Practical training of pedestrian skills for older people does not seem to have been evaluated systematically, although, for example, Sheppard and Valentine (1979) found that about a third of RSOs providing programmes for older pedestrians used some form of practical training. OECD (1985) mentioned that one RSO in London had tried practical training with older people. It was found to be labour intensive, but brought to light specific problems in individual cases. There are studies examining pedestrian training in children. An issue in children's training has been the extent to which training needs to be realistic. Evaluations suggest that practical training (training real perceptual and motor activity) in the road environment or in environments like it is most effective. Transfer from training, as opposed to knowledge, is otherwise often poor. That is, many interventions may increase children's ability to talk about safety (when prompted) without having clear-cut effects on their road behaviour. Traffic clubs (a community-based intervention combining practical training with other materials) have shown some positive effects. For example, accident rates were lower for members than non-members of the Norwegian Traffic Club (Schioldborg, 1974, 1976). However, covert observation of road behaviour showed relatively small differences, which disappeared when children were accompanied. This was, of course, not a true experiment, because children, or rather their parents, self-selected for club membership, and so differences in accident rates could be attributed to other differences between these groups. Similar interventions without any practical element have tended not to show benefits. For example, one report concluded that British "Tufty Club" trained children did not even have greater road safety knowledge (Antaki et al., 1986).

Practical training methods, like the pretend road of Lee et al. (1984), have been shown to influence behaviour. Of particular relevance is a finding that this method (even in simplified forms) reduces starting delays, i.e. it seems to improve anticipation (Demetre et al., 1993; Young and Lee, 1987). Practical training was explicitly recommended by an early OECD report (OECD, 1978; cited in Thomson et al., 1996). The potential for the use of simulated pedestrian tasks for training has not yet been explored with older people, but findings with children imply that it may be more effective than information campaigns.

An area of training that would be expected to have benefits on pedestrian safety are those that train aspects of visual attention. For example, work by Roenker et al. (2003) has suggested that UFOV (section 2.4.3) can be expanded by training and this expansion lasts. It remains for the research to demonstrate whether this improvement in UFOV can result in fewer accidents in the long term. For example, Roenker et al. (2003) examined whether UFOV and other driving-related abilities could be trained and whether that had any impact on driving performance. Training on speed of processing was successful (about four hours training on a UFOV type programme to reduce a loss of greater than 40% in UFOV to a loss of less than 20%). UFOV trainees also committed 30% fewer dangerous driving manoeuvres (an on-road measure) after training, whereas there was little change for simulator-trained or control groups. The difference in number of dangerous manoeuvres between the speed-of-processing trainees and the other two groups at the 18 month follow up was significant. Other studies have also demonstrated small improvements in hazard perception and collision avoidance (Sifrit et al., 2001).

Kramer et al. (1995) have shown that a couple of hours practice can improve both speed and accuracy in a dual-task setting. They found that variable priority training, in which participants have to vary the relative priority given to the tasks across different trials during practice, generalised to novel tasks. Both young and old adults showed this benefit, although there remained an age difference in performance. Kramer et al. (in press; cited in McDowd and Shaw, 2000) showed that, with around twice the amount of initial practice, the benefit was retained over a period of 60 days. This increased practice also led to a reduction in the difference between older and younger participants' performance. Whether such laboratory training can transfer into divided attention skills in the environment, such as those used in the pedestrian task, e.g. walking and monitoring traffic at the same time, remains to be seen.

7.1.3 Equipment to help older pedestrians

Many older people find wayfinding and navigation in unfamiliar places difficult. Hand-held route guidance devices may have potential here. Some of the problems of divided attention inherent in such guidance systems in cars may not be such a difficulty for pedestrians – it is feasible to stop and examine the device safely when walking. Zimmer (1998) reported a continuing evaluation of such a device for use in large airports, and new generations of mobile telephones can deliver such information through location-based services, which are already available in some countries. These tend to be commercially oriented, but because they can be provided through the World Wide Web, services for older people could be published straightforwardly.

At a more prosaic level, Langlois et al. (1997) recommended appropriate prescription of walking equipment such as canes. In winter, slipping is a particular problem for older people. Gard and Lundborg (2000) evaluated footwear designed to prevent slipping by observing older people walking on different surfaces. Standardised ratings by physiotherapists and subjective reports of usability were used. Some devices were found to alter movement patterns. They reported on specific designs that rated highest for comfort and effectiveness.

In the accident phase of prevention, emphasis is placed on moderating the consequences of a collision. Drivers wear seatbelts to reduce injury if an accident does happen, and older pedestrians could take analogous steps. An older pedestrian is, however, so physically vulnerable that it is not realistic to rely on this aspect of intervention. Nevertheless, in relation to falls, some authors have suggested that protective clothing could be helpful. Björnstig et al. (1997) discussed padding to protect joints, and cited a study (Lauritzen et al., 1993) showing that this can be effective. A key issue is acceptability to users.

The chance of surviving serious injury is greatly affected by the speed with which the victim can receive specialist medical care. The Federal Highway Administration has recently carried out a trial of a sophisticated collision notification system for cars (National Highway Traffic Safety Administration, 2001). The system gave good, but in a few respects imperfect, information on details such as the severity of impact, where the vehicle was, whether it had rolled over, and so on. In the event of an incident, this information was automatically sent to an emergency centre using a cellular telecommunications network. Fitted to 800 cars and tested for five years in a rural area, the system improved mean response time to 44s, compared with an average of seven minutes for similar accidents in that area. Less sophisticated systems are already being fitted commercially, although NHTSA concluded that their system needed some further development, and there remain issues such as how to use the information optimally (Editorial, 2001). An analogous system designed for a pedestrian to carry that was integrated with mobile phone technology could be helpful.

7.2 Other participants in the road environment

Some interventions are aimed at the relationship between pedestrians and drivers. Interventions could target the pedestrian with information about driver behaviour, as Mathey (1983b) suggested. In the future, a larger proportion of older pedestrians will have held driving licences, which may be helpful (OECD, 1970). Alternatively, measures could target other road users, particularly drivers.

7.2.1 Driver training

A number of authors have recommended informing or training other road users, especially drivers (e.g. Gorev, 2001; Mathey, 1983a,b; NCC, 1987; OECD, 1986; Sarkar et al., 1999; Sheppard and Pattinson, 1986; Sheppard et al., 1988; Sjögren et al., 1993; Thompson et al., 1985; Wouters, 1991; Yaksich, 1965). Mathey (1983b) recorded changes in German law in the early 1980s creating a responsibility for drivers to make concessions to vulnerable road users, which goes beyond the guidance currently given in the UK Highway Code. Legislation of this sort was a specific recommendation of OECD (1986, p. 37), which drew attention to an emphasis on residential areas (p. 42). Brown (1980) discussed aspects of driver performance and their relationship to pedestrian accident risk. Although his discussion was to some extent programmatic, on the basis of a consideration of accident data he emphasised focusing on, first, the skills of younger drivers and, second, the ability of drivers to notice or anticipate the behaviour of pedestrians. Drivers can be influenced to be more considerate of pedestrians in some circumstances (Boyce and Geller, 2000; Koenig and Wu, 1994).

Preusser and Blomberg (1987, see section 0 above) developed a message for drivers to help avoid particular types of accident with adult pedestrians. They reported some success for the Spanish version of their materials, which encouraged drivers to “take a last look for pedestrians before turning” (p. 121). Graham (1998) described an intervention, Walk Safe Baltimore, to help alcohol-intoxicated pedestrians. As well as addressing people who drink heavily themselves, the programme aimed to raise awareness in drivers.

Sheppard et al. (1988) developed a lecture to teach learner drivers about the issues raised by older pedestrians. Delivered by driving instructors, effectiveness was assessed by a questionnaire mailed to participants. There was no control group, and no quantitative indication was given of how well the learners did, and so it is difficult to assess this study. The pattern of responses did suggest that the young people tended to remember information in a fairly general way. For example, when asked what they could do as drivers to help, they tended to say things like "watch out for old people" rather than mentioning specific things like "take care when reversing".

Howarth has argued that the burden of responsibility for avoiding accidents should be shared more by drivers (Howarth, 1986; Howarth and Lightburn, 1980). Howarth and Lightburn reported two observational studies of children's crossing behaviour in the UK (see section 5.5 above). They found that children responded to approaching vehicles when they were present in a very high proportion of cases. For example, they might stop at the kerb. On the other hand, drivers rarely took avoiding action further than 20 yards from the pedestrian. Educating drivers to reduce speed near pedestrians is likely to be especially helpful (see 1.3.4 above, and 7.3.3 below). Howarth (1986) recommended that drivers should do three things when children approach the road: slow down; make sure the vehicle is being attended to; and take a driving line further from the nearside kerb. Similar allowances would probably also be helpful to older pedestrians, especially if, as discussed in section 5.4 above, older people sometimes rely on drivers to accommodate their crossing.

A specific message that could be added would be that drivers who see an older person crossing from the offside ahead of them should proceed cautiously. Although they might assume the pedestrian will stop in the middle, as they would themselves, sometimes the pedestrian will continue without reappraising the situation (see section 5.5 above).

Al-Kaisy (1996) reported that many drivers were unaware of their responsibility to give way to pedestrians at certain junctions. A similar finding was made by Job (1998). Al-Kaisy reported that the presence of appropriate signs improved compliance. The role of signs is discussed in more detail in section 7.2.3. Carthy et al. (1995) reported that older people they interviewed complained about drivers' behaviour at a particular signal-controlled crossing near a major roundabout. They said drivers were "jumping the lights, travelling too fast, or failing to stop at the lights" (p. 43).

7.2.2 *Training other pedestrians*

No interventions to train other pedestrians were found. However, older people probably find busy pavements difficult to cope with, and can be led into the roadway by faster-moving groups of pedestrians (Silcock et al., 1998). Some other studies have observed older pedestrians apparently using others as a guide as to when to cross (Harrell, 1996; Lawton and Azar, 1964), and this has even been recommended as a strategy for older pedestrians (Yaksich, 1965). Studies of crossing behaviour have also indicated that pedestrians are generally influenced by the behaviour of those ahead of them on the crossing (Katz, 1991), particularly by people who appear to be well-dressed (Lefkowitz, Blake, and Mouton, 1955). Younger pedestrians might behave more helpfully if they were more aware of the difficulties encountered by less mobile people.

7.2.3 *Helping other road users to anticipate the presence of older pedestrians*

Interventions that make it easier for road users to see each other in poor light are effective. Both drivers and pedestrians are safer when they are aware of each other's presence earlier. Elvik (1999) found that reflective clothing is one of the most cost effective interventions for pedestrians, and PROMISING (2001) reported that road lighting is especially effective for pedestrians. Better lighting was recommended by OECD (1985; 1986). OECD (1985) emphasised lighting at crossings.

Some reports have suggested that older pedestrians are in part more vulnerable because they wear darker, less conspicuous, clothing (e.g. Dewar, 1995). Shinar (1984) found that retroreflective patches roughly doubled the distance at which participants, travelling as passengers beside the driver, detected a pedestrian standing at the roadside at night. The effect was greater than the effect of switching headlights from low to high beam or removing a source of glare. Luoma et al. (1996) also found that in dark conditions drivers noticed pedestrians wearing retroreflective material from further away. Harrell (1994) compared the effectiveness of a sign warning drivers of a pedestrian crossing with the effectiveness of bright clothing. This was done in the context of a well-publicised enforcement campaign prosecuting drivers who fail to yield to pedestrians. Harrell found that motorists were more likely to stop for a brightly clothed pedestrian than for the same person when he was wearing a drab jacket. The sign seemed to have little effect. Shinar (1985) also found that pedestrians wearing high visibility clothing were detected at a greater distance. It has been reported, however, that adults are unlikely to respond to advice on wearing conspicuous clothing (Sheppard and Valentine, 1980).

A scheme under evaluation in Florida, USA, is examining the use of an illuminated crossing. This is aimed at non-signalled pedestrian crossings such as zebra crossings. Lights are planted in the road surface. They are directed at the traffic in both directions and come on when there is a pedestrian standing or walking on the surface of the crossing. This would increase the distance at which drivers notice that there is a pedestrian on the crossing, giving them longer to react safely.

Some studies have found that the presence of warning signs has little effect on the behaviour of drivers at a pedestrian crossing (e.g. Harrell, 1994; Van Houten, 1988), but factors such as illumination of the crossing at night and the visibility of the pedestrians themselves have a much greater effect. Indeed, Van Houten et al. (1985) observed that drivers were more likely to stop at crossings for pedestrians who signalled to them. However, Van Houten and Malenfant (1999) described a study by Van Houten et al. (1998), which found that augmenting beacons with warning signs increased the percentage of drivers yielding to pedestrians. Van Houten and Malenfant (1992) reported a 67% reduction in pedestrian–vehicle conflicts when a sign was used, and 90% when advanced stop lines, requiring vehicles to halt at a greater distance from the crossing, were used along with signs.

7.2.4 Modifying vehicles

Pedestrians often fail to see the vehicle that hits them (Sheppard and Pattinson, 1986). This is sometimes because of an obstruction, but changes that improve the visibility of vehicles will probably benefit older pedestrians.

Daytime running lights are effective in drawing attention to a vehicle (Dahlstedt and Rumar, 1973), and are believed to reduce accidents involving more than one vehicle, except for rear-end collisions. If cars were more visible, this might also help pedestrians assessing a road. Although Dahlstedt and Rumar found that the optimal vehicle colour for detection varied according to the colours of the background, headlights gave the same effect as the best colour for a given background. Drivers estimated cars with headlights to be closer, which should encourage greater caution, and could more easily tell whether a vehicle was moving or not. When daytime running lights became standard in Sweden, car-pedestrian collisions fell 17%, relative to expectation (Anderson and Nilsson, 1981). Subsequently, Theeuwes and Riemersma (1995) pointed out that the absolute fall in daylight pedestrian accidents had been just 2%, and recent studies in North America have reported lower estimates of the reduction in vehicle accidents (Farmer and Williams, 2002; Tofflemire and Whitebread, 1997). Nevertheless, a meta-analysis of 17 evaluation studies found that pedestrian accidents reduced 10–20% depending on the measure used (Elvik, 1996, Table 5). Because older pedestrians tend to have their accidents more often in daylight, one would predict a particular benefit to them, but none of the studies reviewed gave results broken down by age. It is generally believed that the benefit is greater at more northerly latitudes, because daily periods of weak light are relatively long there. Two reservations are, first, that older people are more likely to be negatively affected by glare from the lights (Holland, 2001), and second, that the relative visibility of pedestrians to drivers might be reduced (PROMISING, 2001). Although there are significant differences between the USA or Sweden and the UK, notably in population density, further research on the benefits of daytime running lights for older pedestrians, combined with a consideration of the effect of glare, would be useful.

Older people often report that a car that hit them did something unexpected, such as reversing (e.g. Sheppard and Pattinson, 1986; Jensen, 1999). The high involvement of older people in accidents with reversing vehicles was noted in 0 above. There are several devices available to help vehicles avoid collisions while reversing. Paine and Henderson (2001) recently reviewed these and concluded that whereas none was likely to be fully adequate to protect pedestrians, particularly children, it should be possible to develop a suitable system using current technology. They recommended combined systems with enhanced rear-view visual information. A critical point made by Paine and Henderson, and the studies they cited, was that the effectiveness of such systems was limited unless the speed of reversing was kept low. Oxley et al. (in preparation) report current projects in Europe and Japan to develop devices, based on radar for instance, to detect pedestrians and so avoid collision. These projects include one to develop external airbags. Audible warning signals given by reversing vehicles could help older pedestrians anticipate movement. Jensen (1999) estimated that the introduction of audible warnings had reduced the number of pedestrian accidents of this type by 34%. Cohen and Preston (1968) advocated the fitting of under-chassis mirrors to vehicles to reduce accidents to children when vehicles move off. They pointed out that such mirrors had been fitted to laundry vans in the UK in 1957.

In the event of an accident, pedestrian injuries can be influenced or reduced by aspects of vehicle design (Hardy, 2000; Oxley et al., in preparation), and this is believed to be an important factor in maintaining a downward trend in casualty rates (Broughton, 1997). However, we have not reviewed this area.

7.3 The road environment

Passive interventions may be especially important for vulnerable road users. Mathey (1983b) argued that these should be a main form of intervention for older pedestrians, and they were prioritised in some of the community-based approaches described below. Langlois et al. (1997) suggested that passive intervention would be most effective for older pedestrians, recommending reduced vehicle speeds, more traffic islands, and greater allowance for crossing time. Section 4.1 above noted that certain road situations, such as crossing roads, and intersections, were especially hazardous for older people, and we focus on those aspects in particular. Many key features have been identified for some time (Yaksich, 1965), and were implemented in St Petersburg, Florida, a city with a large population of older people, by the early 1960s (Lawton and Azar, 1964).

An absolute emphasis on preventing conflicts between pedestrians and vehicles by channelling them separately could create problems, particularly for older or disabled pedestrians (Seneviratne and Shuster, 1989). When walking, people want to move directly to their destination (OECD, 1970). Placing barriers and re-routing pedestrians will reduce conflicts but may create difficulties if the alternative routes are inconvenient. For example, Sheppard and Valentine (1980) found that RSOs thought it relatively unlikely that older pedestrians would be persuaded to use footbridges. This needs to be borne in mind when designing facilities.

PROMISING (2001) made many suggestions for traffic calming, with emphasis on conflict points between pedestrians and faster moving traffic. Examples would be the use of by-pass planning, speed limit feedback to drivers who have exceeded the limit, and so on. PROMISING also outlined design features of pavements, of "walking networks", and particularly useful for older pedestrians, shortening crossings by the use of refuges and median strips, or by "build out" of pavements at crossings (narrowing the road). One welcome suggestion was providing rest points – benches and shelters along frequently walked routes, e.g. between shops and residential areas (FEPA, 1995).

Hauer (1988) considered the design of intersections from the perspective of older road user safety. Hauer emphasised the importance of systematic evaluation and the development of detailed guidelines based on such evidence. In the USA, the Federal Highway Administration has published guidelines to accommodate older drivers and pedestrians in the design of the road environment (Staplin et al., 2001). The guidelines cover details such as the maximum departure from orthogonal road intersection, design and positioning of road signs, and timing of crossing signals. For example, recommendations on 17 design elements were made to help older road users at junctions. Criteria are derived explicitly from research on older people, which they review insightfully. Retting et al. (2002) reported an experimental evaluation of similar guidance on the timing of traffic signals previously issued by the Institute of Transport Engineers. Vehicle accidents fell by about 10% at experimental sites. Pedestrian and bicycle accidents fell by over a third compared to control sites, but this reflected an increase at control sites rather than a reduction at experimental ones. Retting et al. point out that most sites in their sample did not meet the standard prior to intervention. The timing change principally involved increasing the period when none of the approaching traffic streams had a green signal, to increase separation between conflicting streams. The equations used to determine timing are different for intersections with different levels of pedestrian traffic. This general approach could be considered doubly passive. From the point of view of road users, it is passive because they just follow the signals they find, and these timings build in more margin for failure by road users to be perfectly obedient to the signals. However, from the point of view of a particular engineer it is also relatively passive, because a standard formula indicates the appropriate timing.

PROMISING (2001) reviewed a number of different interventions, and illustrated the application of cost–benefit analysis to evaluations of these changes. Reductions in pedestrian accidents were given by roundabouts, by upgrading pedestrian crossings, and integrated area-wide speed reduction. Removing parked cars also reduced accidents overall. Dijkstra and Bos (1997) evaluated a variety of measures in the Netherlands, and found that only measures related to junctions (e.g. introducing a roundabout, providing a median island) consistently reduced overall accident rates. In fact, only roundabouts reduced pedestrian injury rates. Jensen (1999) summarised a review of several interventions that reduced pedestrian accidents. He reported, for example, that roundabouts reduced accidents by between 46% and 89%.

Van Houten and Malenfant (1999), in a review of Canadian and US interventions to reduce collisions between pedestrians and vehicles turning at intersections, found that signals encouraging pedestrians to look for traffic as they crossed were effective in increasing looking behaviour and in reducing pedestrian–vehicle conflicts. They described in detail a carefully designed evaluation by Van Houten et al. (1998), which experimented with an animated display of eyes scanning that augmented the normal crossing signal. Although results were not reported separately for different age groups, the new signals increased pedestrian looking and greatly reduced vehicle conflicts.

Sarkar (1993; 1995) proposed an approach for assessing the quality of a road environment from the pedestrian perspective. This system involves evaluating the safety, security, comfort, convenience, continuity, system coherence and attractiveness of a street area. The focus is principally on urban areas, and the approach emphasises physical separation of pedestrians and vehicles to achieve the highest levels of safety. Fruin (1972) pointed out that even in Roman times steps were taken in some cities to protect the pedestrian environment in this way.

7.3.1 Pedestrian crossings

Older pedestrians would like more signal-controlled crossings, longer crossing time allowances, and signals whose meaning is clearer (Savill and Chinn, 1993). Jacobs and Wilson (1967) reported that older pedestrians in London and four other English towns were more likely to use crossing facilities than younger adults. At younger ages, more women than men used crossings, but over 60 years the difference was less. Bailey et al. (1992, p. 71) found that 86% of their sample of older Americans "frequently or always cross only at designated crosswalks". The design of pedestrian crossings needs to be considered carefully, and issues such as signalling, provision of central refuges, and the siting of crossings, in relation to junctions for example, can affect the safety of a crossing (DUMAS, 1998). PROMISING (2001) cited the meta-analysis of Elvik et al. (1997), which found that at an ordinary marked pedestrian crossing, accidents increased by 25% compared to the same location before the crossing was installed, although results vary from country to country (Boot, 1987; cited in Hummel, 1999). Bailey et al. (1992) cited unpublished data from Florida, indicating that 70% of older pedestrian fatalities happen when they have right of way at a signal-controlled pedestrian crossing. The explanation for this is unclear, but may in part be that some pedestrians become overconfident or place too much faith in driver behaviour at a crossing (Ekman and Hyden, 1999). A number of measures were found to improve safety at crossings, such as better lighting, safety barriers, central refuges, and raised crossings. A package of these measures could reduce accidents by as much as 60% (PROMISING, 2001).

Bailey et al. (1992) found that almost 25% of their sample of pedestrians aged over 56 years reported that they had difficulty seeing pedestrian signals. A recent study in the USA compared different lighting systems for pedestrian signals, using older people aged 62 or more as participants (Mace et al., 1997). Three different types of light (incandescent, fibre optic, and light-emitting diode; LED) were evaluated for recognition of the signal, uncertainty, and judgements that the light was too bright. Testing was carried out at different brightness levels and distances. Phantom signals, observations for which the person believed the signal was on when it was not, were more common for incandescent than LED signals, and were more common for larger than smaller signals, but were not observed for fibre optic lights. Mace et al. recommended a minimum intensity of 25cd under most lighting conditions, but noted that lower intensities may be acceptable for fibre optic signals.

One problem in the use of signal-controlled pedestrian crossings is that people do not generally use crossings as they were intended. For example, in a survey by Davies (1992), 51% of people using a particular crossing in a small UK town did not press the button, and 73% of those using a particular crossing in central London did not do so. A comparative figure from a crossing in Toulouse, France, was 82% not using the request button (Levelt, 1992a). People may believe that the button has no effect and that the light is controlled by some external system. However, research suggests that older people may be more likely to follow signals as long as they understand them (Wilson and Rennie, 1981). Job et al. (1998) observed people crossing at two busy signal-controlled intersections in Sydney, and found that older people (over 60 years) were less likely to cross against the signal (22% of older men and 10% of older women versus 34% and 25% of younger men and women, respectively).

Many older people report being anxious when using signal-controlled crossings because they perceive that the green signal time is not long enough (Bailey et al., 1992; Savill and Chinn, 1993), and similar concerns can also occur on rail crossings (Smith, 2002). Studies of walking speed and road-crossing speed are reviewed in 0 above. Older people in particular often do not understand that they have the right to continue to cross when the green man is flashing (Al-Kaisy, 1996; Todd and Walker, 1980; Wilson and Rennie, 1981), producing anxiety when the non-flashing green phase is not long enough for people's walking speeds. Similar observations in the USA led to a change in guidelines, to recommending that flashing "Walk" or "Do not walk" signals should not be used (Hauer, 1988). Studies on signal phasing and on the effect of increasing the available crossing time have indicated that safety can be improved (e.g. Garder, 1989). An Australian study made a detailed evaluation of extending the clearance phase at two signal-controlled crossings at one intersection to allow for a walking speed of 0.9m/s (Job et al., 1994). Although across all pedestrians there was a reduction in pedestrian–vehicle conflicts, three out of four periods of observation after the intervention showed higher levels of conflict for over 65 year olds. Pedestrians who were asked had very rarely noticed the change in crossing timing. Department of Transport (1995) gave specifications for the timing at different types of crossing in the UK, and recommended, for example, that timings be lengthened for wider roads or roads where many disabled or older people used the crossing.

As well as signal timing, the uniformity of crossings along common routes is also important. As shown in the sections above, older people are particularly compromised by unexpected behaviour of vehicles. There needs to be consistency of operation and phasing, particularly in complex scenarios such as crossings at junctions, so that accurate anticipation is made possible.

The European DRIVE II project VRU-TOO (Vulnerable Road User Traffic Observation and Optimization) tested the usefulness of puffin crossings for pedestrians (Carsten et al., 1998). Puffins use microwave devices to detect pedestrians. Detectors activate the pedestrian phase earlier (replacing a request button), and extend the crossing phase for pedestrians who arrive late or when there are many people crossing at once. Puffins can also cancel the pedestrian phase if the pedestrian abandons their request. Hagenzieker (1996) argued that this is better than simply extending crossing times, because it is likely to lead to less frustration in, and possibly violation by, drivers. In a validation study across six sites in three different countries (UK, Portugal and Greece), Carsten et al. found a small but consistent decrease in the number of pedestrian–vehicle conflicts (defined as either a pedestrian or a vehicle having to change speed or direction to avoid each other). At UK sites (Leeds), fewer pedestrians crossed against the signal, and a larger proportion of pedestrians started to cross on green and completed the crossing still on a green signal. These studies found no major side effects on vehicle travel times or queuing. Innovations such as this would increase the comfort of slower walkers at crossings.

Older people's slower reactions, as well as their slower walking, should be accommodated in crossing design. Older people can react up to twice as slowly as young adults (Cerella, 1985, 1990). Because older people tend to consider different information sources in series, rather than in parallel (Rabitt, 1985), this delay could be multiplied in complex situations in which several things must be considered, such as different traffic streams, other pedestrian movements, and signals. Thus, the more complex the crossing task, the longer it could take an older person to start. Staplin et al. (2001) advised that to allow for the longer time older pedestrians take to leave the kerb, and their slower walking pace, a design walking rate of 0.85m/s should be used.

Another approach would be to help older people anticipate the green phase, for example using “countdown” signals, in use in some US states, which tell pedestrians how many seconds there are until the end of the green phase. Belanger-Bonneau et al. (1994; cited in Van Houten and Malenfant, 1999) evaluated countdown signals during the green phase. Although there was no measured safety improvement, pedestrians, especially older pedestrians and children, reported feeling more secure.

A number of studies have examined ways to make the light signals easier for pedestrians to interpret. Janssen and van der Horst (1991; cited in Hummel, 1999) evaluated a flashing yellow “cross at your own risk” opposed to green “no conflicting traffic” scheme in comparison to the conventional red/green opposition, which did not guarantee no conflict, even on green. They found no change in the number of pedestrian–vehicle conflicts, even for older pedestrians, and found that pedestrians were prepared to cross during flashing yellow, thus avoiding the delay that a red signal would have imposed. However, de Lange (1996; cited in Hummel, 1999) reported that the over 65s, interviewed at busy junctions, did not regard waiting times as a problem. Janssen and van der Horst suggested that this type of arrangement could be helpful for crossings at less busy junctions. Levelt (1992b) described pussycat crossings in the Netherlands. These used a number of features, such as sensors to detect pedestrians. The most intriguing feature was the placement of the signal on the pavement at the start of the crossing, so that a pedestrian could not see the signal once they began to cross. There were two reasons: to encourage pedestrians to look at the traffic rather than the signal while crossing, and to forestall anxiety that arises when the signal changes while a pedestrian is still crossing. Their evaluation used observation of, and interviews with, pedestrians. They found that pedestrians did make more head movements, but some felt less safe and said this was because they were not able to see the signal while crossing.

Van Houten and Malenfant (1999) summarised a study by Gouvril et al. (1994), which tried adding a third, yellow, light to the pedestrian signal sequence. They found that although pedestrians said they understood the yellow light better than the previous “do not begin to cross” signal, given by a flashing “do not walk” signal, they did not prefer it, and did not comply better.

In Enschede, some older pedestrians were given a portable switch they could use to double the length of the green phase at crossings (Municipality of Enschede, 1992; cited in Hummel, 1999). A survey of users found the device was regularly used, and 70% said it allowed them to use routes they would not otherwise be able to follow. Allowing more time at signalled crossings is likely to increase feelings of security, and in this case increased mobility.

Signal-controlled pedestrian crossings in the UK include an audible beep during the green phase. This is intended for pedestrians with impaired vision, but could also help other road users (Department of Transport, 1995). Van Houten et al. (1997) used a woman’s or child’s voice to supplement light signals at an intersection in

Florida. Just before the visual signal, the voice instructed pedestrians to look for turning vehicles while crossing. They found fewer than 5% of pedestrians failed to look when the voice was present, compared to typically 10–15% not looking without it. Pedestrian–vehicle conflicts were almost eliminated.

An early survey in the USA found that 36% of older pedestrians were concerned about confusion at road crossings (Carp, 1972). They reported concern with too many signals, but also with inconsistent signals and layouts from crossing to crossing. Part of the older people's concern was that drivers would become confused, creating a hazard for the pedestrian.

An alternative to a crossing at road level is to separate pedestrian crosswalks physically, using a subway or footbridge. This prevents conflict from occurring and spares traffic flow. However, older people typically dislike such arrangements because of the extra physical difficulty of climbing up steps, or feelings of insecurity. According to DUMAS (1998), they see them as barriers to mobility. Stevenage New Town built major roads on embankments so that underpasses were at ground level with no slopes for pedestrians (C.G.B. Mitchell, October 2002, personal communication). DUMAS identified the Donaukanal pedestrian–cycle bridge in Vienna as an example of good practice, with high user acceptance. DUMAS also advised particular care be taken at roundabouts to avoid locating crossings in ways that create excessive detours for pedestrians.

7.3.2 Pedestrian refuges or islands

Many studies have emphasised the value of median refuges for older people, although of course it is also important to consider the potentially conflicting needs of other road users (e.g. DUMAS, 1998; Federal Office of Road Safety, 1987; OECD, 2001; Oxley et al., 2001). Zegeer et al. (1994) advocated refuges on the basis of their analysis of several thousand pedestrian accidents in the USA between 1980 and 1990. They found that older people were over-represented in accidents on roads four lanes or more wide. An island at the middle of a crossing allows an older pedestrian to tackle a two-lane road one part at a time and thus simplify the task (Moore, 1953; Road Research Laboratory, 1963). When only one lane needs to be crossed, only one direction of traffic needs to be considered, and pedestrians who encounter unanticipated traffic in the middle of crossing can consolidate their position more safely. Carthy et al. (1995), summarising a pilot road-crossing observation study at two problematic sites in Newcastle, indicated that one of the two main causes of potentially unsafe crossings was the situation in which an older person carefully negotiated the first half of the road but did not consider the situation in the second half of the crossing. On the other hand, there have been reports that some older people express anxiety about becoming stranded at a refuge (Wilson and Rennie, 1981). Ekman and Hyden (1999) described results showing that on average refuges reduce pedestrian–vehicle conflicts at comparable locations.

Other recent evaluations in Australia and the UK have been more equivocal (Cairney, 1999; Davis, 1999).

Yaksich (1965) recommended reducing conflicts with turning vehicles and simplifying the pedestrian task through the greater use of one-way streets. Jacobs and Wilson (1967) found lower accident rates in one-way streets, but attributed this to lower traffic flow.

7.3.3 *Vehicle speed*

The relationship between vehicle speed, pedestrian accidents, and the severity of injury was reviewed by Leaf and Preusser, who also analysed accident data sets in the USA. For example, they analysed data from single-vehicle pedestrian accidents in Florida between 1993 and 1996, and found that older people were more easily injured at all speeds. Even below 20mph, the risk of fatality was three times greater for those over 65. From 21–30mph, those over 45 had more than double the risk of fatality of younger adults, and the risk was about five times greater for those over 65. Over 45mph, older people were found to die in about 60% of accidents. Those over 65 had higher injury rates than younger people at all speeds. Savill and Chinn (1993) found that the most common suggestion made by older and disabled pedestrians in an English town was to reduce the speed or volume of traffic.

Speed increases the energy in a collision, and reducing vehicle speed should reduce the harm done by accidents (Oxley et al., 2001). Moreover, if cars are moving more slowly, drivers will be operating with margins for error that better match their true capacity to respond, and pedestrians will have more time to detect and respond to their presence. This should reduce the number of accidents occurring, and should particularly help older road users who react more slowly. A study of pedestrian fatalities in Adelaide estimated that a 5km/h vehicle speed reduction would spare 30% of pedestrian fatalities (McLean et al., 1994). The link between vehicle speed and pedestrian accident severity in London was noted by Hillman and Whalley (1979). Two recent reports provide detailed information on possible interventions to reduce vehicle speed. DUMAS (1998) reviewed modifications to the road environment that are used to slow vehicles in Europe. Leaf and Preusser (1999) reviewed strategies to reduce vehicle speed, including changes to the road environment, education, and enforcement. In the remainder of this subsection we briefly give some examples highlighted in recent reviews.

Research in the UK has shown that injury accidents in 20mph areas are reduced by 64% in town centres and 68% in residential areas, with reductions in mean vehicle speed of 11.5mph (from 32.0mph) and 12.1mph (from 35.6mph), respectively (PROMISING, 2001). Traffic volume was also reduced. On rural main roads such schemes achieved smaller reductions in speed and traffic volume, and accidents fell by 53%. Vis and Kaal (1993; cited in Hummel, 1999) examined 151 30km/h zones in the Netherlands, and found accident reductions of 22 ± 13%, but pedestrian accident rates were not reported separately. Kraay and Dijkstra (1989; cited in Hummel, 1999) reported injury accident reductions in 30km/h zones of up to 70%, and 20% in neighbouring main roads. Dijkstra and Bos (1997) reported mixed results, with not all sites showing accident reduction.

Oxley et al. (2002) argued that area-wide speed interventions are more effective than blackspot targeting, and described an intervention on an arterial route in a commercial area of Melbourne combining measures such as speed limit signs, painted median strips, and raised crosswalks. Vehicle speeds did fall, but for reasons that were unclear, bigger speed reductions occurred at the control site. Elvik (2001) reported a careful meta-analysis of 33 evaluations of area-wide traffic calming, and concluded that injury accidents are, on average, reduced by 25% on residential streets, and by 10% on main roads. In general, the data suggest that speed restriction reduces accidents overall, as one would expect. Because older people tend to have their accidents close to home, are especially vulnerable to impact, and are slower themselves, they should particularly benefit from this type of intervention. Speed reduction in residential areas and shopping streets was recommended as a measure to benefit older pedestrians by the OECD (1986).

The Dutch model of "Woonerven" (pedestrian precedence residential areas) has been adopted in several European countries. In these areas, the pedestrian has priority. The effectiveness of such schemes varies between countries, partly as a function of enforcement (PROMISING, 2001). Plowden and Hillman (2001) reviewed a number of schemes in residential areas to reduce conflict between pedestrians and vehicles. Some were evaluated in terms of speed reduction, others in terms of accident rates. In general, they found that such measures often did reduce vehicle speeds or accidents. Schemes that focus on the design of residential areas will particularly benefit older people whose accident involvement tends to be on familiar streets close to home. Some piloting of "living street" projects is underway in various towns and cities in the UK, where regulations are being prepared by the DTLR, and the Institute of Highway Incorporated Engineers is expected to publish guidelines in 2002. Similar ideas were implemented in the UK as "Play Streets" in the 1930s, and were termed "environmental areas" in the Buchanan Report (Cohen and Preston, 1968). An existing publication provides a detailed illustration of traffic-calming measures at sites in England, together with a commentary on their relative success (County Surveyors Society, 1994). In most cases, intervention successfully reduced speed and was judged to have reduced the likelihood of pedestrian accidents.

The safety benefits of pedestrianisation in town centres are widely recognised. The rebuilt centres of cities like Coventry have been designed in part around this principle. York has demonstrated that pedestrianisation can lead to a more rapid rate of casualty reduction for all road users. and that there can be an economic benefit to commercial property in "footstreets" (Transport Committee, 1996).

Taylor and Tight (1996) carried out surveys during traffic-calming interventions at 10 sites in Scotland. They found that the larger local people felt the speed reduction had been, the more they were prepared to walk or cycle. High vehicle speed causes accidents, increases injuries, and may deter walking. Older people are especially vulnerable to injury (section 1.3.4) and tend to express particular concern about traffic speed (Carp, 1971; Savill and Chinn, 1993).

7.3.4 *The quality of the walkway*

At a more elementary level, the quality of the walking surface is important to older people who may have difficulty with physical mobility. Zegeer et al. (1994) indicated the importance of sidewalks, absent on many suburban roads in the USA, and the value of dropped kerbs. Savill and Chinn (1993) surveyed older and disabled pedestrians in an English town, and found the biggest complaint about walkways was the uneven surface, mentioned by over 80%. Narrowness (20%) and steepness (about 10%) also caused difficulties for many people. FEPA (1995) audited a sample pedestrian journey in several European towns, identifying problems for older people. These included obstructions on the pavement, high kerbs, and pavements in poor repair. Carthy et al. (1995) found that older people in a city in the UK, particularly older women, were concerned about the state of pavements. Older women only rated the fear of violent crime or burglary as a greater source of concern or anxiety. Atkins (2001) reporting the results of a survey with older people in the UK, particularly emphasised that the walkway should be easy for older people to walk on (free of obstacles, in good condition, with dropped kerbs, and so forth). This applies not only to the pavement (sidewalk) but also to the road surface at pedestrian crossings (crosswalks) (Bailey et al., 1992).

The MORI poll by NCC (1987) found that 19% of adults of all ages mentioned the condition of pavements as a problem without prompting, with only volume of traffic mentioned more often (22%). On prompting, cracked and uneven pavements were said to be a problem by 52% of women and 39% of men of all ages, and over half of all people over 55. Of 132 who had fallen on uneven pavements, only four people felt they were at fault. In Gallon et al. (1995), 79% of the visually impaired respondents who reported an accident walking on pavements said it had not been their fault. Problems with the walking surface and obstacles were frequently mentioned causes. Hillman and Whalley (1979) cited a study that found "housewives and pensioners" felt the quality of the walkway was more often a barrier to mobility than crossing roads.

DUMAS (1998) advised that walkways should be flat and wide, and noting that European countries tend to have regulatory standards for sidewalks, listed eight recommendations for walkway design (p. 60). These included avoiding detours that tempt pedestrians to risk the roadway, and improving pedestrian visibility by widening pavements. Oxley et al. (in preparation) provide a similar list based on American Association of State Highway and Transportation Officials (2001). Savill and Chinn (1993) referred to guidelines applicable in the UK (Institution of Highways and Transportation, 1993).

Leake et al. (1991) highlighted the poor quality of the walking surface as one of the three principal difficulties faced by pedestrians with physical mobility problems, including older people. They compared self-reported difficulty to observations of walking behaviour and objective measurements of the walking surface in English urban centres. For example, they found that when the mean undulation of a surface exceeded 8mm, 20% of older people reported difficulty. Interestingly, they found there was not always a good match between subjective and objective assessment of particular sites. Leake et al. provided design standards on aspects such as the slope of the surface (both in the direction of travel and across it), although more exacting standards tended to be needed for categories of disability than for older people as such. Highlighting the important role of local authorities, they noted the importance of, among other things, preventing encroachment by heavy vehicles that damage the walkway.

One aspect of the walkway that older people identify as a problem is overhanging trees or branches. NCC (1987) found as many over 55s (15%) reported this as a problem as complained about having too little time at signal-controlled crossings. Lindqvist et al. (2001) mentioned the control of vegetation on driveways as one of the key aspects of a community safety intervention in Sweden. Gallon et al. (1995) found that 72% of a sample of visually impaired people of all ages reported problems with overhanging objects when walking.

7.4 Community involvement

A number of interventions have encouraged “bottom-up” involvement in projects aiming to increase safety for older or disabled people walking in public places. These projects have sometimes taken their lead from the World Health Organisation Ottawa (WHO, 1986) and Jakarta (WHO, 1987) Charters on Health Promotion, which set out principles to empower local communities in improving the safety of the local environment. The focus has often been on fall prevention. In British Columbia, Gallagher and Scott (1997) used a telephone hotline to encourage people to report hazards. Older women made 80% of the calls, and many called having fallen themselves. Atkins (2001) reported that many older people in her focus groups in England wanted a central telephone line they could use to report potential hazards. Powell et al. (2000) described an Australian project with a similar aim, but which assigned a more specific role to older people. A team of older people was trained in aspects of fall prevention, and encouraged to survey local places. The team identified many specific hazards, and brought each to the attention of those responsible, such as local businesses or local government, resulting in corrective steps being taken.

The older people trained by Powell et al. (2000) were also encouraged to act as “peer educators”, visiting local groups to pass on information. Deery et al. (2000), following Dychtwald (1986), used peer educators in a fall prevention programme described in section 6.1, and found that the group receiving training had more knowledge than a control group given no training when tested 12 months later. However, this was not a true experiment, and there were other differences between the groups that may have confounded the comparison. Moreover, the intervention group reported a higher fall rate over the subsequent year (19.6% compared to 12.9%).

Even more thorough community involvement in interventions targeting older road users has been reported from Scandinavian countries. Several reports describe programmes running over periods of years, which have mobilised local communities as active participants in identifying risks to target and measures to take. These programmes combined education, engineering, and enforcement measures, the classic “three Es” of intervention.

Bjerre and Schelp (2000) reported on an injury prevention intervention in a community in Sweden. The emphasis was on information and education, but passive regulatory and physical changes formed part of the programme. Particular risks were targeted. These were selected because of the similarity of situations leading to the event as well as a high casualty rate, because it was felt this would make it easy to convey the prevention message concretely. Falls from height, for example, were not targeted because many different situations had been found to lead to such falls. On the other hand, the risk of slipping or tripping was one of the four targets. Following the intervention, hospital admissions for targeted risks reduced initially, whereas those for non-targeted risks rose. In a comparison area, and Sweden nationally, both rose. The final two years of the intervention, which ran for seven years beginning in 1989, were reported to be the most intensive periods of the intervention. However, targeted accident rates in the intervention area bounced up again during those two years. It was not clear why this happened.

Lindqvist et al. (2001) evaluated a community-based traffic injury prevention programme. Coordinated by local government representatives and relevant local professionals in a Swedish town, the intervention encompassed changes in the physical environment and educational programmes aimed particularly at young people. Participation was encouraged by involving existing local organisations. These interventions were planned following an initial phase in which specific local patterns were analysed by the team, and specific issues were targeted. Older women pedestrians were identified as one group at high risk (but the authors did not report any effects of the intervention on this group). They found a substantial decrease in moderate injuries in a “before–after” comparison, but no effect on severe or fatal injuries. The report does not indicate whether older women pedestrians showed a lower rate, but women overall did not.

Ytterstad and Wasmuth (1995) reviewed a project conducted in Harstad, Norway.

This involved a wide range of interventions, including regulatory, environmental, and information programmes aimed at reducing traffic injuries. Key features were targeting high-risk groups, targeting accident blackspots, regular feedback of accident data to raise public awareness through concrete and locally relevant information, and a preference for passive over active intervention. A high level of public involvement was encouraged. The programme was coordinated initially by local health professionals and some representatives of local organisations. Overall traffic injury rates reduced across the seven-and-a-half-year period of the project, including the target groups. However, for older drivers, who had not been a target group, the injury rate rose. This supports the conclusion that targeted interventions were effective. Ytterstad and Wasmuth do point out that it would be impossible to evaluate which individual programmes had particular effects, given the global nature of the project.

The Scandinavian community interventions coordinated local action extensively, involving many organisations, professionals and private individuals, making changes in local regulation and resource allocation. They have also focused on communities of a particular size. The results have been encouraging, but are inconclusive in some respects. Although good attempts have been made to evaluate the projects, it is inherently difficult to attribute success to individual strands of a tapestry of intervention. Whether this approach could be successfully transplanted to other settings is not immediately clear. As Lindqvist et al. (2001, p. 606) put it:

> "In Sweden there is a tradition of broad participation in popular movements and collective action. In regions characterized by an individualistic culture, a similar outcome from a programme based on collective action may require more effort."

However, part of the philosophy of the approach is that methods should be adaptable to local circumstances. Atkins (2001) pointed out that the Local Traffic Plan process introduced in the UK provides an opportunity for community representatives to play an active role. Atkins outlined a range of interventions to support older pedestrians, including several we have mentioned, such as improving lighting, consultation, the use of good practice guidance, and enforcement. The active involvement of local communities was also recommended by Yaksich (1965), and by Leaf and Preusser (1999) in relation to speed reduction. Taylor and Tight surveyed studies of public consultation on speed-reduction schemes, and carried out field research on the topic at 10 locations in Scotland. They found, for example, that when local people felt there had been good consultation they evaluated the outcome of the intervention more positively. When local communities are not incorporated, opposition can defeat traffic-calming proposals (Savill and Chinn, 1993).

One of the most successful community interventions documented was carried out in Canada. Van Houten and Malenfant (1999), in a review of Canadian research on pedestrian safety, summarised a community-based programme first described by

Malenfant and Van Houten (1989), which combined education, engineering and enforcement in three Canadian cities. The aim was to get more vehicles making left (cross-stream) turns at intersections to give way to pedestrians. Signs for pedestrians were erected, leaflets were distributed to households, posters were sent to schools for older children and senior citizen homes, and a lesson plan incorporating practical training was sent to schools for younger children. Pedestrians were encouraged to extend their arm until cars stopped, and to smile and wave their thanks to drivers after crossing. Advance stop lines and warning signs were erected for drivers, and large signs were erected in visible locations to return local information on the percentage of drivers yielding in the past week. Other measures included police monitoring. Evaluation at five to 10 months found large increases in driver compliance, rising consistently from the time of intervention, and a 50% reduction in pedestrian injuries at crossings. This intervention is interesting because some components have been evaluated separately (see section 7.2.3 above).

7.5 Evaluation

The OECD (1986) recommended that intervention projects should be evaluated, and this is a wise counsel. However, evaluation must be carried out well, with a view to the way the results can be used. Wagenaar et al. (1995) pointed out that when evaluations are designed weakly they are hard to interpret, and if they do not report suitable statistics it is difficult to use their data in meta-analysis, a very powerful way of drawing conclusions across several studies. Results of meta-analyses have been reported in the relevant sections above.

One difficulty with evaluating accident prevention is the rarity of accidents. Meta-analysis can help overcome this problem, but investigators have also explored the use of proxy measures. For example, Silcock et al. (1998) used “encounters” between pedestrians and vehicles as a proxy. Such proxies may also be useful in evaluations (Davis et al., 1989).

PROMISING (2001) noted that the effectiveness of a given intervention could vary between countries. They gave the example of cycleways (p. 63), which have been found to change the number of bicycle accidents between −17% (Denmark) to +73% (USA). As with any empirical research, care must be taken in generalising findings to dissimilar contexts. Differences such as level of pedestrian activity, traffic patterns and road layout will affect the possibility of generalising.

Typically, innovators carry out their own evaluations. We particularly recommend that the evaluation of interventions should be carried out independently of those designing interventions.

7.6 Summary

Interventions can be targeted at older pedestrians themselves, other road users, and the road environment. Because older people are so vulnerable to the consequences of physical injury, there is an onus on the system designer to minimise potential conflicts between older pedestrians and vehicles through the design of the road environment. However, interventions must be evaluated systematically and objectively to develop effective solutions, and to help achieve a balance between costs and benefits.

7.6.1 Information and training aimed at older pedestrians or other road users

- Few existing programmes to develop information for broad distribution to older pedestrians were found. Evaluations suggest that even if such programmes affect knowledge, they may not affect practical behaviour.
- A targeted programme, recently trialed in the USA, to encourage better self-regulation by high risk, visually impaired, older drivers has been shown to affect self-reports of relevant behaviour, but validation is incomplete.
- Practical training interventions have been designed to address aspects of performance relevant to the pedestrian task, and these have been shown to achieve their immediate goals. However, there is little direct evidence linking them to changes in behaviour in the road environment or reduced accident risk.
- Information on functional impairment, self-awareness and compensation, and high-risk scenarios can be used to identify advice that should be useful to older pedestrians. However, there is typically not yet direct evidence for a link with reduced accident risk.
- Other road users, particularly drivers, can be effectively targeted by coordinated programmes, and this has been demonstrated to reduce accident risk for pedestrians.
- Psychological research has implications for the effective design of information or training interventions. One specific issue that programmes may need to address to achieve behaviour change is some older people’s weaker belief that accidents are preventable.
- There are technological innovations, such as protective clothing, that might help to reduce accident risk or moderate injuries for older people.

7.6.2 Road environment

- Passive interventions, such as signal-controlled crossings and area-wide speed reduction changing the road environment, are likely to be most effective for older pedestrians.
- Standard setting by central authorities, not necessarily central government, is potentially the most effective passive intervention. Guidelines have already been prepared in some countries.
- Modifications to the road environment have been shown to reduce accident and fatality risk. Interventions that reduce vehicle speed, reduce opportunities for conflict between vehicles and pedestrians, and afford protection when a pedestrian negotiates the roadway, are effective. Improving the visibility of both pedestrians and vehicles is also effective.
- Maintaining a high quality walking area is important to reduce accidents from tripping and falling, which can be serious for older people.
- Signal timing at crossings needs to allow for the lower walking speed of older people. Puffin crossings adapt the crossing time by detecting the presence and speed of pedestrians, and appear to be an effective solution.

7.6.3 Strategy

- It is frequently argued that comprehensive programmes, coordinating aspects like engineering, education, and regulation, are more effective than isolated measures like installing street furniture at an individual location with a poor accident history. However, it is more difficult to analyse the effectiveness of multi-faceted programmes.
- Most existing programmes, whether multi-faceted or not, identify specific high-risk groups or situations to be targeted by the intervention.
- Active involvement of the local community is often said to be important. People can be encouraged to input information and ideas relating to potential measures, and recent accident data can be reported back. Many intervention programmes have been structured around local communities, in line with the Ottawa Charter.
- Effective evaluation normally must be built into the design of interventions, and typically raises difficult questions of method. Meta-analysis is a powerful tool for evaluation, and individual studies should be reported with this in mind.

8 CONCLUSIONS

In this section, we draw together the key findings of the review. The evidence supporting these conclusions is not repeated here, and many detailed and specific findings are not highlighted. We focus, rather, on the most central conclusions with a direct bearing on pedestrian safety.

8.1 Summary of key findings

Although older people tend to travel less, the ability to move around their community is important to them. They have less need for travel connected to work, but like other members of the community, older people travel for social contact and to access services. In the future, people are likely to have high expectations for their own mobility and will probably keep driving as long as they can. However, their pedestrian activity will probably also increase, and the safety of older pedestrians in the road environment should be an important concern.

Older people are at heightened risk of pedestrian accident involvement, and especially of serious injury or fatality. UK data (1998) have shown that people aged 60 or older, who were 20.5% of the population, accounted for 14.6% of pedestrian accidents involving physical injury, but 46.6% of pedestrians killed. Older people have a low casualty risk compared to younger adults up to around 65 years old, but at older ages their casualty risk begins to rise quite rapidly. The injury rate per 100,000 pedestrian journeys in the UK rises from 156 at 65 years to 406 at 85 years. This rate rises partly because of the increased vulnerability of older people to physical injury, which is also reflected in the very high fatality rates for older pedestrians. A study in the USA found that in collisions below 20mph, the risk of fatality was three times greater for those over 65. Over 45mph, older people died in about 60% of accidents. However, the increase in casualty rates is not entirely due to increased frailty. There is evidence that, when frailty is allowed for, by the age of 80, older people have a substantially increased risk of being in an accident of a given severity while crossing the road.

The impairments created by normal ageing include changes to eyesight, hearing, and visual attention, all of which are likely to be important for the pedestrian task. There are changes in physical mobility, including changes brought about by common medical conditions, such as arthritis, that will restrict walking. Older people are also more likely to be taking medication that may make them less able to cope with demanding situations in the road environment. Although there is some good evidence linking functional impairment to increased risk for older drivers, there is almost no direct evidence for older pedestrians. Without relevant data it is not possible to quantify the level of risk or to target specific mechanisms with interventions.

There are other effects of ageing. Older people's cognitive resources diminish with age, leaving them less able to respond quickly or flexibly. Older people do worse on divided attention tasks and on more complex tasks generally. In addition, they use more of their available cognitive resources to achieve adequate performance on basic tasks such as maintaining balance and walking. This leaves them especially vulnerable in unfamiliar situations and complex situations such as those requiring assessment of more than one source of information. For example, crossing a two-way road with an unfamiliar layout would be challenging. Cognitive decline also reduces older people's ability to react effectively to rapidly changing events, such as unexpected car movements.

Theoretically, it is not clear whether these effects are the cumulative result of general processes of deterioration, or whether specific mental components, such as the executive control system, are selectively lost. Some theorists would argue that general slowing can explain most age-related cognitive changes, whereas others would say the detailed pattern of change is better accounted for by decline in specific components of the cognitive system. This remains an open question in the theoretical literature. What is clear is that the pattern of decline is similar, and correlated, for many different measures of performance. One specific measure of visual attention that has been linked to accident risk for older drivers (UFOV) correlates strongly with general measures of mental impairment. Cognitive decline also correlates with some measures of perceptual decline.

In spite of these functional declines, there are some mechanisms that help preserve performance. There is evidence that older people who remain generally fit and active experience less cognitive decline. There have been some studies suggesting that training programmes targeted at specific skills can improve performance. For example, people can improve their attention skills with training. There is good evidence that older people try to behave more safely as they begin to find certain kinds of situation more difficult to cope with. For example, older drivers reduce night time driving and drive more cautiously, and there is indirect evidence that older pedestrians try to be more careful. Older people can also compensate for functional impairment by concentrating more heavily on basic tasks. For example, some older people with balance problems can maintain a safe gait by focusing attentional resources on walking. In these ways, functional impairment can be ameliorated.

The more precisely people are aware of the problems afflicting them, the more likely it is that they can do things to accommodate those difficulties. Older people are aware of functional changes if they receive clear feedback from everyday experience. For vision, the everyday difficulties they report correspond well with expected increases in specific problems such as sensitivity to dim illumination. There is also evidence that older people given professional feedback on their vision problems take appropriate steps.

However, cognitive impairment is particularly likely to be unnoticed, and may itself impair insight. Older people's self-reports of poorer cognitive performance may reflect feelings of unhappiness or discomfort rather than direct awareness of specific cognitive processes, although there may be, nevertheless, an indirect correspondence with objective performance. Research on older drivers suggests that conditions affecting insight, such as AD, are most dangerous.

Because older people may not notice some of the relevant changes in their perceptual and cognitive abilities, or may not accurately appreciate their bearing on road safety, it is unclear whether their own attempts to compensate for functional impairment are effective in reducing accident risk. It is also not clear to what extent they are aware of their compensatory behaviour. However, the adjustments they make, such as avoiding walking in the dark, do at least reduce their exposure to risky situations.

Older people often report that they find road crossing difficult, and their behaviour tends to be more cautious. However, there is evidence to suggest that their increased caution is not sufficient to compensate fully for functional decline. For example, some research suggests that although they wait for bigger gaps before crossing than younger adults, they accept gaps that are not big enough given their slowed walking. In these situations, they depend on the drivers of approaching cars to accommodate their crossing. It is not known whether older pedestrians are aware of this. Some patterns of behaviour that stem from a need to compensate for functional decline may be objectively more dangerous. For example, older people appear to be more likely to cross a road by crossing to the middle before assessing traffic in the far lane. This would simplify the task cognitively, but potentially places them in a difficult position.

More research on older pedestrian behaviour is needed. The studies of pedestrian behaviour have been useful, but there is much that is unknown. Different road situations affect behaviour, and little systematic research has been done on this issue. For example, road width, the amount of traffic, vehicle speed, and the presence of parked cars all have effects that may be larger than age effects. There is also a need for more cognitively direct studies that explore what older people see, rather than just where they look, and address the reasons why they behave in specific ways. Laboratory tasks have an important role in allowing systematic exploration of these questions, but they must be linked carefully to real world roadside behaviour to ensure validity.

Certain circumstances are associated with increased accident risk for older pedestrians. To some extent, these factors simply reflect different patterns of exposure. For example, older pedestrians have most of their accidents in daylight, but that is when they do most of their walking. In the USA it was found that 31% of older pedestrian fatalities, and 51% of injuries were at junctions, rates roughly double those for younger adults. Older people are also over-represented compared to younger groups in accidents with reversing vehicles. These data are mainly based on comparisons of population rates, and further research is needed to establish whether they might be explained by exposure differences or differences in frailty. However, the high risk of accidents at junctions could be related to the specific patterns of functional impairment experienced by older people. Junctions are complex situations, which place high demands on older people's cognitive resources.

Some groups of older people are at higher risk as pedestrians. There is direct evidence from accident data that the older old (80 and over) have a higher risk of being in an accident and an even more greatly increased risk of being in a fatal accident. Accident data is also clear that alcohol is a risk factor for pedestrians. Although older pedestrian accident victims are much less likely than younger adults to be intoxicated, this risk should not be ignored. Statistically, men are more likely to be injured or killed as pedestrians at most ages, although the difference between men and women may narrow in some older age groups. For example, 1993 UK data showed that the rate of pedestrian fatality per 100,000 people was 1.58 times greater for men compared to women aged 70–79 years (estimated from Broughton, 1997, Figure 2.6). More research is needed to relate sex differences in casualty rate to exposure. Some studies of this kind have suggested that women may be at greater risk when detailed patterns of pedestrian activity are allowed for. Women do have a high risk of falling while walking, and this risk appears to rise from late middle age. In addition, more older women suffer from pathologies of vision such as cataract or macular degeneration, which may contribute to accident risk.

There are particular groups of older people who we would expect to be at greater risk, but for whom direct accident data are not available. People suffering a medical condition or taking medicine that affects pedestrian behaviour will, of course, be impaired. The magnitude of the effect of an illness will vary from person to person according to their existing cognitive status and other factors. The combined effect of different impairments needs to be taken into account when evaluating the difficulties faced by a particular individual. Slower walking older people and former drivers are also likely to be high-risk groups, but empirical research is needed to establish links with accident rates.

Older people can be helped to improve the safety of their own road behaviour. They can be given information on risky situations, and ways of monitoring or improving their own performance. However, there is little evidence that interventions that merely provide information are effective in changing behaviour or reducing accident risk. Moreover, even if older pedestrians' accident rates were kept at the level of middle-aged adults, who have low accident rates, they would still suffer a higher rate of fatality than other age groups because of their fragility. The consequences of a given accident are greater for an older person. It is therefore important to consider ways of minimising the possibility of accidents.

There are several strands to intervention that we conclude are most important.

Interventions that help older people to maintain good levels of mobility but protect them from increased accident risk have a contribution to make. These could involve efforts to support older people as drivers, and to improve the quality of access to public transport. Second, interventions that make the road environment safer and easier for users will be especially helpful for older people. Such interventions include vehicle speed reduction, the provision of crossings, and other physical changes to the road environment. Basic measures like ensuring the quality of the walking surface are important to older adults. Design standards providing guidance on things like traffic signal timing can play an effective role. The best evidence for effectiveness in the literature is found for this type of intervention. Another way to make the road environment safer for older pedestrians is to educate other road users, particularly drivers, about their responsibility to protect other people's safety. These three kinds of intervention would benefit all vulnerable road users, not just older pedestrians.

The literature contains descriptions of many studies advocating the active involvement of road users and communities in the development of interventions. Many programmes have been multi-faceted, introducing a range of measures. Evidence that they succeed is frankly mixed, and further research is needed to establish the facets that are effective and those that are not. The very nature of these programmes makes it difficult to disentangle the effects of different measures taken. Nevertheless, to the extent that they have successfully identified local priorities, encouraged safe behaviour, removed particular hazards, and reduced accident rates, they show that grassroots activity can usefully complement interventions planned and deployed more centrally. Older people themselves can play an active part in developing a safer road environment.

It is essential that interventions are carefully evaluated, and evaluation requirements should be considered at the project design stage. Meta-analysis of intervention evaluations provides a powerful tool, but care must be taken to allow for factors that may cause the same intervention to be more effective in some contexts than others.

As people remain vigorous into older age, they look forward to participating actively in society. Secure mobility for older people will take place in a safe road environment, within a community that takes account of their changed capacities.

8.2 Recommendations

In this section we summarise the main recommendations following from our review of the literature on older pedestrians. Justification for these is given in the report, which contains many other more specific recommendations on assisting mobility, research, and intervention. Detailed illustration of what information should be included in a campaign or what types of engineering intervention may be most useful is also given in the report. Here, we concentrate on listing priority areas.

8.2.1 Mobility

1. Ways should be explored to improve access to safe transport alternatives for older people who may no longer be able to drive.

8.2.2 Research

2. Research that makes careful allowance for exposure differences should be carried out to investigate relationships between accident risk for older pedestrians and the following variables:
   - Age
   - Sex
   - Walking speed
   - Recent cessation of driving
   - Medical disorders and medication
   - Cognitive status
   - Perceptual status
3. Research should be done to establish valid methods for laboratory investigation, and a systematic programme of research on cognitive aspects of road crossing then implemented.
4. Research on the problems of older pedestrians in rural areas and the psychological consequences of accidents for older people is almost non-existent. These significant gaps in knowledge should be addressed.

8.2.3 Intervention

5. Intervention should focus on making the road environment safer. Centrally produced standards, guidelines, and regulation should play a key role. Specific measures should include reducing vehicle speeds, improving visibility of pedestrians and vehicles, the use of puffin crossings, which adapt timing to the pedestrian, and maintaining a high quality walking surface.
6. Older people and older people's organisations should be actively involved in planning local interventions.
7. Information campaigns should be considered. Training drivers to understand the difficulties of older pedestrians is particularly important. Although it is not clear that information campaigns directed at older pedestrians would reduce accident risk in themselves, they may at least play a role in informing public debate and planning.
8. Interventions should be systematically and objectively evaluated.

It is useful to compare this list with a recent Australian report that identified ordered lists of eight priorities for research and intervention relating to older pedestrians through an international survey of road safety specialists (Oxley and Fildes, 1999). Their research priorities included investigation of accident data, exposure patterns and mobility needs, and the role of engineering changes to the road environment. Older pedestrian performance in complex settings was their second priority (cf. item 3, above). Intervention priorities were the development of alternative mobility options and improved public transport access, and improvements to the road environment, including reducing vehicle speed and traffic density, maintenance of sidewalks and lighting, and guidelines for crossing times. There is good agreement between these themes and the recommendations we have made in this report.

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