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ACADEMIC LITERATURE REVIEW

# The potential role of physical activity on driving performance and safety among older adults

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**Abstract** The elderly represent the fastest growing driving population. Older drivers have a high crash rate per distance traveled, a high risk of injury or death in traffic accidents, and are commonly found to be 'at fault' in crashes. This reality has focused more interest on issues associated with the fitness to drive and the safety of older drivers. Many older adults depend greatly on their personal vehicle for transportation and suffer a marked loss of quality of life when, as a consequence of no longer being able or permitted to drive, their mobility becomes significantly restricted. The reasons for the deterioration of driving performance that occur during the aging process are multi-factorial and a great deal of research has focused on the identification of those factors. Nevertheless, some studies incorporating training programs have tried, with some success, to improve the driving-related abilities of older drivers. It has been demonstrated that physical activity can promote several skills that are associated with driving performance in older drivers. Few studies, though, have conducted exercise interventions among older drivers intended to enhance their driving-related abilities and promote road safety. In this context, the purpose of this work consists of examining the perceptual, cognitive, health, and physical factors related to fitness to drive in older adults and identifying possible strategies that can enhance their driving-related abilities. Moreover, potential mechanisms underlying the relationship among physical activity, driving ability, and road safety are discussed.

**Keywords** Driving · Aging · Physical activity

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## Introduction

Considering the data regarding road accidents and the demographic evolution, namely the increase in the older population, researchers and public health authorities are showing more interest in issues associated with fitness and safety to drive in older adults. In fact, older adults have become a larger part of the driving population and will continue to do so as "baby boomers" reach retirement age [58, 72].

In developed countries, the older population has become more dependent on their private cars and it seems very unlikely that other transportation alternatives can fully provide the level of mobility that older adults need [92, 93]. Driving is essential for older adults to continue their engagement in civic, social, and community life, and to remain involved in the human interactions necessary for health, well-being, and quality of life [26, 117]. Driving cessation has been linked to decreased participation in out-of-home activities and increased depressive symptoms [31, 66].

The number of crashes per distance traveled is higher in elderly drivers than in all other groups of drivers [38, 84].

Older drivers also have a high risk of injury or death in traffic accidents [55, 73] and are commonly found to be 'at fault' in crashes [84]. There is strong evidence that older drivers will make up a substantially larger proportion of drivers involved in fatal crashes in the next few decades. This is due to the proportional increase in the older population, the increment of the driving licensure rates, and higher annual distances covered [58, 72, 119].

Nevertheless, the crash rates for older drivers are lower per capita than for drivers of other ages since they drive shorter distances and are less often licensed to drive [58, 119]. Functional declines associated with aging appear to prompt some drivers to voluntarily change their driving habits [57, 104]; many older drivers report limiting their driving, especially to avoid complex driving situations such as peak travel times, night-time driving, and adverse weather conditions [9, 46]. However, because older occupants of vehicles comprise a large proportion of future deaths in motor vehicle crashes, public health efforts to reduce their morbidity and mortality should be pursued [58].

The most widely recommended road safety strategy for older drivers relates to the restriction of their driving licenses [113]. Nevertheless, this type of countermeasure needs to be carefully evaluated due to the negative consequences related to the restriction of elderly mobility, and increased emphasis should be placed on effective methods of protecting older drivers and passengers when they travel in vehicles [58].

Diverse perceptive, cognitive, and motor factors have been associated with driving difficulties and crash incidence in older adults. In a literature review, Anstey et al. [5] reported that measures of attention, reaction time, memory, executive function, mental status, visual function, and physical function were associated with driving outcome measures. Health status (e.g., cardiovascular illnesses, diabetes mellitus, state of depression, and dementia) has also been linked with the occurrence of crashes in older drivers [2, 73, 96].

Aging is associated with a decline in several cognitive skills and brain functions [17, 111] which can result in driving difficulties. For example, a decline in information processing speed, loss of efficiency in acquiring new information, cognitive inflexibility, a decline in executive functioning, a reduction in attentional resources, and a reduction in working memory function have been demonstrated [10, 111].

Interestingly, the practice of physical activities has a positive effect on perceptive, cognitive, and physical abilities as well as on health factors that are considered important for driving performance and safety among older adults. For instance, older people with a good physical fitness level show greater efficiency in information processing [29, 52], enhancement of attention capacity in dual-task situations [40], and better performance on tasks that require visual–spatial processing [102]. The effects of physical activity on cognitive factors seem to be more accentuated for tasks that request greater attention resources [22, 29, 116]. Furthermore, physical activity is a key factor for healthful aging [4, 120].

In this context, the purpose of this review is to examine the perceptual, cognitive, health, and physical factors that are related to fitness to drive in older adults and at the same time to identify possible strategies that could enhance their driving-related abilities. Moreover, we intend to identify and analyse the potential mechanisms that could support and promote a relationship between physical activity, driving ability, and road safety.

## Visual attention

Visual attention is a cognitive function involving search, selection, and switching that plays an important role in driving [88]. Changes in visual attention often occur in older adults, leading to marked difficulties in driving [5, 8, 30, 79].

Standard clinical measures of visual function tests have demonstrated little sensitivity for identifying risky drivers [7, 78]. Conversely, a computer-based test—the UFOV® test—supported by the concept of useful field of view (UFOV), was identified as a valid and reliable index of driving performance and safety in older adults [5]. The concept of UFOV was introduced by Sanders [98], who used the term "functional visual field" to indicate the visual area over which information can be acquired in a brief glance without eye or head movements. The UFOV® test combines the evaluation of visual processing speed and selective and divided visual attention, and evidence has shown that its performance also relies on higher-order cognitive abilities as well as visual sensory function [8].

The possible effects of age on the UFOV have been examined. Ball et al. [12] found slight differences in visual attention performance between young (22–33 years old) and middle-aged individuals (40–49 years old) but large performance differences between both groups and a sample of elderly individuals (60–75 years old). Other authors have found similar results, suggesting that critical changes in the UFOV occur around 60 years of age [63, 100]. However, a recent investigation conducted in a driving simulator reported that middle-aged drivers (46–57 years old) already showed a substantial decrease on the UFOV when their performance was compared with that of younger drivers (21–34 years old) [91]. Sekuler et al. [101] concluded that the UFOV size does not decrease with age but that older people process the received information less efficiently within the UFOV. These changes appear to occur gradually

during the normal lifespan. Such an interpretation is quite different from that originally suggested by Ball et al. [12], in which UFOV is constricted in older people.

A study on the relationship between exercise and visual attention have shown that 10 weeks of aerobic exercise (aquatic training) induced a beneficial influence on attention in older adults during dual-task processing [40]. Roth et al. [94] concluded that individuals who regularly engaged in physical activity had significantly better UFOV® scores than less active individuals. Recently, it was reported that elderly individuals who have expertise in orienteering activities have developed attentional skills that outweigh the age-related changes of visual attentional focusing [82]. Marmeleira et al. [62] showed that an specific exercise program that incorporated open skills and demanding perceptive activities was successful in improving visual attention in a group of older drivers (60 to 81 years old). It has been suggested that participation in exercise programs can induce brain-vascular and neurochemical benefits that allow the preservation of attention function in the elderly [21, 27].

Driver distraction is another critical factor for driving safety and is closely associated with visual attention. It can be defined as the momentary or transient redirection of attention from the task of driving to a thought, object, activity, event, or person and represents approximately 24% of the human causal factor contribution to all accidents [18]. It is known that secondary tasks interfere with driving performance, affecting visual search, detection of hazards, and detection of changes in the driving scene [86]. Dual-task changes are more frequently observed in older than in younger adults [16, 19].

The research regarding driving and distraction has been focused essentially on the negative effects of using cell phones. Older drivers are more adversely affected by using a cell phone than younger drivers [19, 39]. On average, reaction time increases by 0.23 s with cell phone usage, but for older drivers this increase can reach 0.46 s [18].

It is promising that dual-task deficits can be reduced, either by specific cognitive training [16] or physical exercise [40, 62].

## Executive function

Executive function consists of a set of higher-order cognitive abilities primarily associated with the frontal and prefrontal structures of the brain; it involves skills such as planning, organizing information, inhibiting responses, and orchestrating mental resources [11]. This set of skills subserves goal-directed, future-oriented behavior and does not become automatic over time, requiring constant mediation by a central executor [23].

Executive function is necessary to plan and coordinate sensorimotor and cognitive responses to complex driving situations and requires adequate working memory resources so that relevant information may be held in mind during the decision-making process [5]. Given that the types of crashes in which older adults are involved often occur in complex traffic situations such as intersections [71, 72], it is reasonable to hypothesize that difficulties occur at the level of executive function (i.e., the planning and decision-making part of the driving task) [5].

Daigneault et al. [24] found that drivers who had accidents during the previous 5 years performed poorly on measures of executive functioning. Another study demonstrated that older drivers with mild dementia showed a positive correlation between the results of an on-road driving test and the performance on executive function control and visual attention tests [118]. Recently, it was reported that executive dysfunction may be an important contributor to pedal errors among older drivers [33] and that poor planning ability is independently associated with driving difficulties [30].

In the last several years, relevant investigations have indicated that the frontal neural system (region that mediates executive function) is the primary locus in which aging-related cognitive changes are found and where physical fitness appears to exert its greatest influence [17, 23, 52]. In older adults, it has been suggested that aerobic fitness has a larger impact on tasks that require controlled and effortful processing compared with tasks that are executed using automatic processing [22, 29, 116]. Furthermore, it was found that tasks pertaining to fluid intelligence are more sensitive to physical fitness than those corresponding to crystallized intelligence [21]; executive function and fluid intelligence are related, involving many of the same cognitive processes [35].

Colcombe and Kramer [23], in a meta-analytic review of fitness intervention studies conducted from 1966 through 2001, found a clear and significant effect of aerobic fitness training in the cognitive function of older adults. The fitness effects were more patent in tasks that involved executive control processes. Those authors also found that participation in relatively brief training programs (1–3 months) provided at least as much benefit as moderate training (4–6 months), but not quite as much as long-term training programs (6+ months).

## Behavioral speed

Slowing of motor performance during human aging is well demonstrated in clinical observation [75, 103, 109, 111]. Behavioral speed consists of two major components: reaction time to environmental stimuli and speed of

execution [111]. Evidence suggests that central mechanisms are fundamental in the aging-related slowing of the speed of response and that the sensory and motor factors have only slight effects on that phenomenon [97].

The effect of age on reaction time is more pronounced in tasks that have high levels of complexity [25, 56, 112]. Reaction time also becomes more variable with age [25, 43]. It has been observed that, although vehicle operations become relatively more automatic with experience, driving is a complex and interactive task involving a variety of skills, requiring the ability to make appropriate and timely decisions [39, 76]. Actually, older drivers are frequently involved in crashes that occur in complex traffic situations; for example, older drivers are over-represented in crashes at intersections, in crashes involving failure to yield the right of way, and in crashes occurring while turning and changing lanes [7, 71, 72].

McKnight and McKnight [74] found a moderate correlation between reaction time and on-road driving performance, with larger associations found for complex reaction times than for simple ones. Green [36] suggested that a behavioral-slowing trend occurs with aging, which is reflected in greater brake reaction times. A recent dual-task study demonstrated that performing mental calculations while driving markedly increased the average reaction time of elderly drivers [59].

A study of 1,425 older drivers (between the ages of 67 and 87 years) showed that age, gender, and cognition are predictive factors for the total brake reaction time [121]. The decline in reaction time was associated with low scores in cognitive factors and visual field deficits. The increase in response time was related to having three or more physical complaints related to legs and feet and poorer vision search. This study concluded that drivers in good physical condition may perform poorly on brake reaction tests if their vision or cognition is compromised.

Research regarding physical activity has reported better performances on simple and choice reaction tasks among active older adults compared with inactive subjects [4, 27, 110]. In the driving-related literature, behavioral speed was studied by Hancock et al. [39] in young athletes on a braking task experiment. Curiously, these authors did not find any advantage of skilled sport practitioners in comparison with non-practitioners in measures of reaction, movement, and response time; they suggested that the advantage of sports participation is not the behavioral speed but the ability to produce the desirable performance in context. Recently, Matos and Godinho [70] reported that a specific perceptual-motor training program could enhance the useful field of view and the peripheral reaction time in novice drivers, suggesting that exercise that requires demanding information processing, and for which event perception is crucial, could be positively transferred to driving situations. Moreover, Marmeleira et al. [62] concluded that a type of exercise focusing not only physiological systems but also perceptive and cognitive mechanisms was successful in improving simple reaction in single- and dual-task condition among older drivers.

## Health status

Several health conditions have been associated with the involvement of older drivers in car crashes, namely heart disease, stroke, arthritis, diabetes, a history of myocardial infarction, poor vision, myopia, sleep onset insomnia, frequent tiredness, anxiety, or feeling depressed [73, 96, 105]. The use of non-steroidal anti-inflammatory drugs, antidepressants, benzodiazepines, angiotensin-converting enzyme inhibitors, hypnotic medications, and anticoagulants was also associated with an increased risk of crash involvement [73, 96, 105].

A large body of laboratory- and population-based studies has documented many health and fitness benefits associated with physical activity, such as improved physiologic, metabolic, and psychological parameters, as well as a decreased risk for many chronic diseases and premature mortality [4, 48, 120]. Given the link between health and driving performance, the positive influence of physical activity on health could positively influence driving performance in older adults.

The problems associated with dementia are particularly relevant to driving [1, 50]. Dementia is a syndrome that affects essential cognitive functions like memory, judgment, and psychomotor abilities [44]. Alzheimer's disease is the most common form of dementia [87]. Compared to most of the general driving population, drivers with dementia are at an increased risk for unsafe motor vehicle operation and crashes [2, 32, 114]. Friedland et al. [34] reported that 77% of patients with dementia of the Alzheimer's type showed deterioration in driving performance and that 63% of those patients stopped driving; however, only 42% of the patients with dementia who stopped driving did so before a crash occurred. Many individuals with dementia continue to drive even after the onset of symptoms [1].

The risk of dementia, cognitive impairment, cognitive decline, and Alzheimer's disease is lower among persons engaging in high levels of physical activity, compared with those performing low levels of physical activity [89]. A study conducted in the USA with 3,375 men and women, aged 65 years or older, showed that participants in the highest quartile of physical energy expenditure had a relative risk of dementia of 0.85 compared with those in the lowest quartile [83].

Since driving is an intense visual task, it has long been thought that visual impairment should be associated with crash risk [95]. Frequently, satisfactory performance on a vision test (often only a visual acuity test) is required to obtain a driver's license [46]. Most aspects of visual function decline after the age of 50 years [45]. Studies have found that drivers with changes in visual acuity, glare sensitivity, binocular visual field, or contrast sensitivity have a greater crash risk [37, 42, 81, 95]. However, most studies have shown weak or no association between crash risk and visual function either in the general driving population or among older drivers [5, 20, 46, 78]. Overall, the scientific literature suggests that visual tests used in isolation are not strong predictors of crash involvement because they do not tap into the visual and cognitive complexity of the driving task [5, 7, 78].

## Physical functioning

A history of falls and poor mobility have been found to be associated with driving difficulties or crash involvement in older drivers [13, 57, 65, 106, 107]. Poor neck rotation was also found to be related to an increased risk of crashing [69]. Marottoli and Drickamer [67] considered that the key elements of motor ability for older drivers include strength, range of motion of the extremities, trunk and neck mobility, and proprioception. However, they noted that limited information is available on the specific level of motor ability necessary for driving.

Previous investigations have explored the potential link between physical training and driving-related abilities. Marottoli et al. [64] demonstrated the possibility of maintaining or enhancing driving performance among physically impaired older drivers (>70 years of age) using a safe, well-tolerated multicomponent physical conditioning program. The intervention protocol targeted axial/extremity range of motion (e.g., cervical and trunk rotation, ankle dorsiflexion, and plantarflexion), upper extremity coordination/dexterity, hand strength, gait, and foot abnormalities.

A randomized control trial reported that an 8-week range-of-motion exercise training program successfully improved older drivers' shoulder flexibility and trunk rotation as well as their scores on the variable "observing" (percentage of appropriate responses in observing to the rear, side, and rear quarter, involving use of mirrors, turning the head, and looking over the shoulder) [77]. Tuokko et al. [115] found that older adults with lower physical activity levels had evident driving difficulties involving the spine and lower body. They suggested that physical activity focused on the improvement of spinal flexibility could enhance specific aspects of driving performance, such as turning to check for traffic or operating a seat belt. Those authors considered it to be encouraging that the most frequently reported symptoms were located in areas highly amenable to modification and pointed out that most of the older drivers expressed a willingness to engage in exercise programs if an association between physical fitness and driving could be demonstrated.

## Speed perception

Speed perception has been identified as an important ability for safe driving [41, 61, 85]. This concept is frequently known as time-to-contact (TTC) [60]. Despite some methodological differences, studies about driving concerning TTC are linked with the visual perception of approaching vehicles. One of the main differences in methodology is related to the fact that the observer is stationary or in motion. TTC involves primarily the local transformation of optical information through changes in the size of the image on the retina [41, 60].

A high proportion of accidents involving older drivers occur at intersections when entering the traffic or crossing a main road [71]. In those situations, it is very important to correctly perceive speed, distance, and "time away" of the approaching vehicle [41, 72]. Previous findings have indicated that older drivers underestimate the TTC of other vehicles to a greater degree than younger drivers [54, 99].

It is a common idea that less accuracy or more variability in the TTC perception of older drivers, combined with factors such as longer road crossing times, could explain their tendency to be more conservative than young drivers when deciding to enter traffic, accepting larger gaps, and by this means, trying to reduce the probability of a traffic accident [49, 108]. Relative underestimation of TTC might reflect some loss of perception capability. On the other hand, it could be beneficial for promoting a more preventive behavior, such as encouraging drivers to choose larger gaps between successive oncoming vehicles [41].

Female drivers tend to exhibit larger TTC underestimations than male drivers [54, 99]. Women often evaluate their driving capabilities more negatively than men, reporting more driving difficulties [30], which could lead to more cautious behaviour. A review of this issue concluded that, after controlling for driving exposure, women were less likely to be involved in vehicle crashes than men, and gender differences were greater among young and inexperienced drivers [28].

In the driving-related literature, we have only found one study [62] that examined the effects of exercise on speed perception in older drivers. After 12 weeks of exercise, there was no evidence of any positive effect on speed perception.

## Training programs for older drivers

A great deal of research has focused on elderly drivers' crash-involvement patterns, but not on the development and evaluation of methods allowing the enhancement of their driving-related abilities [53]. However, some scientific research has examined the effectiveness of retraining programs for older drivers using interventions in areas such as education, visual attention, or physical functioning. In-class and on-road education programs may help older drivers to improve their knowledge of safe driving practices and actual driving performances [15, 68]. However, not all education interventions have been found to improve driving performance in older drivers [14], and there is no evidence that post-license educational programs are effective in preventing road traffic crashes [15, 47].

Other methods have been used to enhance driving-related abilities in older adults. It has been reported that visual attention retraining programs using the UFOV® software resulted in fewer dangerous maneuvers during an open-road driving evaluation [6, 90] and that simulator-training was capable of enhancing driving performance in older adults [3, 90]. As already described, some studies have also demonstrated that programs focused on physical mobility retraining could enhance driving skills [68, 77].

Some interventions for older drivers have focused only on high-risk groups. Owsley et al. [80] reported that an educational program promoting safe-driving strategies among visually impaired older drivers did not enhance driving safety. Kooijman et al. [51], in a study among drivers with visual field defects, reported that a compensatory viewing training (laboratory and mobility training, including driving instruction) improved the driving performance in an on-road test.

Interestingly, research among older drivers has not consistently explored the possible benefits of multi-faceted intervention programs that integrates educational, motor, sensory, and cognitive components; all of those factors have individually been shown to be reasonably effective in improving driving behavior [53]. It is promising that, in a recent experimental study, a specific exercise program planned to stress perceptive, cognitive, and physical abilities was successful in improving several abilities (behavioral speed, visual attention, and psychomotor performance) considered critical for driving performance and safety among older adults [62]. Given that the task of driving involves a complex interplay of factors, more specific intervention programs capable of targeting several important domains are needed.

## Summary

The elderly represent the fastest growing driving population, and despite their lower crash rates per capita compared with drivers of other ages, they are believed to represent a high risk to road safety given their high crash rate per distance traveled.

Many older adults depend greatly on their personal automobile for transportation. They suffer a marked loss of quality of life when their mobility becomes significantly restricted, as a result of being no longer able or permitted to drive.

The reasons for the deterioration in driving performance occur along the aging process and are multi-factorial. A great deal of safety research on older drivers has focused on the identification of these factors. Some training programs directed to factors like visual attention, physical mobility, and driving education have improved the driving performance of older drivers.

It has been demonstrated that physical activity is capable of enhancing several perceptive, cognitive, physical, and health factors associated with driving performance in older drivers. However, few studies have conducted exercise interventions among older drivers that were intended to enhance their driving-related abilities and promote road safety.

Future research should explore the potential role of physical activity in preventing the deterioration or enhancing the driving-related abilities of older adults.

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