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WHAT AFFECTS THE SAFETY OF OLDER PEOPLE IN ROAD TRANSPORTATION? A NARRATIVE REVIEW

Joanna WACHNICKA[1], Natalia KONKEL[2], Dagmar POSPÍŠILOVÁ[3]

[1, 2] Gdańsk University of Technology, Faculty of Civil and Environmental Engineering, Gdańsk, Poland
[3] Transport Research Centre, Brno, Czech Republic

***Abstract**:*

This narrative review examines the factors affecting the safety of road users aged 65 years and older, with particular attention to drivers, pedestrians, and cyclists. Its purpose is to integrate evidence that has usually been discussed separately for individual road-user groups and to identify both group-specific risks and cross-cutting prevention priorities. Publications were selected through iterative, relevance-based searches of the Web of Science database using combinations of terms relating to older road users, crashes, health, functional limitations, behaviour, infrastructure, technology, and regulation. The final narrative synthesis comprised 141 analysed publications and documents. The scientific literature covered 1995-2024; three additional official statistical and institutional sources provided contextual data, while a later legal document was consulted to verify the current regulatory framework. The synthesis shows that age-related deterioration in visual, cognitive, and motor functions affects the ability to perceive hazards, process complex traffic situations, maintain balance, and react in time. Older drivers are particularly vulnerable at intersections, where failure to yield and difficulties in rapid situational assessment are recurrent crash factors. Chronic disease, visual impairment, polypharmacy, and mental workload can further reduce driving fitness. Older pedestrians face elevated injury and fatality risk because of slower walking speed, impaired estimation of vehicle speed and distance, unsafe crossing choices, greater physical frailty, and emerging conflicts with e-scooters in pedestrian space. Among older cyclists, loss of balance during mounting, stopping, low-speed manoeuvres, or encounters with kerbs is a major crash mechanism, and head and lower-extremity injuries are especially important. The review indicates that no single intervention is sufficient. The most promising approach combines age-friendly infrastructure, vehicle and bicycle technologies, targeted education and practical training, medical and cognitive assessment, proportionate licensing procedures, and viable alternatives to private-car use. Safety measures should reduce crash and injury risk without unnecessarily limiting mobility, independence, and social participation. The review's added value lies in analysing the three principal older road-user groups within one road-safety framework and in linking individual limitations with environmental, technological, and regulatory responses. The findings can guide coordinated infrastructure, policy, screening, and mobility-support measures.

Keywords: *older road user, road safety, ageing population, crash risk; mobility*

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Contact:
1) joanna.wachnicka@pg.edu.pl [https://orcid.org/0000-0003-1946-0237] – corresponding author; 2) s178082@student.pg.edu.pl [https://orcid.org/0009-0008-9092-0316]; 3) dagmar.pospisilova@cdv.gov.cz [https://orcid.org/0000-0002-1300-7290]

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1. Introduction

Safety is a fundamental requirement of a well-designed and functioning road-traffic system. Risk analysis supports efforts to improve safety and reduce the adverse consequences of crashes. This article examines the risks affecting older road users. The topic is increasingly important because population ageing is changing the demographic structure of road traffic (Statistics Poland, 2023; Polish Road Safety Observatory, 2023; Budzynski and Tubis, 2019). Older people constitute the fastest-growing population group in Europe. Approximately one in five people in the European Union is currently aged 65 or older. Forecasts indicate that, by 2050, more than half of Western Europe's inhabitants will be over 50 years of age and life expectancy will approach 90 years. People aged 65 and older are also expected to account for more than 28% of Europe's population.

As the number of older people increases, so does their participation in road traffic as drivers, pedestrians, and cyclists. Ageing is associated with changes in motor and cognitive performance, vision, and hearing, while reduced physiological reserve increases vulnerability to injury. These changes do not make chronological age a sufficient indicator of unsafe behaviour: risk depends on functional capacity, exposure, the traffic task, and the extent to which the road environment and technology compensate for limitations. The growing number of older road users therefore warrants measures that reduce crash and injury risk without unnecessarily restricting mobility and social participation.

Previous reviews have made important contributions but have usually been organised around a single road-user role or a narrowly defined field of intervention. Examples include reviews of safety and mobility among older pedestrians (Tournier et al., 2016), the effectiveness of older-driver retraining (Korner-Bitensky et al., 2009), healthcare and nursing assessment of older drivers (Savoie et al., 2022), and the risks and benefits of cycling in later life (Ikpeze et al., 2018). Marin-Lamellet and Haustein (2015) adopted a broader mobility perspective, but their review primarily matched good practices to different segments of the older population rather than comparing risk mechanisms across road-user roles. The present review addresses this fragmentation by examining drivers, pedestrians, and cyclists within one road-safety framework. Its novelty does not lie in identifying a previously unknown age-related impairment, but in showing how shared visual, cognitive, motor, and physiological changes interact with different traffic tasks and environments. This cross-role comparison distinguishes common upstream determinants from mode-specific failure mechanisms and reveals interactions between interventions that remain difficult to identify when each group is reviewed separately.

Accordingly, the aim of this review is to determine how individual, environmental, regulatory, and technological factors affect the safety of older drivers, pedestrians, and cyclists, and to identify interventions that may reduce their risk without unnecessarily limiting mobility. The remainder of the article first defines the review design, search and selection approach, evidence base, and methodological limitations. It then presents a thematic synthesis and discussion of risk factors affecting older drivers, pedestrians, and cyclists, followed by preventive measures and conclusions.

2. Methodology

2.1. Review design and scope

This study was designed as a narrative review because its objective was to integrate a broad and heterogeneous body of engineering, behavioural, psychological, medical, regulatory, and technological evidence rather than to estimate a single pooled effect. The unit of analysis was evidence relevant to people aged 65 years and older participating in road traffic as drivers, pedestrians, or cyclists. Studies using slightly different age thresholds were retained when they provided directly relevant evidence on ageing and road safety. The review addressed age-related functional decline, crash and injury patterns, medical and behavioural determinants, mobility needs, infrastructure, technology, regulation, and preventive measures.

2.2. Search strategy and publication selection

Publications were identified primarily through iterative searches of the Web of Science database. The core Boolean logic can be expressed as: (older OR elderly OR ageing OR aging) AND (driver* OR pedestrian* OR cyclist* OR "road user*") AND ("road safety" OR crash* OR accident* OR injur* OR mobil*). Targeted searches added terms for health and functional capacity (vision, cognition, physical function, medication, or polypharmacy), the road

environment and technology (infrastructure, intersection, crossing, driver assistance, automation, or bicycle design), and policy or prevention (licensing, assessment, screening, training, education, or intervention). The queries were refined iteratively as themes emerged; consequently, this Boolean expression documents the search logic rather than a single invariant query used to generate the entire corpus.

For retrospective transparency, the substantive selection criteria were made explicit. Publications were included when they: (1) addressed road safety, crash involvement, injury consequences, mobility, or a safety-relevant functional determinant; (2) concerned older drivers, pedestrians, or cyclists, or provided age-stratified evidence applicable to these groups; and (3) contained sufficient empirical, review, methodological, statistical, or regulatory information to support the synthesis. Publications were excluded when they did not concern road transportation, contained no separable evidence relevant to older people, duplicated another record, or were non-scholarly web materials without an official statistical, institutional, or legal function.

Titles and abstracts identified through successive searches were assessed against the scope above, followed by full-text relevance assessment. The final analytical corpus comprised 141 publications and documents, including the two e-scooter studies added in response to peer review. Most scientific publications were published between 1995 and 2024; one 2025 legal document was used to verify the current regulatory framework. Three additional official statistical and institutional sources (Statistics Poland, 2023; Polish Road Safety Observatory, 2023; Central Register of Vehicles and Drivers, 2023) provided contextual data and were not counted among the 141 analytical items. The reference list therefore contains 144 entries. The process is summarised in Figure 1. Because the review was narrative and no prospective screening register was maintained, the numbers of records initially retrieved, deduplicated, and excluded cannot be reconstructed reliably and are not presented as a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

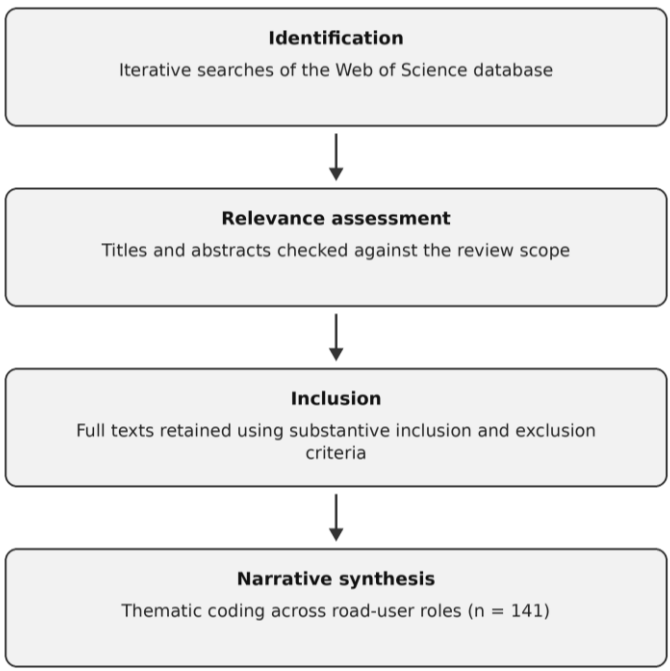


Fig. 1. Search, relevance assessment and synthesis process used in the narrative review. Source: own elaboration

2.3. Evidence classification and synthesis

A more detailed thematic analysis was conducted for 59 publications representing the main research perspectives identified in the reviewed literature. The studies were grouped according to the predominant research area, main topic, and methodological approach. As several studies combined medical, behavioural, and infrastructure-related issues, the categories were not treated as mutually exclusive. Table 1 presents the distribution of the publications across these categories.

To clarify the analytical contribution of the review, Table 2 contrasts the dominant scope of the preceding literature with the integrated approach adopted here. The comparison is not intended to claim that every earlier review had a narrow scope; rather, it identifies recurring forms of fragmentation that the present cross-role synthesis is designed to address.

Table 2 therefore links the scope of the review directly to its research objective. Its added value lies not in repeating separate descriptions of older drivers, pedestrians, and cyclists, but in testing whether shared age-related determinants lead to comparable or different safety consequences across roles and whether interventions in one mode affect the wider mobility system.

2.4. Methodological limitations

This study has several methodological limitations. First, its narrative and iterative search was not governed by a prospectively registered systematic-review protocol. Only Web of Science was used as the bibliographic database; a formal screening register, duplicate independent screening, and a formal study-level quality appraisal were not maintained. Therefore, the completeness and reproducibility of the selection process cannot be demonstrated to the same extent as in a PRISMA-compliant systematic review, and initial retrieval and exclusion counts cannot be reconstructed reliably. Second, the review synthesises heterogeneous evidence rather than primary data from one defined population, so pooled effect estimates and a quantitative ranking of interventions are not justified. Third, the two e-scooter studies added to address pedestrian exposure broaden the scope but do not constitute a comprehensive review of micromobility. Consequently, the preventive measures should be interpreted as evidence-informed recommendations and hypotheses for future evaluation, not as interventions whose effectiveness was directly tested in this study. These limitations define the review's conceptual and hypothesis-generating contribution while preserving the value of its multidisciplinary, cross-modal synthesis.

Table 1. Distribution of the thematic subset by predominant research element (n = 59). Source: own elaboration

Research element	Main topics	No. of pubs.	Typical methods
Medical / health factors	Chronic diseases, vision impairment, medication use	12	Epidemiological and medical studies
Psychological / cognitive factors	Attention, perception, reaction time	10	Simulator experiments, cognitive tests
Physical / functional limitations	Mobility, muscle strength, balance	7	Biomechanical and observational studies
Behavioural / human factors	Risk perception, decision-making	9	Surveys, behavioural analysis
Infrastructure / environmental factors	Road design, intersections, traffic density	8	Traffic safety and accident analysis
Legal / policy factors	Licensing rules, screening policies	7	Policy and legal analysis
Vehicle / technology factors	Driver assistance systems, vehicle ergonomics	6	Technology evaluation studies

Table 2. Added value of the present review in relation to the dominant scope of previous studies and reviews. Source: own elaboration

Analytical dimension	Dominant scope in previous literature	Approach adopted in this review	Added scientific value
Road-user roles	Drivers, pedestrians and cyclists are commonly examined as separate groups.	Evidence concerning all three roles is interpreted within one road-safety framework.	Reveals common determinants and role-specific failure mechanisms that are difficult to identify in separate accounts.
Age-related limitations	Sensory, cognitive, physical and medical factors are often considered within separate disciplinary perspectives.	Functional limitations are considered jointly and compared across road-user roles.	Shows how the same age-related change may produce different hazards depending on the traffic task and environment.
Crash occurrence and injury consequences	Behavioural and engineering studies tend to emphasise crash occurrence, whereas medical studies focus on injury outcomes.	Crash probability and injury severity are analysed as related but distinct dimensions.	Connects engineering, behavioural and medical evidence and supports both crash prevention and injury mitigation.
Mobility transitions	Driving cessation is frequently considered mainly as an outcome relevant to older drivers.	Changes in driving are linked to possible shifts toward walking, cycling and public transport.	Makes visible that exposure and risk may be transferred between modes rather than simply eliminated.
Preventive measures	Interventions are usually organised by one road-user group or one type of measure.	Common and role-specific measures are assessed as a coordinated package.	Supports integrated action across infrastructure, speed management, technology, health assessment, training and mobility support.
Research implications	Recommendations are commonly framed within a single mode or discipline.	Evidence gaps are identified across the mobility system of older people.	Provides a basis for longitudinal, cross-modal evaluation of safety, mobility, independence and social participation.

3. Thematic synthesis and discussion

3.1. Older drivers

Driving a vehicle is a complex task requiring coordinated interaction between sensory, cognitive, and motor processes (Hojjati-Emami et al., 2014). All of these processes deteriorate with age, significantly affecting the safety of drivers aged 65 and above. In the visual domain, older drivers experience disturbances in peripheral vision, reduced visual acuity, and impaired adaptation to varying light conditions (Hojjati-Emami et al., 2014). Cognitive difficulties can affect the perception, processing, and response to information and may contribute to errors such as failing to observe road signs, disregarding stop lines, or braking late before pedestrian crossings (Thompson et al., 2012; Susilowati and Yasukouchi, 2012; Cuenen, 2015). Longer reaction times and difficulties maintaining concentration may increase crash risk. In the physical domain, drivers aged 65+ experience reductions in muscle strength, limited joint mobility, and decreased manual dexterity, all of which impair the execution of complex driving manoeuvres (Hojjati-Emami et al., 2014).

Despite these limitations, older drivers display a marked reluctance to give up driving, since mobility represents an important dimension of their social participation (Parker et al., 2000; Donorfio et al., 2008). In suburban and rural areas, alternative means of transport are often unavailable or perceived as inadequate (Parker et al., 2000; Arai et al., 2010). Statistical data show that drivers aged 65 and above constitute the second largest group of licence holders after the 35–44 age bracket (Donorfio et al., 2008). A driver aged 75+ covers on average approximately 100 km per week within a radius of 28 km from their home – short, familiar journeys (Payyanadan et al., 2018). Older drivers generally drive less aggressively and avoid difficult road and weather conditions (Parker et al., 2000; Central Register of Vehicles and Drivers, 2023; Coxon et al., 2015; Ball et al., 1998); however, due to impaired assessment of speed and distance, they less frequently accept safe gap opportunities for left-turn manoeuvres at unsignalised intersections (Ball et al., 1998).

Analyses of crashes involving drivers aged 65+ consistently show that the greatest proportion occurs at

unsignalised intersections, primarily as a result of failure to yield the right of way – when entering the intersection or executing a turning manoeuvre (Zhou et al., 2015; Lee and Gim, 2020; Zhang et al., 1998; Hong et al., 2016; Zhang et al., 2000; Preusser et al., 1998; Keskinen et al., 1998; Clarke et al., 2010). The cognitive and perceptual demands of assessing traffic conditions and performing rapid vehicle manoeuvres exceed the capabilities of many older drivers. Driving errors and traffic rule violations additionally cause head-on and side collisions, wrong-way driving, incorrect manoeuvres from the wrong lane, and improper overtaking (Coxon et al., 2015; Hong et al., 2016; Clarke et al., 2010). Cases of driving without a fastened seatbelt have also been reported among older drivers (Hong et al., 2016; Koppel et al., 2011).

Environmental risk factors include densely built-up areas with high traffic volumes, school zones, roads with speed limits above 70 km/h, and adverse weather conditions (Zhou et al., 2015; Hong et al., 2016; Koppel et al., 2011; Alrumaidhi and Rakha, 2022). The most common injuries sustained by older drivers are chest and neck injuries – approximately 40% of fatalities involve rib fractures (Clarke et al., 2010). In frontal impacts, chest injuries result from the compressive force of seatbelts and airbags; in side impacts, from the force of the vehicle door (Lee and Gim, 2022). Older drivers die from chest injuries more frequently than other age groups because reduced physiological reserve can limit recovery after serious trauma such as rib fractures, lung collapse, cardiac damage, or arterial rupture (Morris et al., 2003). The risk of fatal injury without immediate death is higher for drivers aged 70+ than for younger drivers (Wang et al., 1996).

Health changes associated with ageing are linked to crash risk among drivers aged 65+ (Hong et al., 2016; Keskinen et al., 1998; Rolison et al., 2012; Zitoun et al., 2022; Skyving et al., 2021; Wang and Carr, 2004). A British analysis of over 2,000 crashes involving drivers aged 60+ found that approximately 10% involved chronic disease or an acute medical condition as a contributing factor (Keskinen et al., 1998). Diseases that substantially increase crash risk include diabetes, heart disease, epilepsy, dementia, cataracts, arthritis, myocardial infarction, Alzheimer's disease, and Parkinson's disease (Hong et al., 2016; Keskinen et al., 1998; Rolison et al., 2012; Zitoun et al., 2022; Skyving et al., 2021; Wang and Carr, 2004). Deficits in key driving domains – vision, attention, and memory – are particularly threatening to driving safety (Zitoun et al., 2022). Specific visual disorders prevalent among those aged 75+ include cataracts, glaucoma, and maculopathy (Hong et al., 2016).

Polypharmacy and the use of centrally acting medications represent another significant risk factor. Older patients take more medications than younger individuals and are more susceptible to side effects affecting the central nervous system (Zitoun et al., 2022; Skyving et al., 2021). High-risk drug classes include benzodiazepines, opioid analgesics, antidepressants, diabetes medications, antihistamines, and sleeping aids (Zitoun et al., 2022; Skyving et al., 2021; Wang and Carr, 2004). Benzodiazepine use is associated with impaired driving performance and an increased risk of traffic crashes (Dassanayake et al., 2011); first-generation H1-antihistamines can cause sedation and significantly impair driving performance, while the effects of second-generation agents depend on the substance and dose (Verster and Volkerts, 2004; Church, 2010). An analysis of 1,783 older drivers in France found that approximately 21% were taking medications considered to increase crash risk (Wang and Carr, 2004). In Japan, 27.6% of the older drivers studied met the criterion for polypharmacy and 16.4% showed cognitive impairment (Hagiya, 2022). Across the European countries included in the Survey of Health, Ageing and Retirement in Europe (SHARE), polypharmacy–defined as the concurrent use of five or more medications–affected 26.3% to 39.9% of adults aged 65 and older (Midão et al., 2018).

Mental workload during driving constitutes an additional risk factor (Cantin et al., 2009). With advancing age, information processing speed and short-term memory capacity decline (Cantin et al., 2009). The road situation is the primary source of cognitive load for older drivers: under complex traffic conditions, drivers aged 65+ experience a higher mental workload than younger drivers, manifested by slower situational analysis and extended response times (Cantin et al., 2009; Makishita and Matsunaga, 2008). Increased cognitive focus on one stimulus – such as negotiating an intersection safely – reduces the attentional resources available for other stimuli, such as an approaching vehicle (de Waard et al., 2009). The more demanding the concurrent mental

task during driving, the worse the driving performance and the higher the crash risk (Verwey, 2000). Legal frameworks governing the issuance and renewal of driving licences for older drivers vary considerably between countries (Langford et al., 2004). Prior to 2013, some European countries allowed licences to be issued indefinitely, without any subsequent medical examination (Lau and Kaber, 2018). Today, licences are generally valid for a maximum of 10–15 years, with shorter periods applying to older drivers.

Sweden issues licences valid for 10 years without age-specific re-testing, allowing most of them to drive for life (Itotani et al., 2022). Finland operates a stricter system in which a licence is valid for 15 years up to the age of 65 and thereafter for a maximum of 5 years; however, the demanding and costly medical requirements have been associated with fewer licences held by older Finns and greater pedestrian crash involvement among people aged 65+ (Lau and Kaber, 2018; Hakamies-Blomqvist et al., 1995). In Great Britain, a licence is valid for 10 years up to the age of 70, after which the driver completes a self-declaration of fitness to drive and a renewed licence is issued for three years, repeatable until the driver voluntarily ceases driving; drivers are obliged to report any relevant medical conditions to the Driver and Vehicle Licensing Agency (DVLA) (Mitchell, 2013). Some regions have introduced particularly restrictive measures – prohibiting night driving, motorway use, or travel beyond a defined radius – which have been shown to reduce traffic offences and risky behaviour without entirely removing mobility (Mitchell, 2008; Hakamies-Blomqvist et al., 1995; Mitchell, 2013).

Comparative analyses suggest that areas with less restrictive licensing procedures tend to have safer road infrastructure for older drivers, but the large number of licence holders who are no longer active drivers distorts accident statistics (Itotani et al., 2022; O'Byrne et al., 2015; Asbridge, 2017). No single legal or medical procedure has been demonstrated to have a clear general effect on the safety of drivers aged 65+; the key issue is functional and medical fitness assessed through appropriate screening (Lau and Kaber, 2018). Under the updated European Union (EU) framework, Member States may reduce the validity period for driving licences held by persons aged 65 or older in order to subject holders to more frequent medical checks or refresher courses (European Parliament and Council, 2025).

3.2. Older pedestrians

In addition to drivers aged 65 and above, older pedestrians constitute an important and particularly vulnerable group of road users. Research consistently confirms that a disproportionately large share of pedestrian accidents involves people over 65 (Thompson and Baldock, 2023; Wilmut and Purcell, 2022). This is illustrated by analyses from 2018 showing that one in two pedestrian fatalities was a person aged 65 or older (European Road Safety Observatory, 2020). In Spain in 2019, older people accounted for approximately 70% of all deaths in pedestrian road accidents (Gálvez-Pérez et al., 2024). The elevated mortality and injury rate among this group stems from the physiological fragility of the ageing body and its reduced capacity to withstand impact forces (Lee, 2019; Niebuhr et al., 2016). At the same time, the ability to move independently outside the home remains crucial for older people, as it directly supports their physical and mental well-being.

Vehicle–pedestrian collisions frequently result in severe or fatal injuries, with older age increasing injury severity (Shrinivas et al., 2023; European Road Safety Observatory, 2020). Among pedestrians aged 75 and above, the risk of being hit per 100,000 inhabitants is higher than in the 18–64 age group (Sklar et al., 1989). In the United States in 2010, pedestrians over 65 had a higher fatality rate than any other age group (Highway Traffic Safety Administration and Department of Transportation, 2010), and in the years 2001–2006, more than 52,000 older pedestrians required hospitalisation annually as a result of non-fatal road incidents (Jasiūnienė and Čygas, 2020; Naumann et al., 2011).

Analyses of crashes in which a vehicle struck an older pedestrian frequently show that the collision occurred when a person aged 65+ was crossing the road outside a designated crossing area (Hirsch et al., 2021; Nakagawa, 2019; Wang et al., 2017). One explanation proposed for this pattern is that some older pedestrians prioritise the shortest available route over a designated crossing. Survey data confirm that most older respondents regularly cross streets at the nearest convenient point, particularly under conditions of good visibility and low traffic density (Bernhoft and Carstensen, 2008). Additional

risk factors include straight road sections along which vehicles can reach high speeds, and raised kerbs, which increase the time needed to step off the pavement and divert the pedestrian's attention from the approaching traffic (Hirsch et al., 2021; Wang et al., 2017; Lalika et al., 2022).

A large number of road incidents involving pedestrians aged 65+ also occur at unsignalised pedestrian crossings and in densely built-up areas with high traffic volumes (Hirsch et al., 2021; Haule et al., 2019; Lee et al., 2020; Lam et al., 2013), as well as after dark or on insufficiently lit roads (Wang et al., 2017; Lalika et al., 2022).

Emerging micromobility creates an additional hazard in pedestrian space. In a case series of 249 emergency-department visits associated with standing e-scooters, 21 patients (8.4%) were non-riders: 11 were struck by a scooter, five tripped over a parked scooter, and five were injured while lifting or carrying one; patient ages ranged up to 89 years (Trivedi et al., 2019). A national trauma-registry study in Israel found that pedestrians accounted for 8% of people hospitalised after crashes involving electric bicycles or motorised scooters, and adults aged 60+ represented 33% of the pedestrian casualties (Siman-Tov et al., 2017). These findings do not establish exposure-adjusted risk specifically for older pedestrians, but they show that moving and parked micromobility devices can create collision and trip hazards in pedestrian areas, where age-related frailty may magnify injury consequences.

Older pedestrians involved in a crash face a substantially higher risk of serious or fatal injury than younger pedestrians (Lee, 2019; Niebuhr et al., 2016). The most common injuries sustained by pedestrians aged 65+ are lower limb injuries and intracranial injuries (Värnild et al., 2003; Liu et al., 2022; Siram, 2011). Due to age-related changes in bone density and tissue resilience, older pedestrians are also susceptible to rib and pelvic fractures even from low-magnitude impacts and falls (Niebuhr et al., 2016; Siram, 2011; Yang, 2005). Among pedestrians aged 75 and above, a higher fatality rate per 100,000 inhabitants is observed compared to those aged 65–74 (O'Hern et al., 2015).

One of the key factors underlying the high number of road accidents involving older pedestrians is the combination of reduced walking speed and impaired perceptual judgement when crossing the road.

Older people move measurably more slowly than other age groups. The difference in walking speed between pedestrians aged 65+ and younger adults is approximately 0.15–0.24 m/s (Stollof et al., 2007). Standard values used in road traffic engineering range from 1.2 to 1.4 m/s, which are appropriate for the majority of younger pedestrians but not for older people (Stollof et al., 2007; Duim et al., 2017; Transportation Research Board, 2006). Research indicates that the comfortable crossing speed for persons aged 65+ is 0.9 m/s, and in some cases as low as 0.7 m/s (Duim et al., 2017; Transportation Research Board, 2006).

Compounding the problem of reduced speed is the tendency of older pedestrians to overestimate their own capabilities when estimating how long they need to cross the road safely. A study conducted on multi-lane roads found that younger pedestrians showed high accuracy in self-assessing their crossing time, whereas people aged 65+ consistently underestimated the time required to traverse the full road width (Zhuang et al., 2020). This misjudgement arises partly because older pedestrians base their decision to cross more on the perceived distance to an approaching vehicle than on its speed (Zito et al., 2015). The gap they judge to be sufficient is frequently, in practice, insufficient (Choi et al., 2019). The lack of adequate awareness of potential risk is a key factor behind the significant number of serious accidents involving pedestrians aged 65+ (Guo et al., 2023).

Additional behavioural aspects further impede safe crossing. Older pedestrians often direct their gaze downward to avoid tripping rather than monitoring the position and speed of approaching vehicles (Zito et al., 2015; Choi et al., 2019). The use of walking aids such as sticks, walkers, or shopping carts increases crossing time, and hesitation at the kerb or a mid-crossing deceleration further reduces the safety margin available (Lachapelle and Cloutier, 2017).

3.3. Older cyclists

Cycling is an important means of transport for people aged 65 and over, particularly as an alternative to public transport in spring and summer. For those who can no longer safely drive a car, a bicycle often becomes the primary means of independent mobility, enabling them to cover longer distances. Like walking, cycling promotes the physical health of older people (Sakurai, 2016). However, with

advancing age, the risk of falling while riding, mounting, or dismounting a bicycle increases significantly (Sakurai, 2016), and cognitive decline, impaired speed assessment, and reduced compliance with road traffic rules further elevate accident risk among cyclists aged 60 and above (Maring and Van Schagen, 1990).

The scale of this issue is reflected in EU-wide data: among all road fatalities, 6% were cyclists, of which 24% were people in the 60–74 age group and 17% were aged 75 and over (SafetyNet, 2009).

Among road incidents involving cyclists aged 65 and over, the most common types were single-cyclist accidents and collisions between cyclists (Reurings et al., 2012). Single-cyclist accidents occurred mainly when mounting or dismounting the bicycle, or when hitting an object or a curb on the road (Ormel et al., 2008; Niska et al., 2013). In all such events, a common factor was loss of balance leading to a fall – a consequence directly linked to age-related physical decline. In cyclist-to-cyclist accidents without motorised vehicle involvement, distraction was a key contributing factor: approximately half of such incidents were caused by an older cyclist being distracted by the behaviour of another road user, resulting in sudden steering corrections and subsequent loss of balance (Boele-Vos et al., 2017).

The growing popularity of electric bicycles introduces additional risks for older cyclists. Research has shown that most falls involving e-bikes occur during mounting or dismounting, largely due to the greater weight of electric bicycles compared to traditional ones (Kruijer et al., 2013). Furthermore, older cyclists tend to ride at higher speeds on e-bikes than on conventional bicycles (Vlakveld, 2015) – a pattern that may increase task demands, because higher speeds require greater focus, faster processing of road conditions, and quicker reactions, while simultaneously increasing the severity of potential injuries.

Regarding injury outcomes, older cyclists are at substantially elevated risk of serious harm. In Germany, a consistent increase in cyclist fatalities was recorded despite a general downward trend in road deaths (Fuchs et al., 2023), and data confirm a clear rise in seriously injured victims among cyclists aged 65 and over compared to younger age groups (Niska et al., 2013; Cheong et al., 2021). The most common injuries were head and hip injuries. Head trauma was the leading cause of death among older cyclists – both in single-cyclist incidents and in collisions with vehicles – and resulted primarily from the cyclist's head striking the road surface without helmet protection (Niska et al., 2013; Matsui et al., 2018). Cyclists who survived head trauma frequently developed intracranial haemorrhage, brain contusion, or concussion with loss of consciousness (Boele-Vos et al., 2017; Thompson and Rivara, 2001). Serious lower-body injuries, particularly femur and pelvis fractures, were also frequently observed (Niska et al., 2013; Boele-Vos et al., 2017). According to forecasts, in ageing-population countries, the incidence of hip injuries is expected to grow by 1–3% annually, driven by the increasing prevalence of osteoporosis and the greater propensity for falls among older people (Cummings and Melton, 2002).

The high frequency of falls among older cyclists is rooted in age-related deterioration of the systems responsible for balance and postural stability – specifically the visual, muscular, somatosensory, and vestibular systems (Preece et al., 2023). Maintaining an upright body posture is itself an intrinsically unstable, highly integrated dynamic process involving multiple components of the nervous system (Fuchs, 2018; Hwang et al., 2016), and represents a biomechanical interaction between the body and its environment (Preece et al., 2023).

Among the balance strategies commonly employed are the ankle joint strategy (used for minor perturbations, activating muscles from ankle upward to hip) and the hip joint strategy (used for more serious balance disruptions, activating muscles from hip downward) (Winter, 1995; Panjan and Sarabon, 2012; Horak and Nashner, 1986). In cycling specifically, additional stabilisation mechanisms include external knee movements, upper-body balance control, and handlebar control (Moore et al., 2011; Cain, 2013).

With age, maintaining control over a bicycle becomes increasingly difficult, particularly at higher speeds, where quick reactions and precise steering adjustments are required to prevent falling. Older cyclists also exhibit reduced efficiency in elbow flexion and extension, further limiting their ability to manage the bicycle (Bulsink et al., 2016). A direct relationship has been observed between declining muscle strength and deteriorating balance during cycling – a relationship that becomes especially pronounced when riding an electric bicycle due to its greater weight (Preece et al., 2023). Importantly,

however, physically active older people demonstrate better postural stability than age-matched peers who do not cycle (Preece et al., 2023), suggesting that sustained physical activity can partially offset age-related balance decline.

3.4. Preventive measures for older road users

A recurring recommendation across the reviewed literature is the introduction of educational and training programmes designed to raise awareness among older road users of the risks associated with age-related limitations and dangerous behaviours (Susilowati and Yasukouchi, 2012; Parker et al., 2000; Donorfio et al., 2008; Clarke et al., 2010; Wang and Carr, 2004; Dassanayake et al., 2011; Ikpeze and Elfar, 2016; Laković et al., 2023; Dommes et al., 2012; Tournier et al., 2016). Such programmes should be tailored to each user group: older drivers need to understand the role of impaired situational assessment and slow reaction time in intersection accidents (Lee and Gim, 2022; Pollatsek et al., 2012; Morgan et al., 1995); older pedestrians require guidance on age-related limitations and safe road-crossing behaviour; and older cyclists should be informed about risks related to adverse weather, darkness, and high-traffic areas (Ikpeze et al., 2018).

Evidence confirms that participation in awareness programmes increases awareness of road risks and encourages behavioural change (Tuokko et al., 2015; Marin-Lamellet and Haustein, 2015). A combined approach – education together with practical on-road training – has been identified as the most effective format for older drivers, as it simultaneously improves skills and consolidates knowledge (Korner-Bitensky et al., 2009). For pedestrians and cyclists, programmes incorporating physical exercise are particularly valuable, given that physical activity has been shown to improve balance, general fitness, and, to some extent, cognitive function (Angevaren et al., 2008; Colcombe and Kramer, 2003; Weuve et al., 2004; Lautenschlager, 2008; Northey et al., 2018) – though the extent of cognitive benefit depends on factors such as gender and training duration, and further research is needed.

Table 3 links the risk mechanisms identified for the three road-user roles with the corresponding preventive measures and their expected safety contribution. It provides the evidence base for the intervention synthesis rather than a ranking of effectiveness, which would not be justified because of the heterogeneity of the reviewed studies. The measures are subsequently integrated into the cross-cutting Safe System framework presented in Table 4.

Advanced driver-assistance systems (ADAS) address the specific deficits most pronounced in older drivers: limited visual field, impaired motion perception, divided attention, and slower information processing and decision-making (Hojjati-Emami et al., 2014). Systems should relay only relevant information to avoid overloading the driver's attention (Davidse, 2006). Research confirms that intersection-support technology enabled older drivers to cross in shorter times with safer behaviour (Dotzauer et al., 2013), while navigation-oriented ADAS reduced stress in unfamiliar or changing road conditions (Payyanadan et al., 2018; Edwards et al., 2016). Vehicle control interfaces must remain intuitive, and familiarisation programmes with new technologies are necessary (Wang and Carr, 2004; Wood, 2024).

Under the SAE International driving-automation taxonomy, older drivers rated Level 2 – simultaneous control of steering and acceleration/braking under defined conditions – most favourably, while Level 5 vehicles, in which the driver becomes a passive passenger, received the lowest ratings (Lajunen and Sullman, 2021). Beyond electronics, traditional optimisation of entry/exit design, seat adjustability, and seatbelt and airbag systems adapted to the injury-susceptible older body also offers meaningful safety gains (Wang and Carr, 2004).

Infrastructure adaptations for older drivers should focus on sign visibility, intersection design, and speed management in complex traffic areas (Clarke et al., 2010; Wang and Carr, 2004; Boufous et al., 2008). Road infrastructure must also support reliable communication between the road environment and autonomous vehicle systems (Hojjati-Emami et al., 2014). For those who have surrendered their licences, improved public transport availability – especially in suburban and rural areas – is essential for maintaining mobility (Donorfio et al., 2008; Ichikawa et al., 2015), and may additionally encourage hesitant licence holders to voluntarily cease driving (Ichikawa et al., 2015).

Table 3. Preventive measures for improving the safety of older road users. Source: own elaboration

Risk mechanism and intervention	Applies to	Preventive measure and expected contribution	Evidence base
Limited awareness of functional change – education and training	All roles	Increase awareness of age-related limitations, hazardous behaviours and the need for regular health assessment; support compensatory behaviour.	(Susilowati and Yasukouchi, 2012; Parker et al., 2000; Donorfio et al., 2008; Clarke et al., 2010; Wang and Carr, 2004; Dassanayake et al., 2011; Ikpeze and Elfar, 2016; Laković et al., 2023; Dommes et al., 2012; Tournier et al., 2016)
Reduced balance, fitness and cognition – physical activity	Pedestrians and cyclists 65+	Improve balance, general fitness and cognitive function, thereby strengthening the capacity to avoid conflicts and falls.	(Angevaren et al., 2008; Colcombe and Kramer, 2003; Weuve et al., 2004; Lautenschlager, 2008; Northey et al., 2018)
Mobility transition after driving reduction – alternative and public transport	People reducing or ceasing driving	Provide viable alternatives to car use, particularly in suburban and rural areas, to preserve mobility without transferring exposure to less protected modes.	(Donorfio et al., 2008; Ichikawa et al., 2015)
Declining driving competence – education combined with on-road practice	Drivers 65+	Combine knowledge with supervised practice in real traffic; improve driving skills and the practical use of compensatory strategies.	(Korner-Bitensky et al., 2009)
Perceptual, decision and manoeuvring difficulties – advanced driver-assistance systems (ADAS)	Drivers 65+	Use warnings, lane-keeping, reversing assistance, pedestrian detection, intersection support and navigation assistance to compensate for selected functional limitations.	(Hojjati-Emami et al., 2014; Davidse, 2006; Albert et al., 2018; Nakamura et al., 2013; Edwards et al., 2016; Dotzauer et al., 2013)
Reduced mobility and biomechanical tolerance – vehicle ergonomics and restraint adaptation	Drivers 65+	Facilitate vehicle entry and exit, seat adjustment and control; adapt seatbelts and airbags to older occupants to reduce injury consequences.	(Wang and Carr, 2004)
Technology acceptance and appropriate automation – SAE International Level 2 support	Drivers 65+	Prioritise assistance that retains driver involvement; surveyed older drivers rated SAE International Level 2 more favourably than fully autonomous SAE International Level 5.	(Lajunen and Sullman, 2021)
Visual and cognitive demands in complex environments – driver-oriented infrastructure	Drivers 65+	Improve sign luminance, reflectivity, symbol size and placement; simplify intersections and reduce speeds where decision demands are high.	(Clarke et al., 2010; Wang and Carr, 2004; Boufous et al., 2008)
Undetected health-related decline – multi-stage screening and assessment	Drivers 65+	Combine cognitive and visual-attention tests with traffic-sign recognition and practical on-road assessment; avoid reliance on a single test.	(Kantor et al., 2004; Stutts et al., 1998; Janke and Eberhard, 1998; Wood and Owsley, 2014; Fildes, 2008)
Undetected health-related decline – involvement of general practitioners	Drivers 65+	Support early identification, specialist referral and advice on driving reduction or cessation when health impairs safe driving.	(Wang and Carr, 2004; Fildes, 2008; Savoie et al., 2022; Butler et al., 2020; Rivera-Izquierdo, 2021)
Need for proportionate fitness oversight – driving-licence regulation	Drivers 65+	Permit more frequent medical checks or refresher courses through shorter administrative validity where justified, rather than treating age alone as proof of unfitness.	(European Parliament and Council, 2025)

Risk mechanism and intervention	Applies to	Preventive measure and expected contribution	Evidence base
Context-specific driving limitations – conditional or restricted licences	Drivers 65+	Apply restrictions on night driving, motorway use or travel radius where appropriate; reduce high-demand exposure without eliminating independent mobility.	(O'Byrne et al., 2015; Asbridge, 2017; Braitman et al., 2010)
Slow walking, limited balance and crossing difficulty – pedestrian infrastructure	Pedestrians 65+	Provide wide, even pavements, appropriate kerbs, sufficient and shorter crossings, and countdown displays to increase decision and crossing time.	(Laković et al., 2023; Tournier et al., 2016; Ståhl et al., 2008)
Shared-space conflicts and trip hazards – e-scooter management	Pedestrians 65+	Separate e-scooter movement from pedestrian space where feasible; keep footways clear through designated parking and enforcement.	(Siman-Tov et al., 2017; Trivedi et al., 2019)
Fatigue and limited walking endurance – rest benches	Pedestrians 65+	Enable rest during journeys and make longer but safer pedestrian routes practically usable.	(Tournier et al., 2016; Ståhl et al., 2008)
Instability during mounting, starting, stopping and steering – bicycle design	Cyclists 65+	Use low-frame geometry, adjustable saddle height, electric start-up support and steering-angle limitation to improve stability and control.	(Dubbeldam et al., 2017)
Difficulty signalling while maintaining balance – bicycle turn indicators	Cyclists 65+	Provide handlebar-controlled flashing indicators so direction can be signalled without removing one hand from the handlebar.	(Westerhuis et al., 2021)
High vulnerability to head injury – helmet use	Cyclists 65+	Increase helmet use, including on short local trips, to reduce the risk of fatal and serious head injury.	(Cheong et al., 2021; Matsui et al., 2018; Ikpeze et al., 2018)

Since not every older person with health problems poses an elevated accident risk, targeted identification is essential. A multi-stage approach is recommended: initial cognitive screening using the Mini-Mental State Examination (MMSE) or the Trail Making Test (Kantor et al., 2004; Janke and Eberhard, 1998), followed – where deficits are identified – by domain-specific assessment, a practical on-road test, or specialist referral (Stutts et al., 1998; Janke and Eberhard, 1998). Poor performance on the Useful Field of View (UFOV) test has been associated with unsafe driving and increased crash risk among older drivers (Clarke et al., 2010; Wood and Owsley, 2014; Fildes, 2008), while the Traffic Sign Recognition Test, combined with visual perception assessment, effectively distinguishes safe from unsafe older drivers (Kantor et al., 2004; Stutts et al., 1998). No single test is sufficient as a standalone diagnostic tool (Stutts et al., 1998). Japan's 2017 introduction of a mandatory cognitive test within the licence renewal process for drivers aged 70 and over resulted in a measurable reduction in crashes involving older drivers (Yang et al., 2021). General practitioners (GPs) represent an additional underutilised resource: as regular contacts for older patients, they are well placed to identify driving-relevant health changes, advise on licence cessation, and refer to specialist assessment – provided they receive adequate training and resources for this role (Wang and Carr, 2004; Fildes, 2008; Savoie et al., 2022; Butler et al., 2020; Rivera-Izquierdo, 2021).

Infrastructure is the primary lever for improving older pedestrian safety (Laković et al., 2023; Tournier et al., 2016; Ståhl et al., 2008). Wide, even, non-slip pavements and appropriate kerb heights – particularly important for pedestrians using walking aids or shopping carts – reduce crossing difficulty and fall risk. A sufficient number of crossings in intersection areas minimises dangerous informal road-crossing, while rest benches along pedestrian routes enable older people to choose longer but safer paths (Tournier et al., 2016; Ståhl et al., 2008). Countdown displays at signalised crossings allow older pedestrians to judge in real time whether they can complete a crossing safely at their own pace. Where shared e-scooters operate, designated parking,

enforcement against obstructive placement, and separation of riding space from footways should be used to preserve clear and predictable pedestrian routes (Siman-Tov et al., 2017; Trivedi et al., 2019).
Bicycle design improvements directly target the balance and stability deficits underlying most older cyclist falls (Boele-Vos et al., 2017; Bulsink et al., 2016; Ikpeze et al., 2018). A Dutch prototype demonstrates the potential: its low-frame geometry facilitates mounting and dismounting, automatic saddle height adjustment reduces instability when stopping, and an electric start-up system supporting the rider up to 18 km/h limits maximum steering angle and reduces rocking – features assessed by older users as supportive, comfortable, and safer than a conventional bicycle (Dubbeldam et al., 2017). A handlebar-controlled flashing turn-signal system would further enable safe direction signalling without arm extension, though flashing bicycle signals are currently prohibited in the Netherlands (Westerhuis et al., 2021). Finally, helmet promotion and, where supported by the policy and enforcement context, helmet requirements should be combined with targeted campaigns emphasising the risk of serious head injury even on short, familiar-route trips (Cheong et al., 2021; Matsui et al., 2018; Ikpeze et al., 2018).

3.5. Cross-cutting synthesis and scientific added value

When the evidence for the three road-user groups is considered together, a common causal structure becomes visible. Declining vision, divided attention, information-processing speed, muscle strength, and postural control are not risks confined to one transport mode; their consequences depend on the task being performed. For drivers, these limitations are expressed mainly as delayed decisions and errors when negotiating complex intersections (Cantin et al., 2009; Clarke et al., 2010). For pedestrians, they contribute to inaccurate estimates of vehicle approach and of the time required to cross (Zito et al., 2015; Zhuang et al., 2020). For cyclists, they appear primarily as instability during mounting, stopping, low-speed manoeuvring, or an unexpected steering correction (Boele-Vos et al., 2017; Preece et al., 2023). The comparison therefore suggests that chronological age alone is an insufficient explanation of risk. A more informative explanation is the mismatch between an individual's functional capacity, the demands of a particular traffic task, and the degree to which the environment compensates for or intensifies that mismatch.
The combined analysis also separates two mechanisms that are easily conflated in group-specific accounts: the factors that increase the probability of a crash and those that determine its consequences. Functional decline contributes to crash occurrence in different ways across the three roles, whereas the biological fragility of the ageing body consistently increases injury severity after an event. The resulting injury patterns remain mode-specific: chest and neck trauma is prominent among older drivers, lower-limb and intracranial injuries among older pedestrians, and head and hip injuries among older cyclists (Clarke et al., 2010; Niebuhr et al., 2016; Niska et al., 2013). This distinction extends the preventive perspective beyond avoiding errors. It indicates that primary prevention must reduce task complexity and exposure to conflict, while injury-mitigation measures must simultaneously reduce impact speed and adapt protective systems, vehicles, bicycles, and infrastructure to the lower biomechanical tolerance of older people.
A further insight concerns transitions between road-user roles. Drivers, pedestrians, and cyclists should not be treated as three independent populations, because the same person may use several modes within a week and may shift from driving to walking, cycling, or public transport as functional ability changes. Evidence that driving cessation can constrain mobility, together with observations reported in the reviewed literature that restrictive licensing may coincide with increased pedestrian crash involvement, raises the possibility that a measure reducing risk in one role may transfer part of that risk to another if safe alternatives are unavailable (Hakamies-Blomqvist et al., 1995; Donorfio et al., 2008; Ichikawa et al., 2015). This should not be interpreted as an argument against fitness-to-drive assessment. Rather, it shows that licensing policy, public transport, pedestrian infrastructure, and cycling conditions need to be assessed as one mobility system. The relevant outcome is the net change in safety and independent mobility across all modes, not only the change in crashes involving older drivers.
This integrated perspective makes it possible to distinguish cross-cutting and role-specific responses. Cross-cutting priorities include managing speed and traffic complexity, providing clear and legible

information, supporting physical and cognitive capacity, improving risk awareness, and ensuring access to alternative transport. These measures should be combined with interventions directed at the dominant mechanism in each role: functional screening, intersection support, and appropriately designed driver-assistance systems for drivers; sufficient crossing time, shorter crossing distances, visible crossing facilities, and even walking surfaces for pedestrians; and stable bicycle geometry, assistance during starting and stopping, and head protection for cyclists (Hojjati-Emami et al., 2014; Tournier et al., 2016; Dubbeldam et al., 2017). The added value of the synthesis is therefore an intervention matrix linking a shared set of age-related determinants to different failure mechanisms and countermeasures, rather than a uniform package defined only by an age threshold.

The scientific contribution of this review is consequently conceptual and hypothesis-generating rather than meta-analytic. It provides a framework for future research in which older road users are classified not only by chronological age and transport mode, but also by functional profile, exposure, and mobility transition. It also indicates that evaluations should follow people across modes and measure both safety outcomes and the preservation of mobility, independence, and social participation. Finally, the comparison supports testing coordinated packages of infrastructure, technology, training, health assessment, and transport alternatives rather than evaluating isolated measures alone. Because the underlying studies are heterogeneous and the review is narrative, the synthesis cannot provide pooled effect estimates or rank interventions by effectiveness. Its value instead lies in making relationships and possible policy trade-offs visible across bodies of evidence that previous reviews have predominantly examined separately.

The cross-cutting conclusions and their practical implications are consolidated in Table 4. The table translates the shared determinants identified across the three roles into coordinated road-safety priorities while retaining the different mechanisms through which risk manifests in driving, walking and cycling.

The practical implication is that older drivers, pedestrians, and cyclists should not be treated as three independent safety categories. Role-specific measures remain necessary, but they should be coordinated within one Safe System and mobility framework so that reducing risk in one role does not unintentionally move an older person toward a less protected mode.

4. Conclusions

Population ageing is increasing the number of people aged 65 and over who participate in road traffic as drivers, pedestrians and cyclists. The evidence synthesised in this review shows that these roles should not be treated as independent safety categories. The same visual, cognitive, motor and physiological changes may contribute to different hazardous situations depending on the traffic task, the surrounding environment and the extent to which infrastructure or technology compensates for functional limitations.

The principal cross-cutting conclusion is therefore that chronological age alone is an insufficient explanation of risk. A more informative framework is the mismatch between an individual's functional capacity, the demands of a particular traffic task and the characteristics of the road environment. This mismatch is expressed differently across roles: in delayed decisions and errors during complex manoeuvres among drivers, difficulty judging speed, distance and crossing time among pedestrians, and loss of stability during mounting, stopping, low-speed riding or sudden manoeuvres among cyclists. Intersections and crossing points concentrate these demands across all three roles and should consequently receive priority in road-safety audits, inspections, speed management and infrastructure programmes.

A second conclusion is that crash occurrence and injury severity represent related but distinct mechanisms. Sensory, cognitive and motor limitations can increase the probability of a conflict or crash, whereas age-related frailty increases the likelihood of serious consequences once an impact occurs. Effective prevention must therefore combine measures that reduce task complexity and crash probability with lower impact speeds, forgiving infrastructure, adapted vehicle and bicycle design, and protective systems that account for the reduced biomechanical tolerance of older people.

Table 4. Cross-cutting findings and practical implications for the integrated safety of older road users. Source: own elaboration

Cross-cutting issue	Manifestation across road-user roles	Integrated finding	Practical road-safety implications
Sensory and cognitive decline	**Drivers:** difficulty at complex intersections, in gap selection and divided-attention tasks **Pedestrians:** difficulty assessing vehicle speed, distance and available crossing time **Cyclists:** difficulty controlling the bicycle while simultaneously monitoring traffic	The same limitations generate different hazardous situations according to the road-user role.	Reduce traffic-task complexity through legible layouts, improved visibility, predictable priority rules and sufficient decision time.
Reduced physical capacity	**Drivers:** restricted neck mobility and slower vehicle-control responses **Pedestrians:** lower walking speed, balance limitations and longer crossing time **Cyclists:** reduced balance, strength and bicycle-control ability	Functional decline affects both crash probability and the capacity to avoid a conflict.	Provide longer crossing times, refuges, forgiving geometry, even surfaces and vehicle or bicycle designs adapted to reduced mobility.
Complex traffic environments	**Drivers:** turning, yielding and intersection manoeuvres **Pedestrians:** road crossing and negotiation of conflicts with vehicles **Cyclists:** intersections, turning and interaction with motor vehicles	Intersections and crossing points concentrate risk across all three roles.	Prioritise these locations in road-safety audits, inspections, speed management and infrastructure improvement programmes.
Biological vulnerability	**Drivers:** greater likelihood of severe injury after a crash **Pedestrians:** high risk of fatal and serious injury in vehicle impacts **Cyclists:** elevated risk of head injuries and fractures	Age-related frailty increases injury severity independently of the role performed.	Combine crash-prevention measures with lower impact speeds and infrastructure, vehicles and protective systems that reduce transferred energy.
Transfer of exposure	**Drivers:** driving reduction or cessation **Pedestrians:** greater reliance on walking and access to public transport **Cyclists:** cycling as a possible alternative to driving	Reducing exposure in one role may transfer rather than eliminate risk.	Assess interventions across the complete mobility chain and provide safe alternatives before or alongside restrictions on driving.
Complementary interventions	**Drivers:** assistance systems, licensing support and targeted health assessment **Pedestrians:** accessible crossings, visibility improvement and speed reduction **Cyclists:** separated infrastructure, safe surfaces, stable bicycles and head protection	Measures directed at only one role do not fully address the mobility needs of an ageing population.	Coordinate infrastructure, technology, education, health assessment and mobility support within a Safe System framework.

No single intervention is sufficient. The strongest practical strategy is a coordinated package comprising legible and predictable infrastructure, speed management, appropriate assistance technologies, education combined where possible with practical training, multidimensional health and functional assessment, and proportionate regulation. Shared measures should be supplemented by role-specific solutions: driver assistance and staged fitness assessment; adequate crossing time, refuges and even pedestrian surfaces; and stable bicycle geometry, support during starting and stopping, safe signalling and head protection. Table 3 links the identified risk mechanisms to the available preventive evidence, while Table 4 integrates these measures into common Safe System priorities.

A third cross-cutting conclusion concerns mobility transitions. Drivers, pedestrians and cyclists are overlapping populations, and one person may move between these roles as functional capacity changes. Restricting or ceasing driving may reduce exposure as a driver but increase walking, cycling or public-transport use. Risk can therefore be transferred rather than eliminated if safe and accessible alternatives are unavailable. The effectiveness of policy should be evaluated across the entire mobility chain and against the combined objectives of safety, independence and social participation.

The added scientific value of this review lies in integrating engineering, behavioural, psychological and medical evidence for the three principal groups of older road users within one conceptual framework. This integration identifies shared determinants, role-specific failure mechanisms, the distinction between crash probability and injury consequences, and the possibility of risk transfer between modes–insights that are less visible in reviews organised around a single road-user role. Because the review is narrative and the included studies are heterogeneous, these conclusions should be interpreted as a conceptual synthesis and a basis for hypothesis development rather than as a quantitative ranking of intervention effectiveness. Future research should follow older people across multiple transport modes and evaluate coordinated intervention packages using outcomes that include both crash reduction and preserved mobility.

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