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Do older drivers (65+) exhibit significant impairments in hazard prediction and attentional processes?

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ABSTRACT

This study pioneers the use of the Hazard Prediction-Orienting Test to examine attentional capture in older drivers (aged 65+). Participants watched short, naturalistic driving videos and were asked to predict what would happen next after the video cut to black just as a developing traffic hazard that would require a behavioral response (e.g., slowing down or changing lanes to avoid a collision) began to emerge. Each trial included three multiple-choice options, with the correct answer corresponding to the developing hazard. Attentional orienting was manipulated through three conditions: simple trials (one developing hazard); valid trials (two hazards: one potential, which does not require driver action, and another developing located nearby); and invalid trials (two hazards: one potential and another developing located at a distance). A total of 141 experienced drivers, grouped by age (middle-aged, young-senior, and elderly) completed the test. A 3 × 3 mixed-effects ANOVA revealed significant main effects by age group and trial type, as well as a significant interaction. Elderly drivers showed the greatest performance decline, specifically under complex hazard conditions (both valid and invalid trials). These results were supported by significant correlations with neuropsychological assessments, including the Trail Making Test, the Useful Field of View (UFOV), and visual function measures such as visual acuity. Furthermore, mediation analysis revealed that the effect of age on hazard prediction in invalid trials was significantly mediated by selective attention, as measured by UFOV subtest 3. These findings suggest that for drivers over 65, both hazard prediction and attentional performance decline to levels comparable to those of inexperienced drivers in our previous study. The test shows promise as a functional assessment tool for identifying age-related declines relevant to traffic safety.

1. Introduction

Driving is associated with wellbeing and quality of life in older adulthood, reflecting independence, cognitive functioning, and the ability to maintain social relationships (Chihuri et al., 2016; Unsworth & Baker, 2014). In fact, the ability to drive in later life is often regarded as a sign of successful aging, as it reflects preserved cognitive function, physical mobility, and independence (Baudouin et al., 2023). However, older drivers face increased risks on the road. According to the Global Status Report on Road Safety (WHO, 2023), approximately 1.19 million people died in traffic accidents in 2021, 23 % of whom were aged 60 or older. In the European Union, the CARE (2023) report documented 20,400 road deaths in 2023, with adults aged 65 and older representing 29 % of fatalities despite comprising only 21 % of the population (https

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://ec.europa.eu/commission/presscorner/detail/es/ip_24_1361). In Spain, adults over 65 accounted for the highest number of fatal crashes in 2024, representing 20 % of the national total (DGT, 2025). Three interrelated factors contribute to the elevated crash risk among older adults: (1) functional limitations; (2) physical vulnerability; and (3) driving exposure and experience. Driving is a complex task that relies on numerous sensory, motor, and cognitive abilities— faculties that often decline with age. For example, age-related changes in vision, cognition, strength, and flexibility can impair performance in challenging traffic situations such as merging, turning, or navigating complex intersections (Karthaus & Falkenstein, 2016). Additionally, compared to younger individuals, older adults are more likely to sustain serious injuries from the same crash impact due to age-related frailty. Further, older adults also account for a disproportionate 23.6 % of all traffic-related injuries (Rolison & Moutari, 2018). Moreover, older drivers tend to travel shorter distances and drive less frequently, which paradoxically increases their crash risk per kilometer driven, a phenomenon known as the "low-mileage bias" (Antin et al., 2017). These risks are particularly concerning in the context of Europe's aging population. European societies are undergoing significant demographic shifts, with a growing proportion of older adults, many of whom continue to hold a driver's license despite potential age-related limitations. The extent of population aging is evident via several indicators. For instance, in 2024, 21.6 % of the European population was aged 65 or older, compared to 16 % in 2001, a 5.6 % increase over two decades (Eurostat, 2024). Given these demographic trends and the increased vulnerability of older drivers, the development of reliable and valid tools to assess fitness to drive is essential. Such measures are critical for guiding targeted health promotion and injury prevention strategies that support both road safety and the autonomy of older adults.

1.1. Older Drivers: Impact of Cognitive and Visual Decline on Driving Safety

Age-related increases in crash risk among older adults are often attributed to declines in both visual scanning efficiency and higher-order cognitive functions, including attention and executive functioning (Milleville-Pennel & Marquez, 2020). While these changes are generally considered part of the normal aging process rather than indicative of pathological decline, they can still undermine the ability to drive safely (Anstey et al., 2005; Mathias & Lucas, 2009; Robertsen et al., 2022). In particular, reductions in processing speed and executive functions, such as planning, anticipation, and decision-making, have been linked to common driving errors in older adults, including delays in braking or making key maneuvers involving interaction with other vehicles or pedestrians (e.g., improper lane changes, failure to yield the right of way) (Baldock, et al, 2007; Peng, et al., 2022; Richardson & Marottoli, 2003). Declines in these cognitive abilities not only impact routine driving behaviors but also undermine older adults' ability to perceive and respond to driving hazards, an essential component of safe driving that has been extensively examined in the literature (Deffler et al., 2024; Horswill et al., 2008, 2010a, 2010b, 2011, 2015; Marrington et al., 2008; Sasaki et al., 2025; Wood et al., 2021; Xu & Bowers, 2024). While much of this research has focused on identifying age-related differences in hazard perception ability, relatively few studies have directly linked slower hazard detection, as measured by traditional hazard perception tests, to increased crash risk. One notable exception is Horswill et al. (2010b), which reported an association between reduced hazard perception speed and accident involvement, highlighting the potential value of targeted training programs to enhance hazard detection skills in older drivers.

To assess age-related cognitive changes, researchers frequently use standardized neuropsychological tools such as the Useful Field of View (UFOV) test and the Trail Making Test (TMT). Performance on these assessments has been shown to correlate with key driving behaviors. For example, McInerney and Suhr (2016) found that lower scores on the UFOV and TMT predict slower reaction times and higher error rates in hazard perception. Similarly, Milleville-Pennel and Marquez (2020) reported that poorer TMT performance is associated with a reduced effective visual field during driving. These cognitive limitations appear to shape compensatory visual strategies in older drivers. Urwyler et al. (2015) observed that while elderly drivers tend to fixate longer on central visual elements, such as traffic signs or vehicles ahead, they check mirrors less frequently than younger drivers. Although this may reflect an adaptive strategy to manage declining processing capacity, it can also limit peripheral awareness and increase vulnerability to overlooked hazards in complex traffic environments. Additionally, age-related challenges may impair older drivers' ability to perform certain tasks, such as turning and changing lanes. These types of errors, which contribute to crashes, tend to increase with age—particularly among drivers aged 75 to 84 (Pae et al., 2025).

These cognitive limitations may also disrupt effective visual scanning. For example, Ma et al. (2020) found that increased cognitive workload during on-road driving, such as varying levels of cognitive distraction, was associated with reduced visual scanning and diminished situational awareness. Analysing older drivers' visual exploration strategies can be an effective way of determining whether they are employing appropriate information search strategies in a visual scene, including adaptation and compensation mechanisms (Milleville-Pennel et al. 2021). Normative aging also brings physiological changes in visual function. These include increased intraocular light scatter, reduced contrast sensitivity, and decreased visual acuity, even in the absence of diagnosed ocular pathologies (Ortiz-Peregrina et al., 2020). These changes compromise the ability to detect and interpret hazards, especially under low-light or high-glare conditions. Hazard perception performance has been shown to correlate with visual metrics such as motion sensitivity and field integrity (Zhang et al., 2020a; Wood et al., 2021), highlighting the integral role of sensory input in hazard detection. Together, these findings underscore the multifactorial nature of hazard perception, involving both cognitive and sensory systems. They suggest that age-related changes in these domains contribute jointly to slower and less effective hazard detection in older drivers, potentially resulting in distinct patterns of driving errors and crash risk across subgroups within the older adult population. But to what extent could this cognitive decline begin before the age of 75?

1.2. Hazard Perception Skills

Hazard perception is a key aspect of driving ability linked to crash risk (Horswill & McKenna, 2004), and it has been shown to decline with age (Horswill et al., 2011). While well-developed hazard perception skills do not guarantee safe driving, their absence poses a significant risk to driver safety (McKenna & Crick, 1991). In the standard hazard perception test, a computer displays videos of traffic scenes from a driver's perspective, and participants must press a button upon detecting a hazard (Horswill, 2016a). The test measures the time taken to identify potential dangers. Wells et al. (2008) found that one year after the hazard perception test was introduced as a requirement for obtaining a driver's license, speed-related road accidents in the UK decreased by 11 %. Researchers have also examined whether improvements in hazard anticipation through these tests translate to real-world driving and contribute to accident reduction (Hill et al., 2019; Horswill, 2016b). The Hazard Prediction Test is an alternative method for assessing a driver's situational awareness (Endsley, 1995) using the question "What happens next?" (WHN). This test evaluates a driver's ability to perceive environmental obstacles, understand their location and context within traffic, and anticipate developing hazards (Jackson et al., 2009). Participants watch videos from a driver's perspective that abruptly cut to black just before a hazard occurs. They must then identify the hazard, determine its location, and predict what will happen next, demonstrating their ability to predict potential hazards. Horswill et al. (2020) found that performance on this test correlates with both driving experience and self-reported accident involvement.

1.3. Manipulations in Road Hazard Types in Hazard Perception and Prediction Studies

Vlakveld et al. (2011) distinguished between *overt* hazards—fully visible—and *covert* hazards, which are partially or temporarily obscured by environmental elements such as parked vehicles or foliage. Crundall et al. (2012) further differentiated hazards based on the type of prediction they require: *behavioural prediction*, such as a pedestrian walking with uncertainty on the pavement and suddenly crossing the street, and those requiring *environmental prediction*, which involves interpreting environmental cues (e.g., a delivery van with its doors open). Similarly, Borowsky and Oron-Gilad (2013) classified hazards as *imminent*, which require immediate evasive action, and *materialized*, which are less urgent and unlikely to lead to a collision.

Visual attention to hazards has also been studied in specific contexts, such as intersections (Robbins et al., 2019) and in response to roadside distractions like advertisements and billboards (Costa et al., 2019; Edquist et al., 2011; Zahabi et al., 2017), often using eye-tracking during simulated driving. Underwood et al. (2013) explored how *abrupt* versus *gradual* hazard onset affects attentional capture, with abrupt hazards triggering faster saccadic responses, while gradual ones require longer processing—especially when drivers are distracted with a secondary task (D'Addario & Donmez, 2019). Attentional capture has also been examined using distractors with varying spatial and feature-based properties. Arexis et al. (2017), for example, embedded red targets in driving scenes and manipulated the color similarity and frequency of distractor appearances. Capture effects were more pronounced when distractors were infrequent and when participants engaged in a secondary task. Pierce and Andersen (2014) similarly found that spatial position and depth of visual stimuli affected attentional capture differentially across young and older drivers.

1.4. Hazard Prediction-Orienting Test

Posner's Spatial Orienting Paradigm (1980) has served as a foundational model in the study of attentional capture. In this task, participants respond to targets preceded by *valid* cues (indicating the correct location) or *invalid* cues (misdirecting attention). Numerous studies have shown that responses are faster and more accurate following valid cues (Chica et al., 2013). Attention may be oriented *endogenously* (voluntarily, top-down) or *exogenously* (involuntarily, bottom-up), and effective attentional functioning depends not only on shifting attention but also on disengaging from irrelevant stimuli (Klein, 2000) (See Fig. 1).

In driving contexts, attentional capture is particularly critical. Sudden hazard onset can automatically attract a driver's focus—even if their attention is currently directed elsewhere (Yantis & Jonides, 1990). The ability to disengage and reorient attention quickly is vital for safe navigation in complex environments (Castro et al., 2016). Building on Posner's model, the Hazard Prediction-Orienting test examines attentional capture by manipulating the number and location of hazards: Our team (Muela et al. (2021) developed this paradigm to assess Hazard Prediction differences in attentional orienting based on driving experience. Mica Endsley's team replicated these findings using multiple measures (accuracy, reaction time, EEG, and fNIRS) using our Hazard Prediction-Orienting test (Festa et al., 2024). And Castro et al. (2025) later identified similar patterns, healthy drivers outperformed stroke survivors, using the same test.

The Hazard Prediction-Orienting test offers two advantages over traditional hazard detection assessments. First, it builds upon one of the most used laboratory paradigms for measuring attentional orientation—the cost–benefit cueing paradigm—and thus allows the measurement of developing hazard detection (i.e., a hazard that requires a behavioral response, such as slowing down or changing lanes) in both attended and unattended locations. To accomplish this, hazards are presented either following a potentially hazardous precursor or not (a potential hazard does not require immediate action). Furthermore, these potential hazards can appear in the same location as the developing hazard (valid trials) or in the opposite location (invalid trials). This design enables the measurement of exogenous attentional capture within complex driving scenes—an aspect not previously assessed in earlier hazard detection tests.

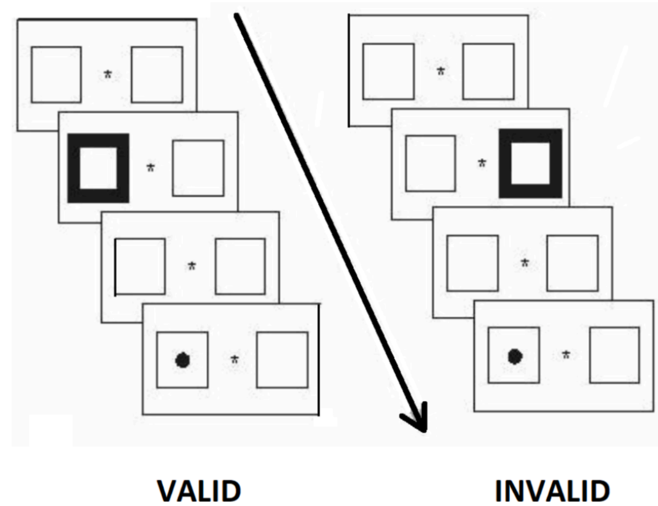


Fig. 1. Spatial Cueing Paradigm. Attention can be directed either endogenously (through internal mechanisms) or exogenously (by external stimuli) (Posner, 1980). Posner's paradigm includes trials with valid and invalid cues. In valid trials, the target appears in the location indicated by the cue. In invalid trials, the target appears in a different location from that indicated by the cue. Detection and discrimination processes are consistently faster following valid cues than invalid ones.

1.5. Research Proposal

This study represents novel research into the combined processes of hazard prediction and attentional capture in older drivers. Understanding the nature of hazard prediction difficulties in aging populations can help inform targeted interventions to improve road safety. Specifically, this is the first study to examine how aging affects accuracy on the Hazard Prediction-Orienting test, which uses the "What Happens Next?" (WHN) question format alongside naturalistic driving videos. This test paradigm offers a method for assessing hazard prediction and attention capture by using complex environments, such as naturalistic traffic scene footage. The first objective was to analyze how hazard prediction accuracy varies with both age and attentional orienting. Participants with prior driving experience were divided into three age groups: middle-aged adults (35–54 years), young-seniors (55–64 years), and elderly drivers (65–85 years). Attentional orienting was manipulated across three trial types: 1) *Simple*, where a single developing hazard appears as the scene cuts off; 2) *Valid*, where a potential hazard cues the spatial location of a subsequent developing hazard; and 3) *Invalid*, where the cue and the developing hazard occur in different spatial locations. The second objective was to explore potential differences between the two older groups—young-seniors and elderly drivers—in terms of their performance across trial types, as well as their cognitive and visual function measures. Cognitive function was treated as a latent variable assessed through neuropsychological tests such as the UFOV and TMT. Visual function was evaluated through concrete measures including visual acuity, contrast sensitivity, and motion sensitivity. The third objective was to examine how performance on the Hazard Prediction-Orienting test is influenced by participant characteristics such as age, cognitive function, and visual ability. This analysis aimed to identify which trial types are most sensitive to individual differences and may therefore serve as early indicators of compromised hazard perception among older drivers.

2. Methods

2.1. Participants

A total of 141 experienced drivers participated in the study. They were divided into three age groups: 39 middle-aged adults (35–54 years of age, 41 % women), 42 young-seniors (55–64 years of age, 60 % women), and 60 elderly drivers (65–85 years of age, 40 % women). Inclusion criteria required participants to have held a valid driver's license for at least eight years, to drive a minimum of 5,000 km per year, and to operate a vehicle at least twice per week. Exclusion criteria included any self-reported history of significant medical or neurological conditions and evidence of global cognitive impairment, as indicated by a score less than or equal to 24 on the Mini-Mental State Examination (MMSE). All participants scored above this threshold and therefore none were excluded on this basis. The sample's descriptive demographic information is provided in Table 1. Participants were recruited via an email sent to the university community, including students, staff, and administrative personnel. Recipients were encouraged to share the invitation with family and friends who met the eligibility criteria. Most participants in the elderly driver group (65 +) were recruited through the AFPA, a university-affiliated educational program for older adults. As a token of appreciation, participants received a small gift (a UGR pen). Prior to participation, all individuals received a detailed explanation of the study and provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Human Research Ethics Committee of the University of Granada (approval number: 750/CEIH/2018).

Table 1
Sociodemographic data of the study's sample of experienced drivers.

	Experienced drivers			
	Middle-aged adults n = 39	Young-seniors n = 42	Elderly drivers n = 60	*p value* [a]
Age (years)				<0.001
Mean *(SD)*	45.7 *(5.37)*	59 *(2.71)*	70.5 *(4.20)*	
Range	35–54	55–64	65–85	
Median	46	59	70	
Educational Level (n, %)				<0.001
Primary	8 (20 %)	3 (7 %)	2 (3 %)	
Secondary	8 (20 %)	1 (2 %)	0 (0 %)	
Sixth form	10 (27 %)	10 (24 %)	15 (25 %)	
Higher Education	13 (33 %)	28 (67 %)	43 (72 %)	
Gender (n, %)				0.11
Women	16 (41 %)	25 (60 %)	24(40 %)	
Men	23 (59 %)	17 (40 %)	36 (60 %)	
Driving experience (years)				<0.001
Mean *(SD)*	24.9 *(6.51)*	38.3 *(4.14)*	48.5 *(6.17)*	
Range	12–37	30–47	22–63	
Median	26	38	49	
Mileage: N° km driven last year				0.002
Mean *(SD)*	21,208 *(19,093)*	11,408 *(5,386)*	11,692 *(5,941)*	
Range	5,000–110,000	5,000–25,000	5,000–35,00	
Median	12,000	10,000	10,000	0.94
Self-reported crashes in the last year (n, %)				
None	35 (90 %)	37 (88 %)	54 (90 %)	
One or more	4 (10 %)	5 (12 %)	6 (10 %)	
Self-reported near-crashes in the last year (n, %)				0.81
None	36 (92 %)	37 (88 %)	55 (92 %)	
One or more	3 (8 %)	5 (12 %)	5 (8 %)	
Points reduction course [b] (n, %)				0.50
No	36 (92 %)	41 (98 %)	58 (97 %)	
Yes	3 (8 %)	1 (2 %)	2 (3 %)	

[a] *p*-values are based on Kruskal–Wallis rank sum test for continuous variables and Pearson's Chi-squared or Fisher's exact test for categorical variables, as appropriate.
[b] Spanish penalty points system.

2.2. Materials and Equipment

2.2.1. Mini-mental State Examination

A comprehensive set of cognitive tests was administered to assess global cognitive function, processing speed, attention, and executive function, as these domains have been shown to be strong predictors of driving ability in healthy older adults (Anstey et al., 2005; Mathias & Lucas, 2009; McInerney & Suhr, 2016). Global cognitive function was assessed using the MMSE (Folstein et al., 1975), a brief cognitive screening test designed to evaluate short-term memory, spatial and temporal orientation, visuospatial skills, executive function, and the ability to follow instructions. Scores range from 0 to 30, with lower scores indicating greater cognitive impairment. Cognitive status is classified as normal (25–30), mild impairment (19–24), moderate impairment (10–18), and severe impairment (0–9) (Vertesi et al., 2001).

2.2.2. Trail Making Test (TMT)

The TMT (Partington & Leiter, 1949) is a brief and easy-to-administer test of processing speed and executive attentional control. It consists of two parts. In Part A, participants connect consecutive numbers (1–24) scattered on a sheet, assessing processing speed. In Part B, they alternate between connecting numbers and letters in sequence (e.g., 1 → A → 2 → B), measuring cognitive flexibility and executive function. Time to completion and number of errors are recorded (Fig. 2). The TMT is a reliable measure (Reitan & Wolfson, 1985) and has been shown to correlate significantly with impaired driving performance in older drivers (Classen et al., 2013; Dobbs & Shergill, 2013; Papandonatos et al., 2015; Stefanidis et al., 2023). Additionally, the TMT is widely used in clinical settings as a screening tool for driving impairment in both cognitively impaired and unimpaired older drivers (Dickerson, 2013). Although evidence supporting the Trail Making Test B cut-offs for fitness to drive at 3 min or 3 errors (the '3 or 3 rule') is limited, a systematic review indicates that these are the most evidence-supported cut-offs available to date (Roy & Molnar, 2013).

2.2.3. Visual Function

Visual acuity is the standardized test used in driver evaluations,

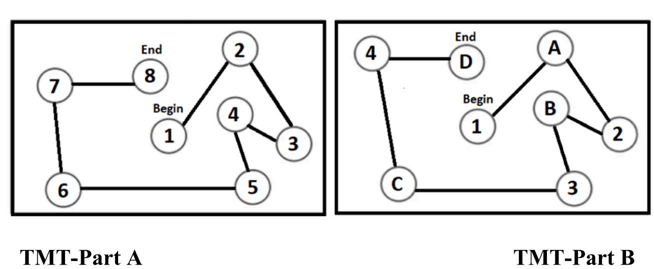


Fig. 2. Example of the Trail Making Test, Part A (left) and Part B (right).

although it has been shown to have limited predictive power for driving safety. Other tests, however, such as motion sensitivity and contrast sensitivity, have been found to anticipate traffic hazards (e.g., Wood et al., 2021). These tests are not included in the evaluation conducted in many countries. Contrast sensitivity is mentioned in Spain's regulations (BOE, 2020 Royal Decree 971/2020, of November 10, which modifies the General Drivers' Regulations), but no specific limit is established; it is simply stated that it must be normal, leaving the judgment to the evaluator's discretion.

Binocular visual acuity and motion sensitivity were assessed using the OptoTab screening test (SmarThings4Vision, Zaragoza, Spain) at a distance of 5.5 m. Visual acuity was expressed in decimal scale. Motion sensitivity was measured using the Coherent Dot Motion perception test (CDM). The test involved a circular array of white dots displayed on a black background, moving randomly in one of four possible directions (upward, downward, left, or right). Within this array, a fixed proportion of dots moved coherently at the same speed and direction, while the remaining dots moved randomly. Before the motion stimulus appeared, a fixation cross was briefly presented at the designated location to guide the participant's gaze. Following this, the dot motion stimulus was displayed, and after its disappearance, participants were required to indicate the perceived direction of global motion. Motion detection was evaluated across four levels of motion coherence (10 %, 20 %, 30 %, and 40 %), with the average performance recorded. The test parameters included a stimulus duration of 300 ms, a dot density of 10 dots per degree, and a coherent dot motion speed of 7 degrees per second. At the end of the test, a value ranging from 0 to 1 was assigned for each motion coherence level. Higher values indicated greater motion sensitivity.

Contrast sensitivity was evaluated using the CSV-1000 test (Vector Vision, Ohio, USA) at 2.5 m. Four different spatial frequencies were measured: 3, 6, 12, and 18 cycles per degree (cpd). Results were expressed in log units, with higher values indicating greater contrast sensitivity (Fig. 3).

2.2.4. UFOV Test

UFOV test (Edwards, et al., 2006) is a computer-based assessment designed to evaluate visual processing speed, divided attention, and selective attention. It consists of three subtests of increasing cognitive complexity. *Subtest 1: Processing Speed* – Participants must quickly identify a car or truck displayed at the center of a screen. The stimulus presentation speed varies (40–240 ms), and the test concludes when participants can no longer identify the stimuli with at least 75 % accuracy. *Subtest 2: Divided Attention* – Participants must recognize a central vehicle (car or truck) while simultaneously detecting a randomly positioned symbol in the periphery at 8 different radial angles and varying distances (see Fig. 4). *Subtest 3: Selective Attention* – Similar to the divided attention subtest, this task presents both central and peripheral stimuli simultaneously. However, the peripheral object is displayed against a cluttered background containing distracting elements (triangles). Performance on each subtest is measured by response accuracy, expressed as average reaction times in milliseconds (ranging from 0–500 ms) (Akinwuntan et al., 2010). Research has shown that UFOV performance is a strong predictor of driving outcomes, including crash involvement, as well as on-road and simulated driving performance in older drivers (Mathias & Lucas, 2009; Gentzler & Smither, 2012; Stefanidis et al., 2023).

The UFOV employs a two-step adaptive staircase algorithm to estimate performance thresholds and adjust the difficulty of subtests (i.e., stimulus duration). After completing the test, threshold performance for each subtest is displayed in milliseconds, with descriptive cutoffs spanning from "normal" to "severe." Lower scores reflect better performance (see Table 2, UFOV cut-offs).

2.2.5. Hazard Prediction-Orienting Test

The hazard prediction videos were recorded in Granada, Spain, using four GoPro4 Black cameras: one for the central view and three for the side and rear mirrors (Fig. 5). Each video was recorded at 1080p resolution and 50 frames per second and presented in full HD (1920 × 1080) using E-Prime 2.0 (Psychology Software Tools, Schneider et al., 2002). Participants responded using a numeric keypad. The test applied in the present study is based on the version developed by Muela et al. (2021). From an initial pool of over 300 recorded driving scenarios, 48 clips were selected and categorized into simple, valid, and invalid trial types. However, following psychometric analysis, 9 clips (3 from each trial type) were removed due to low or negative item-total correlations, resulting in a final version with 39 clips. This 39-item version showed acceptable internal consistency (Cronbach's α = 0.731) and has been adopted in subsequent studies using this paradigm (e.g., Festa et al., 2024). Next, participants answered 39 multiple-choice "What happens Next" (WHN) questions after each video. The instructions provided were

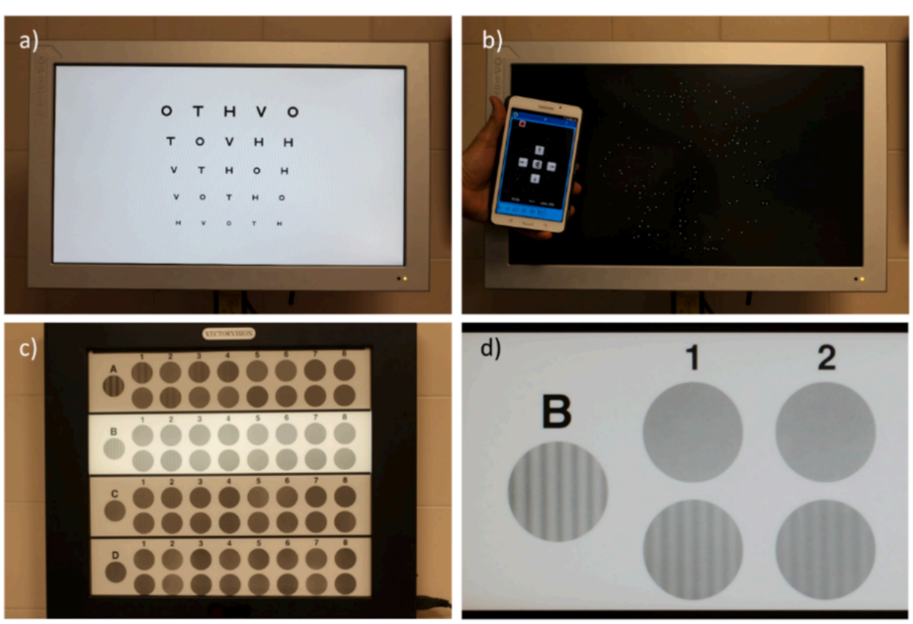


Fig. 3. The 3 tests used to assess visual function: a.) Visual acuity; b.) Motion sensitivity (the test operating tablet is displayed), and c.) Contrast sensitivity. Image d.) shows detail of one of the evaluated spatial frequencies (6 cpd).

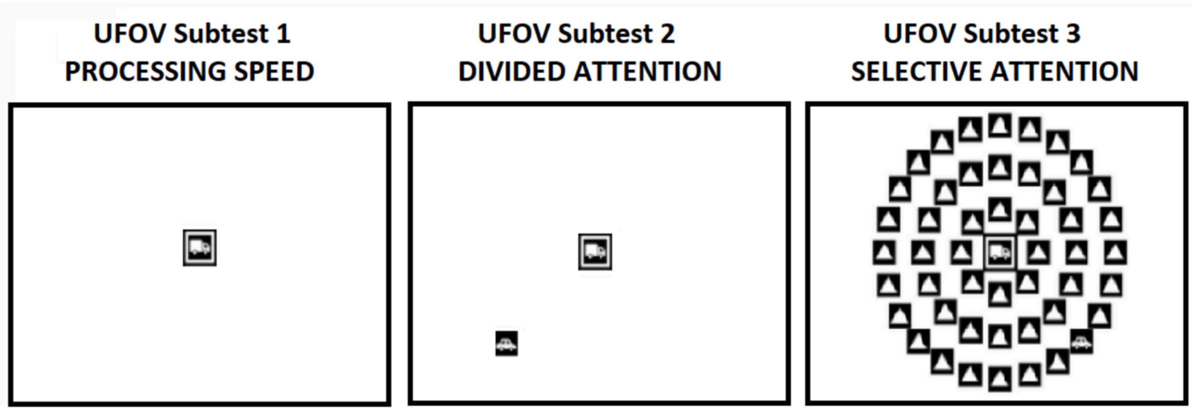


Fig. 4. Examples of the Useful Field of View subtests.

Table 2
Estimated UFOV subtest cut-off points (Ball et al., 2002; Wolinsky et al., 2009).

UFOV Subtest	Processing Speed Score (in milliseconds, ms.)
UFOV-1	$> 0 \leq 30$ Normal central vision and processing speed $> 30 \leq 60$ Normal central vision but somewhat slowed processing speed $> 60 < 350$ Central vision loss and/or slowed processing speed $\geq 350 \leq 500$ Severe central vision loss and/or very slowed processing speed
UFOV-2	$> 0 < 100$ Normal divided attention ability $\geq 100 < 350$ Some difficulty with divided attention $\geq 350 \leq 500$ Severe difficulty with divided attention
UFOV-3	$> 0 < 350$ Normal selective attention ability $\geq 350 < 500$ Some difficulty with selective attention 500 Severe difficulty with selective attention

as follows: "*In this test, you will watch 39 driving videos recorded from a driver's perspective. It is very important that you watch these videos as if you were driving the vehicle. The videos abruptly cut to black just before a hazard begins to develop; that is, when an obstacle starts to appear on the road, requiring you to react by performing an evasive maneuver to avoid hitting it (e.g., by releasing the accelerator, braking, or altering the vehicle's trajectory). Your task is to answer the question: What will happen just as the* video *cuts off? Specifically, what obstacle would you hit if you didn't perform an evasive maneuver? You will be given three alternative answers on the screen, each describing how the hazardous situation might develop. After selecting your answer, the next video will start.*".

An example of each trial condition is shown in Fig. 5, with the correct answer indicated in bold. The order of the correct response was randomized for each participant. A comprehensive description of the video stimuli, including examples for each experimental condition, is available in the supplementary materials provided by Muela et al. (2021).

2.3. Procedure

Before beginning the assessment session, participants were given detailed information about the study and were asked to provide written informed consent. Once consent was obtained, the evaluation began. All participants were assessed individually in quiet, isolated rooms. First, participants provided sociodemographic information, including age, gender, years of education, and number of years holding a driver's license. They were then administered the MMSE to screen for cognitive impairment. All participants scored above 24, allowing the remaining assessments to proceed. Next, participants completed the TMT Parts A and B using pencil and paper. Completion times for each part were recorded with a stopwatch. For the visual function assessments—visual acuity, contrast sensitivity, and motion sensitivity—stimuli were presented on a display positioned at a fixed distance from the participant. Responses were recorded using a tablet. The computer-based tests, including the UFOV and the Hazard Prediction–Orienting Test, were conducted with participants seated approximately 60 cm from the laptop screen. Before each test, participants read and confirmed their understanding of the instructions and completed a set of practice trials. Lastly, participants were asked about their traffic history, including fines, points on their license, near-crashes, and accidents. The entire session lasted approximately 60 to 75 min. For an overview of the procedure, see Fig. 6.

2.4. Data Analysis

Data analysis was conducted in R (version 4.3.2; R Core Team, 2023) using RStudio (version 1.3.1093) for macOS. A 3 × 3 mixed-effects ANOVA was first performed using the *ez* package (version 4.4–0; Lawrence, 2016) to examine differences in hazard prediction accuracy across three groups of experienced drivers: middle-aged adults; young-seniors; and elderly drivers. Driver age group was treated as a between-subjects factor, while attentional orienting condition (invalid, valid, and simple trials) was included as a within-subjects factor. Effect sizes were reported using partial eta squared (η_p^2). Subsequently, a multivariate analysis of variance (MANOVA) was conducted using the *stats* package (base R) to assess group differences in cognitive and visual function measures between the two older age groups (young-seniors vs. elderly drivers). Significant multivariate effects were followed up with univariate F-tests. Assumptions for this analysis were evaluated using the *rstatix* (version 0.7.2; Kassambara, 2023), *mvnormalTest* (version 1.0.1; Zhang et al., 2020b), and *heplots* (version 1.7.3; Fox et al., 2024) packages. In addition, Spearman's rank-order correlations were computed between Hazard Prediction–Orienting accuracy (simple, valid, and invalid trials) and all continuous predictors, including age, UFOV subtests, TMT A and B, and visual function measures (visual acuity, motion sensitivity, and contrast sensitivity). Spearman's method was selected due to the presence of significant skewness in most variables, except for age and contrast sensitivity, which met normality assumptions.

Finally, a multiple mediation analysis (Model 4 of PROCESS for R; Hayes, 2022) was conducted to assess whether the relationship between age and percentage accuracy on invalid trials was mediated by cognitive and visual function measures that showed moderate correlations in the previous analyses. This approach allowed for the examination of indirect effects of age via relevant cognitive and/or visual pathways. The significance of the effects was estimated using bootstrapped confidence intervals based on 5000 samples (Hayes & Rockwood, 2017). Standard regression diagnostic analyses were carried out using the *performance* R package (version 0.10.1; Lüdecke et al., 2021). All statistical tests were

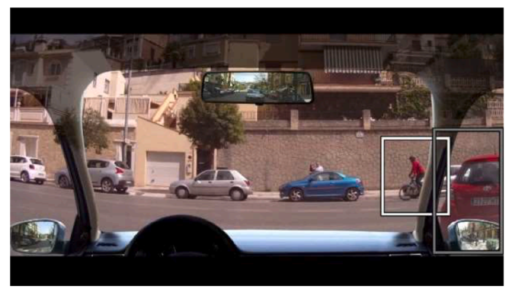
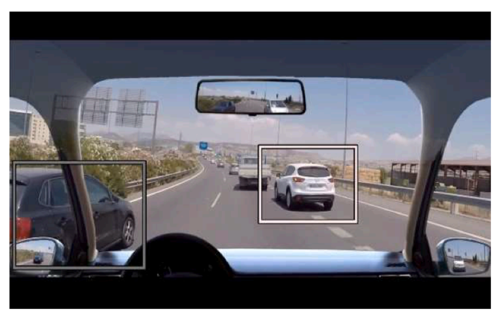
Video N. º (sec.)	Potential & Developing Hazard	*"What will happen after the video is cut?"* (the order of the three response choices was randomised between participants)	Last frame before the cut
A) Simple trial			
13 (17')	**Developing hazard (target):** A motorbike is approaching from the left and is encroaching on our lane.	**- A motorbike is approaching from the left and is encroaching on our lane.** - A pedestrian is walking on the left-hand pavement and crosses our lane. - A pedestrian is approaching from the right and crosses the road.	
B) Valid trial			
10 (13'')	**Developing hazard (target):** The cyclist pulls out in front of us on the lane we are joining. **Potential hazard (invalid key):** - A car coming towards us.	**- The cyclist pulls out in front of us on the lane we are joining.** - The red car in front of us brakes and goes into reverse. - The pedestrians on the pavement opposite cross the road.	
C) Invalid trial			
1 (11'')	**Developing hazard (target):** The white car on the right is joining the motorway and encroaching on our lane. **Potential hazard (invalid key):** A dark car overtaking in the left-hand lane.	**- The white car on the right is joining the motorway and encroaching on our lane.** - A black car coming from the other lane overtakes us on the left and moves into our lane. - The van in front of us brakes sharply.	

Fig. 5. Description of 3 examples of hazard situations in which the orientation is manipulated: A) *Simple*; B) *Valid*; and C) *Invalid* trials. The grey marker represents the potential hazard (which does not require the driver to take action) and the white marker represents the developing hazard (which does require a behavioral response, e.g., slowing down or changing lanes to avoid a collision). The correct response is indicated in bold.

performed using a 95 % confidence level, with *p*-values adjusted for multiple comparisons using the Bonferroni correction where appropriate. To assess the adequacy of the sample size, a post hoc sensitivity power analysis was conducted using G*Power 3.1 (Faul et al., 2009). Assuming an alpha level of 0.05 and a statistical power of 0.95, the analysis indicated that for the study's total sample (n = 141), the minimum detectable effect size in a repeated-measures ANOVA with three groups was $\eta_p^2 = 0.11$. According to Cohen (1988), this corresponds to a medium effect size. Thus, the sample was deemed sufficient to detect the critical interactions relevant to the study's objectives.

3. Results

The internal consistency of the Hazard Prediction–Orienting test was assessed using Cronbach's alpha. Across the 39–item scale, α = 0.696, approaching the conventional 0.70 benchmark. Muela et al. (2021) reported a Cronbach's alpha of 0.731, indicating acceptable reliability of their scale.

3.1. Part I: 3 Age x 3 Attention Capture on Hazard Prediction

Before analyzing the results of the 3 × 3 mixed-effects ANOVA, Box's M test for equality of covariance matrices was conducted to assess the assumption of homogeneity of variance. The results of Box's M test revealed a significant result (*Box's M* = 37.531, $p < 0.001$), indicating that the assumption of homogeneity of covariance matrices was not met. However, the assumption of sphericity was supported by Mauchly's test (p = 0.440). The descriptive statistics of the results are presented in Table 3.

A **significant main effect of attentional orienting** [F (2,276) = 179.52, $p < 0.001$, $\eta_p^2 = 0.565$] was found. Significantly higher accuracy percentage scores were observed for Simple trials (*Mean*, *M* = 87.5, Standard Deviation, *SD* = 8.26), followed by Valid trials (*M* = 78.24, *SD* = 14.71) and Invalid trials (*M* = 65.43, *SD* = 14.41). Pairwise comparisons yielded significant differences between Invalid and Simple trials (*Mean Difference*, *MD* = 22.63, *Standard Error*, *SE* = 1.15, $p < 0.001$, $\eta_p^2 = 0.46$), between Invalid and Valid trials (*MD* = 12.84, *SE* = 1.26, $p < 0.001$, $\eta_p^2 = 0.15$) and between Valid and Simple trials (*MD* =

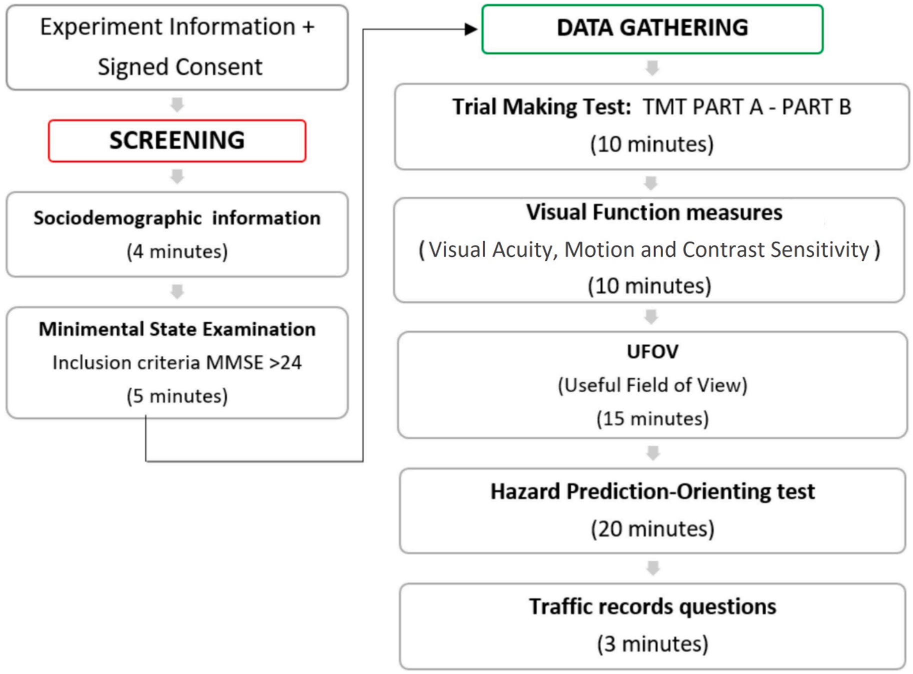


Fig. 6. Procedure description. Experiment duration was approximately between 60 and 75 min.

Table 3
Descriptive statistics for accuracy percentages on the Hazard Prediction-Orienting test across different age groups of experienced drivers.

Accuracy % Hazard Prediction Score		N	*Mean*	*(SD)*	*SE*	CI 95 % Lower	CI 95 % Upper	Min	Max
Invalid	**45-54 years old (Middle-age adults)**	39	71.4	*(11.8)*	1.89	67.6	75.2	46.2	92.3
	55-64 years old (Young-seniors)	42	66.8	*(10.7)*	1.65	63.5	70.2	46.2	84.6
	65-85 years old (Elderly drivers)	60	57.8	*(15.5)*	2.00	53.8	61.8	15.4	84.6
Valid	**45-54 years old (Middle-age adults)**	39	81.1	*(10.27)*	1.64	77.7	84.4	61.5	100
	55-64 years old (Young-seniors)	42	83.5	*(9.84)*	1.52	80.4	86.6	61.5	100
	65-85 years old (Elderly drivers)	60	70.0	*(16.92)*	2.18	65.6	74.4	30.8	100
Simple	**45-54 years old (Middle-age adults)**	39	89.7	*(7.56)*	1.21	87.3	92.2	76.9	100
	55-64 years old (Young-seniors)	42	90.1	*(7.27)*	1.12	87.8	92.4	76.9	100
	65-85 years old (Elderly drivers)	60	84.1	*(11.23)*	1.45	81.2	87.0	53.8	100

9.79, $SE = 1.19$, $p < 0.001$, $\eta_p^2 = 0.12$).

We also found a **significant main effect for driver age group** [F (2,138) = 20.31, $p < 0.001$, $\eta_p^2 = 0.227$]. Middle-aged adults ($M = 80.7$, $SD = 9.42$) and young-seniors ($M = 80.23$, $SD = 13.43$) had higher accuracy percentage scores than elderly drivers ($M = 70.62$, $SD = 17.28$). Post hoc multiple comparisons showed significant differences between middle-aged adults and elderly drivers ($MD = 10.10$, $SE = 1.86$, $p < 0.001$, $\eta_p^2 = 0.10$) and between young-seniors and elderly drivers ($MD = 9.52$, $SE = 1.82$, $p < 0.001$, $\eta_p^2 = 0.08$). No significant differences were found between middle-aged adults and young-seniors. The Games-Howell correction was used for those comparisons that violated the homogeneity of variance assumption.

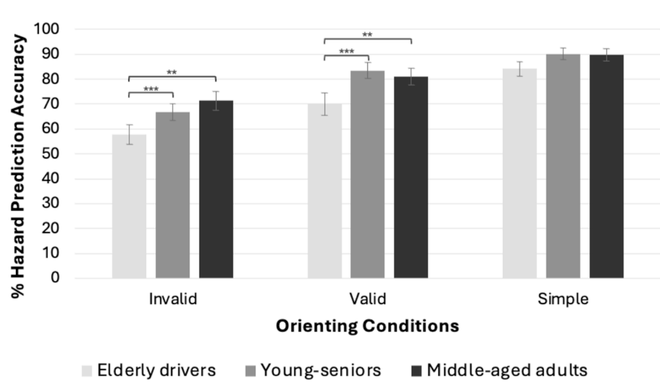


Fig. 7. Percentage accuracy on the Hazard Prediction-Orienting test across conditions (invalid, valid and simple) and age groups. Error bars represent standard errors. Note: * $p < 0.05$, ** $p < 0.01$, ***, $p < 0.001$.

The interaction between attentional orienting and driver age group was significant [F (4,276) = 3.47, $p < 0.01$, $\eta_p^2 = 0.048$, indicating a small-to-moderate effect size, slightly below the conventional threshold for a moderate effect of 0.06] (see Fig. 7). Elderly drivers demonstrated impaired performance compared to both middle-aged and young-seniors across both valid and invalid conditions (all p-values < 0.05 after Bonferroni correction). Specifically, in invalid conditions, elderly drivers were less accurate than middle-aged adults (MD = 13.580, SE = 2.72, $p < 0.001$, $\eta_p^2 = 0.18$) and young-seniors (MD = 9.029, SE = 2.66, $p = 0.032$, $\eta_p^2 = 0.09$). In valid conditions, they also showed lower accuracy than both groups (middle-aged adults: MD = 11.065, SE = 2.76, $p = 0.004$, $\eta_p^2 = 0.12$; young-seniors: MD = 13.516, SE = 2.70, $p < 0.001$, $\eta_p^2 = 0.17$). No significant differences were observed between middle-aged and young-seniors. Descriptive statistics for these results are presented in Table 3.

3.2. Part II: Age and Hazard Prediction, Cognitive and Visual Function Measures

A MANOVA was performed to identify differences in the cognitive and visual function measures across the two older driver groups (young-seniors vs. elderly drivers). Prior to conducting this analysis, the assumptions of multivariate normality and homogeneity of variance–covariance matrices were assessed. Results of *Box's M* test indicated that the assumption of homogeneity of covariance matrices was violated (*Box's* $M = 133.121$, $p < 0.001$), and therefore, a more robust version of MANOVA (e.g., *Pillai's trace*) was used. The analysis revealed a significant multivariate main effect, *Pillai's trace* $= 0.307$, $F(14, 84) = 2.66$, $p = 0.005$, $\eta_p^2 = 0.307$, indicating that age group significantly influenced the outcome variables. Results of the univariate follow-up tests are presented in Table 4.

3.3. Part III: Relationship Between Measures

Results from the Spearman correlation analyses (Table 5) revealed significant relationships between hazard prediction accuracy and several cognitive and visual function measures. Age was moderately and negatively correlated with performance across all trial types, with the strongest correlation observed in valid trials ($r_s = -0.439$, $p < 0.001$). Among the UFOV subtests, Subtest 3 (selective attention) showed the strongest associations, particularly with invalid trials ($r_s = -0.476$, $p < 0.001$). Performance on the Trail Making Test also correlated negatively with hazard prediction, especially for Trail A completion time in invalid and valid trials. Regarding visual measures, visual acuity was positively correlated with accuracy in simple and invalid trials, while contrast and motion sensitivity showed no significant associations. These findings suggest that selective attention and particularly age-related cognitive decline impact performance under more complex driving scenarios.

Next, due to moderate significant correlations found between UFOV subtests 2 and 3, age, and the invalid trials, a mediation analysis was conducted to examine whether the effect of age on accuracy in invalid trials was mediated by these attentional factors. To meet the assumptions of normality and homoscedasticity, the dependent variable (percentage accuracy in invalid trials) was transformed using a logit transformation. This transformation is appropriate for proportion data bounded between 0 and 1 and allowed for more reliable estimation of model parameters (Seiffert et al., 2024). The resulting logit-transformed accuracy variable was used in the mediation analysis as the outcome variable, with age as the predictor and UFOV subtests 2 and 3 as mediators. The total effect of age on accuracy was significant ($p = 0.012$), indicating that older age was associated with diminished percentage accuracy on invalid trials. However, the direct effect of age on accuracy became nonsignificant when UFOV subtests 2 and 3 were included as mediators ($p = 0.456$), suggesting that the relationship between age and accuracy is fully mediated by these attentional factors. The indirect

Table 5
Spearman correlations between the percentage accuracy on the Hazard Prediction-Orienting test and age, UFOV, TMT, and visual function measures.

	% Hazard Prediction-Orienting Accuracy		
	Invalid Trials	Valid Trials	Simple Trials
Age	**−0.398*** **	**−0.439*** **	**−0.272** **
Useful Field of View			
UFOV 1: Processing speed	**−0.286** **	**−0.257* **	−0.185
UFOV 2: Divided attention	**−0.366*** **	−0.138	−0.017
UFOV 3: Selective attention	**−0.476*** **	**−0.273*** **	**−0.232* **
Trail Making Test			
Trail A (sec)	−**0.253***	**−0.252***	−0.093
Trail A errors	0.031	0.157	0.064
Trail B (sec)	**−0.200***	−0.096	−0.065
Trail B errors	−0.143	−055	0.005
Visual Function Measures			
Visual acuity	**0.279** **	0.134	**0.307** **
Motion sensitivity	0.114	−0.060	0.174
Contrast sensitivity	0.141	0.077	0.115

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Moderate Significant Correlations between 0.3 and 0.5
Weak Significant Correlations below 0.3

Table 4
Group differences in the performance of the Hazard Prediction-Orienting test, cognitive and visual function measures.

	Young-seniors **(55–64 years)** n = 42	Elderly drivers **(65–85 years)** n = 60	Significance tests[a] Pillai's trace = 0.307 $F(14, 84) = 2.66$**	$\eta_p^2 = 0.307$
% Hazard Prediction-Orienting	Mean *(SD)*	Mean *(SD)*		
Simple Trials	90.11 *(7.26)*	84.10 *(11.23)*	$F(1,97) = 7.52$**	$\eta_p^2 = 0.072$
Valid Trials	83.52 *(9.84)*	70 *(16.92)*	$F(1,97) = 21.53$***	$\eta_p^2 = 0.182$
Invalid Trials	66.85 *(10.68)*	57.82 *(15.48)*	$F(1,97) = 10.29$***	$\eta_p^2 = 0.092$
Mini-mental	28.90 *(0.93)*	28.62 *(1.22)*	$F(1,97) = 0.81$	$\eta_p^2 = 0.008$
Trail Making Test (TMT)				
TMT-A sec	45.38 *(11.65)*	56.48 *(20.40)*	$F(1,97) = 9.18$**	$\eta_p^2 = 0.086$
TMT-A errors	0.05 *(0.22)*	0.06 *(0.30)*	$F(1,97) = 0.12$	$\eta_p^2 = 0.001$
TMT-B sec	91.38 *(33.97)*	120.87 *(62.05)*	$F(1,97) = 7.93$**	$\eta_p^2 = 0.076$
TMT-B errors	1.05 *(2.38)*	1.40 *(2.51)*	$F(1,97) = 1.02$	$\eta_p^2 = 0.01$
Useful Field of View (UFOV)				
UFOV 1	18.97 *(11.46)*	26.02 *(23.60)*	$F(1,97) = 2.79$	$\eta_p^2 = 0.028$
UFOV 2	46.66 *(17.14)*	67.95 *(32.98)*	$F(1,97) = 12.57$***	$\eta_p^2 = 0.115$
UFOV 3	140.25 *(37.51)*	193.89 *(66.98)*	$F(1,97) = 20.29$***	$\eta_p^2 = 0.173$
Visual Function Measures				
Visual acuity	1.15 *(0.16)*	1.08 *(0.18)*	$F(1,100) = 3.37$	$\eta_p^2 = 0.034$
Motion sensitivity	0.61 *(0.19)*	0.62 *(0.20)*	$F(1,100) = 0.02$	$\eta_p^2 = 0.001$
Contrast sensitivity	1.64 *(0.17)*	1.54 *(0.24)*	$F(1,100) = 5.92$*	$\eta_p^2 = 0.058$

Note*: * < 0.05, ** < 0.01, ***< 0.001*
[a] Statistics are the results of a multivariate analysis of variance (MANOVA), where all cognitive and visual function measures were entered as dependent variables, with age group as the independent variable with the results of Pillai's Trace statistic.

Table 6
Regression coefficients and bootstrapped confidence intervals for the multiple mediation model of age on percentage accuracy in invalid trials through UFOV subtests 2 and 3.

Term	Estimate	SE	t	Bootstrapping 95 % CI[1]	
				Lower levels	Upper levels
Total Effect (c):					
Age → % Invalid trials	−0.022*	0.009	−2.56	−0.039	−0.005
Direct Effect (c'):					
Age → % invalid trials	−0.007	0.009	−0.75	−0.024	0.011
Indirect effects:					
Age → UFOV2 → % Invalid trials	−0.002	0.005	−0.35	−0.010	0.008
Age → UFOV3 → % Invalid trials	−0.014**	0.005	−2.63	−0.033	−0.003
Total Indirect:					
Age → UFOV2/UFOV3 → % Invalid trials	−0.016*	0.007		−0.032	−0.005
Model Summary:	$R^2 = 0.25$, $F_{(3,94)} = 10.59$**				

[1]Based on $n = 5000$ bootstrap samples.
SE = standard error; Significance levels: * $p < 0.05$, ** $p < 0.01$.

effect through UFOV subtest 3 was significant ($p = 0.008$), whereas the indirect effect through UFOV subtest 2 was not significant ($p = 0.726$). These results suggest that selective attention (UFOV subtest 3) significantly mediates the relationship between age and percentage accuracy on invalid trials, whereas divided attention (UFOV subtest 2) does not. The overall indirect effect of age on percentage accuracy in invalid trials through both mediators was significant (95 % CI [-0.032, −0.005]). See Table 6 for detailed results.

4. Discussion

4.1. How Does Hazard Prediction Accuracy Vary with Age and Attentional Orienting?

The first aim of this study was to examine how aging affects accuracy on the Hazard Prediction-Orienting test, which uses the "What Happens Next?" (WHN) question format with naturalistic driving videos. Within the more complex context of driving, our findings replicate the effects of attentional orienting previously demonstrated in controlled laboratory settings (Chica et al., 2013). Specifically, simple trials including a single developing hazard elicited the highest levels of hazard prediction accuracy across participants. In contrast, performance declined in both valid and invalid trials, with the largest performance decrease observed in invalid trials, where participants had to divide attention between two spatially distinct hazards. These results suggest that attentional competition in complex visual environments significantly impairs hazard detection, particularly when spatial cues are presented in multiple locations. Our findings are consistent with previous research by Muela et al. (2021), which used the same Hazard Prediction-Orienting test in drivers with different levels of experience, and with under review, which extended the paradigm to stroke participants. Similarly, Festa et al. (2024) observed this pattern in a sample of younger drivers (n = 42; age range: 18–55 years, M = 22.5, SD = 6.4), using EEG and fNIRS measures to explore the neural correlates of attentional orienting during hazard prediction. Collectively, these studies reinforce the robustness of our findings and underscore the task's sensitivity to both age and attentional load in dynamic driving scenarios.

Elderly drivers (65 +) exhibited significantly lower accuracy in predicting road hazards compared to younger seniors, with no significant differences between the younger seniors and middle-aged groups. Of particular concern was the elderly group's performance, which deteriorated to levels comparable to that of inexperienced drivers in our previous study (Muela et al., 2021). Importantly, elderly drivers showed significant impairment in both valid and invalid trials, suggesting that individuals over the age of 65 have greater difficulty managing attention across multiple spatial locations. This finding highlights the challenges older drivers face in dividing attention, which may be exacerbated by the cognitive changes associated with aging. With increasing life expectancy, many individuals over the age of 65 continue to drive, underscoring the need for awareness regarding this decline in driving performance.

These results partially replicate the age effect found in traditional Hazard Perception tests, which measure RTs. Specifically, our findings are consistent with those of Zhang et al. (2020a), which reported a 350 ms increase in RTs with age in a simulated Hazard Perception test, suggesting a slowing of hazard detection with aging. However, our results only partially align with those of Horswill et al. (2009), which compared hazard perception in traditional RT-based tests across three age groups: middle-aged drivers (35–55 years), younger-old drivers (65–74 years), and older-old drivers (75–84 years). Horswill's study found no significant RT differences between middle-aged and younger-old groups, whereas the older-old group exhibited significantly slower RTs. In contrast, our study found significant differences in hazard prediction accuracy between the 55–64 and 65–85 age groups, with notable performance declines observed in drivers as young as 65, approximately 10 years younger than those in Horswill's study. Our findings also diverge from those of Borowsky et al. (2010), which reported minimal impairment in hazard anticipation among younger older drivers (ages 65–72) with extensive driving experience. Similarly, Sasaki et al. (2025) found no significant differences between middle-aged and older drivers in a traditional Hazard Perception test. These studies suggest that extensive driving experience may offset some age-related declines. However, the current results indicate that the Hazard Prediction-Orienting test, which emphasizes attentional orienting across trial types, may be more sensitive than traditional RT-based tests in detecting subtle age-related differences in driving performance. This conclusion aligns with Ventsislavova et al. (2019), which demonstrated the superior sensitivity of the Hazard Prediction tests over traditional tests in differentiating drivers with varying experience levels across multiple countries, including China, Spain, and the UK.

Overall, these results provide valuable insights for driver safety and policy development, particularly in enhancing driving assessments for older adults. Our findings highlight the importance of considering attentional factors when evaluating the driving performance of elderly drivers. Specifically, the results suggest that the Hazard Prediction-Orienting test offers a more nuanced and sensitive measure of age-related declines in hazard perception compared to traditional reaction time-based tests. This is especially crucial given the growing aging population and the associated traffic safety risks. Moreover, our study emphasizes the need to promote safe driving habits among drivers over 65, an area that has been underrepresented in prior research. As noted in a recent Directorate-General for Traffic report there is an urgent need for better detection of health conditions and more comprehensive fitness-to-drive evaluations (Castro et al., 2024). These findings support further exploration of alternative testing methods that more accurately capture the complexities of hazard detection across age groups. Ultimately, this research advocates for targeted intervention programs and refined driving assessments that address the unique challenges faced by older drivers, with the goal of reducing accident risk and promoting safer driving practices within this demographic.

4.2. Performance Differences Between Young-Seniors and Elderly Drivers Across Cognitive and Visual Function Measures

The second aim of this study was to examine potential differences in cognitive and visual performance between the two older age groups: young-seniors and elderly drivers. While no significant differences emerged in global cognitive functioning as measured by the MMSE, age-related declines were evident in specific cognitive domains, particularly attention and executive functioning. In the UFOV assessment, elderly drivers performed significantly worse than their younger-senior counterparts on UFOV subtest 2 (divided attention) and UFOV subtest 3 (selective attention), highlighting age-related impairments in the ability to process and prioritize multiple visual stimuli. Although a similar trend was observed in UFOV-1 (processing speed), the difference did not reach statistical significance. Nevertheless, a subset of elderly participants exceeded the 30-point clinical threshold on UFOV subtest 1, which may reflect declines in central visual processing or generalized cognitive slowing (Ball et al., 2002; Wolinsky et al., 2009). These findings align with prior research demonstrating progressive deterioration in UFOV performance with advancing age (Ball et al., 1988; Edwards et al., 2006; Lunsman et al., 2008; Rao et al., 2013). According to these results, the capacity to divide attention between central and peripheral stimuli, a function critical for safe driving, is particularly vulnerable in older adults and becomes further compromised under increased cognitive load (Sekuler et al., 2000). Furthermore, older drivers in our sample also demonstrated slower completion times on both TMT-A (sequential number tracking) and TMT-B (number-letter alternation). This result is consistent with previous studies showing that TMT performance tends to decline with age (Hashimoto et al., 2006; Specka et al., 2021), likely due to a general age-related slowing of central cognitive processes, particularly cognitive flexibility, visual attention, and task-switching abilities. Taken together, the UFOV and TMT results reinforce the impact of aging on core cognitive processes essential for safe driving, particularly attentional control, cognitive flexibility, and processing speed. The consistent slowing observed in elderly participants underscores the value of incorporating cognitive screening tools into driver assessments to more effectively identify those at elevated risk.

In terms of visual function, all participants had normal or corrected vision, and no significant age-related differences were found in either visual acuity or motion sensitivity. However, contrast sensitivity did differ significantly between younger-senior and older-senior drivers. According to Horswill et al. (2008), hazard perception response times increased significantly with age; and this age-related decline was largely explained by reductions in contrast sensitivity and useful field of view. And Swan et al. (2019) found that loss of contrast sensitivity was a stronger predictor of detection performance than visual acuity, although it is not measured for licensure. Reduced contrast sensitivity was significantly correlated with an increased risk of safety-related events (Guo et al, 2015). And it may also play a crucial role in night-time hazard detection performance (Jones et al., 2022).

Overall, while basic visual function appeared preserved in our sample, age-related declines in cognitive flexibility, divided attention, and contrast sensitivity were evident. These findings highlight the importance of multidimensional assessments that include both cognitive and visual components. Integrating such measures into fitness-to-drive evaluations could help identify subtle declines not captured by standard vision tests, ultimately contributing to safer mobility for older drivers.

4.3. What Factors Account for Performance Accuracy in the Hazard Prediction-Orienting Test?

The third aim of this study was to explore how individual characteristics influence performance on the Hazard Prediction-Orienting test. Significant correlations between performance across simple, valid, and invalid trials and established cognitive measures, such as the TMT and UFOV, suggest that this tool captures critical psychological domains fundamental to safe driving in older adults without global cognitive impairment.

One factor that notably influenced hazard prediction performance was the UFOV. Specifically, performance on invalid trials, where potential hazards appear in different spatial locations, was negatively correlated with all three UFOV subtests. These scenarios demand enhanced visual attention, particularly divided and selective attention, and rapid processing speed, aligning closely with the attentional challenges of real-world driving. Consistent with this, prior research has demonstrated that a reduction in the useful field of view impairs hazard detection and increases crash risk (De Raedt & Ponjaert-Kristoffersen, 2000; McInerney & Suhr, 2016). This finding is further supported by studies showing that older drivers, especially those with limited UFOV, exhibit slower hazard detection times, particularly in divided attention conditions (Bromberg et al., 2012; Horswill et al., 2009). Furthermore, two *meta*-analyses (Mathias & Lucas, 2009; Seong-Youl et al., 2014) report medium to large effect sizes for the UFOV test's ability to distinguish between safe and unsafe drivers across various performance indicators, including on-road evaluations, simulator outcomes, and self-reported driving difficulties. Notably, among the three UFOV subtests, performance on UFOV subtest 2 has been found to predict real-world driving outcomes, including both retrospective and prospective crash involvement, as well as performance in on-road and simulator assessments (Bowers et al., 2013; Clay et al., 2005; Gentzler & Smither, 2012; Molnar et al., 2007; Rubin et al., 2007). Interestingly, performance on valid trials, where hazards appear in the same spatial location, also correlated with UFOV subtests. Specifically, negative correlations between valid trial accuracy and UFOV subtests 1 and 3, which assess processing speed and visual selective attention, suggest that these cognitive functions also play a role in hazard detection.

In addition, significant weak correlations were found (less than −0.3) between Invalid trial accuracy and the time measures of the TMT-A and TMT-B subtests. McInerney and Suhr (2016) observed slower performance in older individuals on the TMT tests, as well as a higher number of errors on the traditional hazard perception task. Performance time on the TMT-A, used as a measure of processing speed, was positively related to the number of errors on the hazard perception test. Our results align with previous research showing that TMT completion time, rather than accuracy, is a strong predictor of driving performance in older adults (Duncanson et al., 2018; Papandonatos et al., 2015). Takahashi et al. (2017) found moderate-to-strong negative correlations between age and TMT performance, particularly for TMT-B. Similarly, Sasaki et al. (2025) reported a gradient of slowing TMT performance linked not only to age but also to neurological health status, with stroke survivors performing the worst. These findings highlight the multifaceted nature of cognitive aging and the importance of considering individual health differences when evaluating older drivers.

In addition, we found a moderate, significant correlation ($r_s = 0.307$) between visual acuity and performance on the Simple trials of the Hazard Perception test. It is well-established that driving is a visually demanding activity, which is why a legal minimum vision standard is required for all motorists (Kotecha et al., 2008). Hazard perception involves the processing of visual stimuli, with factors such as visual acuity and contrast sensitivity potentially influencing or mediating hazard perception ability (Horswill et al., 2008). Furthermore, advancements in technology have led to more sophisticated methods for assessing visual attention, including the binocular visual field, contrast sensitivity, and motion sensitivity. Although our study did not find significant associations between motion sensitivity and hazard perception performance, this may be due to the limited sample of drivers aged 55 and above, all of whom had normal vision. Previous research has indicated that deficits in motion sensitivity, visual acuity, and central vision are predictive of poorer performance on hazard perception tests (Anstey et al., 2012; Wood et al., 2021). For example, Zhang et al. (2020a) demonstrated that simulated central vision loss led to disproportionately longer reaction times (RTs) in older drivers compared to younger drivers.

To further examine the cognitive mechanisms underlying the relationship between aging and performance in the most cognitively demanding attentional condition (invalid trials), a multiple mediation analysis was conducted. This analysis revealed that the negative effect of age on accuracy in invalid trials was fully mediated by attentional factors, specifically the UFOV subtests. Among them, only UFOV subtest 3 (selective attention) significantly mediated this relationship, while UFOV subtest 2 did not show a significant indirect effect. These findings suggest that age-related declines in selective visual attention may be a key mechanism through which aging impairs the ability to detect hazards appearing in unexpected locations. Our findings are consistent with prior research indicating an age-related decline in the overall efficiency of visual search performance. Although top-down control of visual attention tends to be relatively preserved in older adults (Madden, 2007), they often show difficulties in selectively allocating attention and inhibiting task-irrelevant information. These deficits are reflected in performance differences associated with both target-location and target-identity cues (Commodari & Guarnera, 2008; Madden & Langley, 2003; Introzzi et al., 2020; Zhuravleva et al., 2014).

These results are also supported by previous studies showing that selective attention, particularly as measured by UFOV subtest 3, is a robust predictor of real-world driving performance in older adults. In fact, many of the problems or errors that we commit in daily tasks are explained by attentional lapses or failures (Introzzi et al., 2020). For instance, Owsley et al. (2012) demonstrated that UFOV subtest 3 was the strongest predictor of driving ability in the presence of distractors, while Huisingh et al. (2018) found that errors in on-road driving assessments were significantly related to performance on this same subtest. Moreover, Pollatsek et al., (2012) showed that older drivers often fail to scan areas of potential risk—such as intersections—due to reduced selective attention, and that this deficit can be remediated with targeted training. Together, these findings reinforce the central role of selective attention in safe driving among older adults and highlight its utility as a cognitive marker for identifying at-risk individuals. By formally testing indirect effects through mediators, this analysis complements the correlational findings and provides a more nuanced understanding of how age and cognitive processes interact to influence hazard prediction within complex driving scenes.

5. Limitations

First, demographic differences between the groups—such as age, gender, education level, and annual mileage—may have partially influenced the results. For example, most participants in the older age groups (young-seniors and elderly drivers) were recruited from the staff and student body of the University of Granada, a population with relatively high educational attainment (67 % of young-seniors and 72 % of elderly drivers held a university degree). As a result, the sample may have higher-than-average cognitive, socio-economic, and cultural backgrounds, which could limit the generalizability of our findings to the broader population. Despite this, impairments in performance were observed in the Hazard Prediction-Orienting test, the UFOV, and the TMT, which could be concerning for individuals over the age of 65. It is possible that individuals from lower socio-economic backgrounds, or those with less access to education, may experience more pronounced deficits in cognitive and visual functioning (e.g., reliance on corrective eyewear). Future studies should consider socio-economic status as a potential health determinant and explore its influence on driving-related cognitive performance, particularly in relation to hazard detection. Another limitation is the difference between real-world driving and the assessment tools used in this study, such as the Hazard Prediction-Orienting test and driving simulators. Although the Hazard Prediction test was designed to replicate real-life driving scenarios based on actual recordings, the consequences of hazardous events in a test setting are not the same as in real-world situations. In addition, during real driving, participants must allocate part of their attentional resources to vehicle control—an element that is absent when watching video clips. The potential difference in ecological validity between these simulated environments and real-world driving conditions may impact the external validity of our findings. Future research should aim to incorporate on-road driving assessments to better capture the complexities of real-life driving behavior and hazards.

5.1. Further Research

To deepen our understanding of how age and cognitive decline impact driving performance, future research should consider a more detailed analysis of age groups, particularly in 5-year intervals starting at age 50. This will allow for more precise identification of age-related trends in cognitive and visual decline. Additionally, future studies should explore the relationship between cognitive decline and driving performance in individuals with Mild Cognitive Impairment (MCI). MCI is characterized by noticeable cognitive decline that does not yet meet the criteria for dementia and is associated with impairments in daily activities, including driving. Determining the precise threshold at which driving becomes unsafe for individuals with MCI remains challenging but is crucial, as early identification could help mitigate the risk of accidents (Doroudgar et al., 2017; Karthaus & Falkenstein, 2016; Toepper & Falkenstein, 2019).

On the other hand, the Mini-Mental State Examination (MMSE) is typically not administered to individuals under the age of 45, as it is designed primarily for detecting mild to moderate cognitive impairment in older adults, particularly in the context of dementia screening. Moreover, a well-documented finding in the literature is that perceptual and cognitive systems change with age (Andersen, 2012; Nagarajan et al., 2022). However, further research may include the total assessment of middle-aged drivers (taking Visual Function, UFOV or TMT measures). This will enhance the generalizability of the results.

Moreover, further research should examine the external validity of the Hazard Prediction-Orienting test. To assess its predictive capacity for identifying safe drivers, particularly among older adults, future research could incorporate regression analyses that evaluate correlations between the test results and real-world driving outcomes. Potential metrics for this analysis include: (a) evaluations by driving instructors based on on-road performance (pass/fail); (b) examination of a driver's traffic records (e.g., fines, accidents, point deductions); and (c) self-reports from the Driver Behaviour Questionnaire (DBQ), which measures lapses, errors, infractions, and aggressive driving behavior. Additionally, determining clinically relevant cut-off scores for the test is essential. This could be achieved through Receiver Operating Characteristic (ROC) curve analysis. Ultimately, the identification of optimal cut-off points should strike a balance between minimizing the risk of overlooking unsafe drivers and avoiding the undue restriction of driving privileges. Another promising area of research would be to assess the effectiveness of Hazard Prediction training as an intervention for older drivers, aiming to reduce performance deficits and enhance overall road safety.

5.2. Conclusions

This study provides compelling evidence that both hazard prediction and attention capture significantly decline in drivers over the age of 65, with performance levels similar to those observed in novice drivers. These findings have practical implications for driver safety and policy development, highlighting the need for targeted interventions to address the declining driving abilities of older adults. Specifically, the results underscore the importance of raising awareness about the cognitive challenges faced by drivers over 65 and promoting safe driving practices among this group. Furthermore, the ongoing development and validation of the Hazard Perception-Orientation test holds significant promise for improving the fitness-to-drive assessment process. This test has demonstrated the ability to differentiate between drivers of various ages and shows concurrent validity with other established measures, such as the UFOV and TMT. Incorporating the Hazard Prediction-Orienting test into driving evaluations could help identify at-risk older drivers and guide interventions aimed at improving hazard anticipation skills. Moreover, training programs that target attentional control and hazard anticipation, such as visual scanning training, may help mitigate age-related declines in driving performance (Lococo & Staplin, 2018). Such training could help free up cognitive resources, enabling older drivers to respond more effectively to competing road obstacles and reduce the likelihood of accidents. By integrating cognitive and attentional training into fitness-to-drive programs, we may be able to mitigate the cognitive deficits that increase crash risk in older adults, ultimately improving road safety for all users.

CRediT authorship contribution statement

Daniel Salazar-Frías: Writing – original draft, Methodology, Investigation, Formal analysis. **Sonia Ortiz-Pergrina:** Writing – original draft, Supervision, Investigation, Conceptualization. **Francesco Martino:** Writing – original draft, Investigation. **Jose-J. Castro-Torres:** Writing – original draft, Investigation. **Jorge Clavijo-Ruiz:** Writing – original draft. **Cándida Castro:** Writing – original draft, Supervision, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

Akinwuntan, A.E., Devos, H., Verheyden, G., Baten, G., Kiekens, C., Feys, H., De Weerdt, W., 2010. Retraining moderately impaired stroke survivors in driving-related visual attention skills. Top. Stroke Rehabil. 17 (5), 328–336. https://doi.org/10.1310/tsr1705-328.

Andersen, G.J., 2012. Aging and vision: changes in function and performance from optics to perception. Wiley interdisciplinary reviews. Cognitive science 3 (3), 403–410. https://doi.org/10.1002/wcs.1167.

Anstey, K.J., Wood, J., Lord, S., Walker, J.G., 2005. Cognitive, sensory and physical factors enabling driving safety in older adults. Clin. Psychol. Rev. 25 (1), 45–65. https://doi.org/10.1016/j.cpr.2004.07.008.

Anstey, K.J., Horswill, M.S., Wood, J.M., Hatherly, C., 2012. The role of cognitive and visual abilities as predictors in the Multifactorial Model of Driving Safety. Accident; analysis and prevention 45, 766–774. https://doi.org/10.1016/j.aap.2011.10.006.

Antin, J.F., Guo, F., Fang, Y., Dingus, T.A., Perez, M.A., Hankey, J.M., 2017. A Validation of the low mileage bias using naturalistic driving study data. J. Saf. Res. 63, 115–120. https://doi.org/10.1016/j.jsr.2017.10.011.

Arexis, M., Maquestiaux, F., Gaspelin, N., Ruthruff, E., Didierjean, A., 2017. Attentional capture in driving displays. Br. J. Psychol. 108 (2), 259–275. https://doi.org/10.1111/bjop.12197.

Baldock, M.R.J., Mathias, J., McLean, J., Berndt, A., 2007. Visual attention as a predictor of on-road driving performance of older drivers. Aust. J. Psychol. 59 (3), 159–168.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., Tennstedt, S. L., Unverzagt, F. W., Willis, S. L., & Advanced Cognitive Training for Independent and Vital Elderly Study Group, 2002. Effects of cognitive training interventions with older adults: a randomized controlled trial. J. Am. Med. Assoc. 288 (18), 2271–2281. https://doi.org/10.1001/jama.288.18.2271.

Ball, K.K., Beard, B.L., Roenker, D.L., Miller, R.L., Griggs, D.S., 1988. Age and visual search: Expanding the useful field of view. J. Opt. Soc. Am. A 5 (12), 2210–2219. https://doi.org/10.1364/JOSAA.5.002210.

Baudouin E, Zitoun S, Corruble E, Vidal JS, Becquemont L, Duron E. Association between car driving and successful ageing. (2023). A cross sectional study on the "S.AGES" cohort. *PLoS One, 4;*18(5): e0285313. doi: 10.1371/journal.pone.0285313.

BOE (2020). BOE-A-2020-13970. Real Decreto 971/2020, de 10 de noviembre, por el que se modifica el Reglamento General de Conductores, aprobado por Real Decreto 818/2009, de 8 de mayo. https://www.boe.es/eli/es/rd/2020/11/10/971.

Borowsky, A., Oron-Gilad, T., 2013. Exploring the effects of driving experience on hazard awareness and risk perception via real-time hazard identification, hazard classification, and rating tasks. Accid. Anal. Prev. 59, 548–565. https://doi.org/10.1016/j.aap.2013.07.008.

Borowsky, A., Shinar, D., Oron Gilad, T., 2010. Age, skill, hazard perception in driving. Accid. Anal. Prev. 42 (4), 1240–1249. https://doi.org/10.1016/j.aap.2010.02.001.

Bowers, A.R., Anastasio, R.J., Sheldon, S.S., O'Connor, M.G., Hollis, A.M., Howe, P.D., Horowitz, T.S., 2013. Can we improve clinical prediction of at-risk older drivers? Accid. Anal. Prev. 59, 537–547. https://doi.org/10.1016/j.aap.2013.06.037.

Bromberg, S., Oron-Gilad, T., Ronen, A., Borowsky, A., Parmet, Y., 2012. The perception of pedestrians from the perspective of elderly experienced and experienced drivers. Accid. Anal. Prev. 44 (1), 48–55. https://doi.org/10.1016/j.aap.2010.12.028.

CARE (2023). *2023 figures show stalling progress in reducing road fatalities in too many countries.* EU CARE database on road crashes and national sources; Population data is from Eurostat.

Castro, C., Ventsislavova, P., Peña-Suárez, E., Gugliotta, A., García-Fernández, P., Eisman, E., Crundall, D., 2016. Proactive Listening to a Training Commentary improves hazard prediction. Saf. Sci. 82, 144–154. https://doi.org/10.1016/j.ssci.2015.09.018.

Castro, C., Doncel, P., Szot, A.C., Laffarga, L., Salazar-Frías, D., Dinu, A.I., Rodríguez-Bailón, M., 2024. Study of the effect of psychophysical conditions on road safety. *Database Records Form the Last Procedure That Drivers Completed at a CRC during the Decade from 2012 to 2022*).

Castro, C., Salazar-Frías, D, Szot, A.C., Laffarga, L., Muela, I., Rodríguez-Bailon, M., García-Fernández, P., Eisman, E., Chica, A., 2025. Using the Orienting Hazard Prediction Test to assess fitness-to-drive: Data from stroke survivors. Applied Cognitive Psychology 70076. https://doi.org/10.1002/acp.70076.

Chica, A.B., Bartolomeo, P., Lupiáñez, J., 2013. Two cognitive and neural systems for endogenous and exogenous spatial attention. Behav. Brain Res. 237, 107–123. https://doi.org/10.1016/j.bbr.2012.09.027.

Chihuri, S., Mielenz, T.J., DiMaggio, C.J., Betz, M.E., DiGuiseppi, C., Jones, V.C., Li, G., 2016. Driving Cessation and Health Outcomes in older adults. J. Am. Geriatr. Soc. 64 (2), 332–341. https://doi.org/10.1111/jgs.13931.

Classen, S., Wang, Y., Crizzle, A.M., Winter, S.M., Lanford, D.N., 2013. Predicting older driver on-road performance by means of the useful field of view and trail making test part B. Am J Occup Ther 67 (5), 574–582. https://doi.org/10.5014/ajot.2013.008136.

Clay, O.J., Wadley, V.G., Edwards, J.D., Roth, D.L., Roenker, D.L., Ball, K.K., 2005. Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: current and future implications. Optometry and Vision Science: Official Publication of the American Academy of Optometry 82 (8), 724–731. https://doi.org/10.1097/01.opx.0000175009.08626.65.

Cohen, J., 1988. Statistical power analysis for the behavioral sciences, 2nd ed. Routledge. https://doi.org/10.4324/9780203771587.

Commodari, E., Guarnera, M., 2008. Attention and aging. Aging Clin. Exp. Res. 20 (6), 578–584. https://doi.org/10.1007/BF03324887.

Costa, M., Bonetti, L., Vignali, V., Bichicchi, A., Lantieri, C., Simone, A., 2019. Driver's visual attention to different categories of roadside advertising signs. Appl. Ergon. 78, 127–136. https://doi.org/10.1016/j.apergo.2019.03.001.

Crundall, D., Chapman, P., Trawley, S., Collins, L., van Loon, E., Andrews, B., Underwood, G., 2012. Some hazards are more attractive than others: drivers of varying experience respond differently to different types of hazard. Accid. Anal. Prev. 45, 600–609. https://doi.org/10.1016/j.aap.2011.09.049.

Deffler, R.A., Cooley, S.L., Kohl, H.A., Raasch, T.W., Dougherty, B.E., 2024. Hazard perception in visually impaired drivers who use bioptic telescopes. Transl. Vis. Sci. Technol. 13 (6), 5. https://doi.org/10.1167/tvst.13.6.5.

De Raedt, R., Ponjaert-Kristoffersen, I., 2000. The relationship between cognitive/neuropsychological factors and car driving performance in older adults. J. Am. Geriatr. Soc. 48 (12), 1664–1668. https://doi.org/10.1111/j.1532-5415.2000.tb03880.x.

DGT (2025). *Informe de siniestralidad mortal en vías interurbanas. Año 2024*. https://www.dgt.es/export/sites/webDGT/.galleries/downloads/nota_prensa/2024-record-historico-desplazamientos-carretera-mientras-se-estabiliza-el-numero-de-fallecidos-en-siniestros-de-trafico/INF_CIERRE_2024_v10_FINAL.pdf.

Dickerson, A.E., 2013. Driving assessment tools used by driver rehabilitation specialists: survey of use and implications for practice. Am J Occup Ther 67 (5), 564–573. https://doi.org/10.5014/ajot.2013.007823.

Dobbs, B.M., Shergill, S.S., 2013. How effective is the Trail making Test (Parts a and B) in identifying cognitively impaired drivers? Age Ageing 42 (5), 577–581. https://doi.org/10.1093/ageing/aft073.

Doroudgar, S., Chuang, H.M., Perry, P.J., Thomas, K.L., Bohnert, K., Canedo, J., 2017. Driving performance comparing older versus younger drivers. Traffic Inj. Prev. 18 (1), 41–46. https://doi.org/10.1080/15389588.2016.1194980.

Duncanson, H., Hollis, A.M., O'Connor, M.G., 2018. Errors versus speed on the trail making test: Relevance to driving performance. Accid. Anal. Prev. 113, 125–130. https://doi.org/10.1016/j.aap.2018.01.004.

D'Addario, P., Donmez, B., 2019. The effect of cognitive distraction on perception response time to unexpected abrupt and gradual onset roadway hazards. Accid. Anal. Prev. 127, 177–185. https://doi.org/10.1016/j.aap.2019.03.003.

Edquist, J., Horberry, T., Hosking, S., Johnston, I., 2011. Effects of advertising billboards during simulated driving. Appl. Ergon. 42 (4), 619–626. https://doi.org/10.1016/j.apergo.2010.08.013.

Edwards, J.D., Ross, L.A., Wadley, V.G., Clay, O.J., Crowe, M., Roenker, D.L., Ball, K.K., 2006. The useful field of view test: normative data for older adults. Archives of Clinical Neuropsychology : the Official Journal of the National Academy of Neuropsychologists 21 (4), 275–286. https://doi.org/10.1016/j.acn.2006.03.001.

Endsley, M.R., 1995. Toward a theory of situation awareness in dynamic-systems. Hum. Factors 37 (1), 32–64. https://doi.org/10.1518/001872095779049543.

Eurostat (2024). The share of elderly people continues to increase. Statistic explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_structure_and_ageing.

Faul, F., Erdfelder, E., Buchner, A., Lang, A.G., 2009. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behav. Res. Methods 41 (4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149.

Festa, E.K., Bracken, B.K., Desrochers, P.C., Winder, A.T., Strong, P.K., Endsley, M.R., 2024. EEG and fNIRS are associated with situation awareness (hazard) prediction during a driving task. Ergonomics 1–16. https://doi.org/10.1080/00140139.2024.2367163.

Folstein, M.F., Folstein, S.E., McHugh, P.R., 1975. "Mini-mental state". a practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Resesarch 12 (3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6.

Fox, J., Friendly, M., Weisberg, S., 2024. heplots: Visualizing Tests in Multivariate Linear Models. R Package Version 1 (7), 3. https://CRAN.R-project.org/package=heplots.

Gentzler, M.D., Smither, J.A., 2012. A literature review of major perceptual, cognitive, and/or physical test batteries for older drivers. Work (reading, Mass.) 41 (1), 5381–5383. https://doi.org/10.3233/WOR-2012-0825-5381.

Guo, F., Fang, Y., Antin, J.F., 2015. Older driver fitness-to-drive evaluation using naturalistic driving data. J. Saf. Res. 54, 49–54. https://doi.org/10.1016/j.jsr.2015.06.013.

Hashimoto, R., Meguro, K., Lee, E., Kasai, M., Ishii, H., Yamaguchi, S., 2006. Effect of age and education on the trail making test and determination of normative data for japanese elderly people: the Tajiri Project. Psychiatry Clin. Neurosci. 60, 422–428. https://doi.org/10.1111/j.1440-1819.2006.01526.x.

Hayes, A.F., 2022. *Introduction to mediation, moderation, and conditional process analysis: a regression-based approach,* third edition. Guilford publications, New York, NY.

Hayes, A.F., Rockwood, N.J., 2017. Regression-based statistical mediation and moderation analysis in clinical research: Observations, recommendations, and implementation. Behav. Res. Ther. 98, 39–57. https://doi.org/10.1016/j.brat.2016.11.001.

Hill, A., Horswill, M.S., Whiting, J., Watson, O., 2019. Computer-based hazard perception test scores are associated with the frequency of heavy braking in everyday driving. Accid. Anal. Prev. 122, 207–214. https://doi.org/10.1016/j.aap.2018.08.030.

Horswill, M.S., 2016a. Hazard perception in Driving. Curr. Dir. Psychol. Sci. 25 (6), 425–430. https://doi.org/10.1177/0963721416663186.

Horswill, M.S., 2016b. Hazard perception tests. In: Fisher, D.L., Caird, J.K., Horrey, W., Trick, L. (Eds.), *The Handbook of Teen and Novice Drivers*. CRC Press, Boca Raton, FL, pp. 439–450.

Horswill, M.S., McKenna, F.P., 2004. Drivers' hazard perception ability: Situation awareness on the road. In: Banbury, S., Tremblay, S. (Eds.), *A Cognitive Approach to Situation Awareness*. Ashgate, Aldershot, UK, pp. 155–175.

Horswill, M.S., Marrington, S.A., McCullough, C.M., Wood, J., Pachana, N.A., McWilliam, J., Raikos, M.K., 2008. The hazard perception ability of older drivers. J. Gerontol. B Psychol. Sci. Soc. Sci. 63 (4), P212–P218. https://doi.org/10.1093/geronb/63.4.p212.

Horswill, M. S., Pachana, N. A., Wood, J., Marrington, S. A., McWilliam, J., & McCullough, C. M. (2009). A comparison of the hazard perception ability of matched groups of healthy drivers aged 35 to 55, 65 to 74, and 75 to 84 years. *Journal of the International Neuropsychological Society : JINS*, *15*(5), 799–802. https://doi.org/10.1017/S1355617709990312.

Horswill, M.S., Anstey, K.J., Hatherly, C.G., Wood, J.M., 2010a. The crash involvement of older drivers is associated with their hazard perception latencies. Journal of the International Neuropsychological Society: JINS 16 (5), 939–944. https://doi.org/10.1017/S135561771000055X.

Horswill, M.S., Kemala, C.N., Wetton, M., Scialfa, C.T., Pachana, N.A., 2010b. Improving older drivers' hazard perception ability. Psychol. Aging 25 (2), 464–469. https://doi.org/10.1037/a0017306.

Horswill, M.S., Anstey, K.J., Hatherly, C., Wood, J.M., Pachana, N.A., 2011. Older drivers' insight into their hazard perception ability. Accid. Anal. Prev. 43 (6), 2121–2127. https://doi.org/10.1016/j.aap.2011.05.035.

Horswill, M.S., Falconer, E.K., Pachana, N.A., Wetton, M., Hill, A., 2015. The longer-term effects of a brief hazard perception training intervention in older drivers. Psychol. Aging 30 (1), 62–67. https://doi.org/10.1037/a0038671.

Horswill, M.S., Hill, A., Jackson, T., 2020. Scores on a new hazard prediction test are associated with both driver experience and crash involvement. Transport. Res. F: Traffic Psychol. Behav. 71, 98–109. https://doi.org/10.1016/j.trf.2020.03.016.

Huisingh, C., Owsley, C., Hawkins, N., Wood, J.M., 2018. *Driving characteristics of older drivers and their relationship to the Useful Field of View test*. Int. J. Geriatr. Psychiatry 33 (2), 189–196.

Introzzi, I., Zamora, E., Aydmune, Y., Richard's, M.M., Comesaña, A., Canet-Juric, L., 2020. The Change Processes in Selective attention during Adulthood. Inhibition or Processing speed? Span. J. Psychol. 23, e37.

Jackson, L., Chapman, P., Crundall, D., 2009. What happens next? predicting other road users' behavior as a function of driving experience and processing time. Ergonomics 52 (2), 154–164. https://doi.org/10.1080/00140130802030714.

Jones, P.R., Ungewiss, J., Eichinger, P., Wörner, M., Crabb, D.P., Schiefer, U., 2022. Contrast Sensitivity and Night Driving in older people: Quantifying the Relationship between Visual Acuity, Contrast Sensitivity, and Hazard Detection Distance in a Night-Time Driving Simulator. Front. Hum. Neurosci. 16, 914459. https://doi.org/10.3389/fnhum.2022.914459.

Karthaus, M., Falkenstein, M., 2016. Functional changes and Driving Performance in older Drivers: Assessment and Interventions. Geriatrics 1 (2), 12. https://doi.org/10.3390/geriatrics1020012.

Kassambara, A., 2023. rstatix: Pipe-Friendly Framework for Basic Statistical Tests. R Package Version (7), 2. https://rpkgs.datanovia.com/rstatix/.

Klein, R. M. (2000). Inhibition of return. *Trends in cognitive sciences, 4(4),* 138–147. Karthaus, M., & Falkenstein, M. (2016). Functional Changes and Driving Performance in Older Drivers: Assessment and Interventions. *Geriatrics*, *1*(2), 12. doi: 10.3390/geriatrics1020012.

Kotecha, A., Spratt, A., Viswanathan, A., 2008. Visual function and fitness to drive. Br. Med. Bull. 87, 163–174. https://doi.org/10.1093/bmb/ldn028.

Lawrence, M. A. (2016). ez: Easy analysis and visualization of factorial experiments. R package version 4.4-0.

Lococo, K.H., Staplin, L., 2018. April). Visual scanning training for older drivers: a literature review (Report No. National Highway Traffic Safety Administration, Washington, DC.

Lüdecke, D., Ben-Shachar, M.S., Patil, I., Waggoner, P., Makowski, D., 2021. Performance: an R package for assessment, comparison and testing of statistical models. Journal of Open Source Software 6(60), 3139, 10.21105/joss.03139.

Lunsman, M., Edwards, J.D., Andel, R., Small, B.J., Ball, K.K., Roenker, D.L., 2008. What predicts changes in useful field of view test performance? Psychol. Aging 23 (4), 917–927. https://doi.org/10.1037/a0013466.

Madden, D.J., 2007. Aging and Visual attention. Curr. Dir. Psychol. Sci. 16 (2), 70–74. https://doi.org/10.1111/j.1467-8721.2007.00478.x.

Madden, D.J., Langley, L.K., 2003. Age-related changes in selective attention and perceptual load during visual search. Psychol. Aging 18 (1), 54–67. https://doi.org/10.1037/0882-7974.18.1.54.

Ma, Y., Qi, S., Zhang, Y., Lian, G., Lu, W., Chan, C.Y., 2020. Drivers' Visual attention Characteristics under Different Cognitive Workloads: an On-Road Driving Behavior Study. Int. J. Environ. Res. Public Health 17 (15), 5366. https://doi.org/10.3390/ijerph17155366.

Marrington, S.A., Horswill, M.S., Wood, J.M., 2008. The effect of simulated cataracts on drivers' hazard perception ability. Optometry and Vision Science: Official Publication of the American Academy of Optometry 85 (12), 1121–1127. https://doi.org/10.1097/OPX.0b013e31818e8d00.

Mathias, J.L., Lucas, L.K., 2009. Cognitive predictors of unsafe driving in older drivers: a meta-analysis. Int. Psychogeriatr. 21 (4), 637–653. https://doi.org/10.1017/S1041610209009119.

McInerney, K., Suhr, J., 2016. Neuropsychological Correlates of Hazard perception in older adults. Journal of the International Neuropsychological Society: JINS 22 (3), 332–340. https://doi.org/10.1017/S1355617715001253.

McKenna, F.P., Crick, J.L., 1991. *Hazard perception in Drivers: a Methodology for Testing and Training*. Final Report, Behavioural Studies Unit, Transport and Road Research Laboratory, Crowthorne, UK.

Milleville-Pennel, I., Marquez, S., 2020. Comparison between elderly and young drivers' performances on a driving simulator and self-assessment of their driving attitudes and mastery. Accid. Anal. Prev. 135, 105317. https://doi.org/10.1016/j.aap.2019.105317.

Milleville-Pennel, I., Zanlonghi, X., Barrucand, A., 2021. Characterization of visual scanning while driving for the identification of drivers' profiles. Transport. Res. F: Traffic Psychol. Behav. 83, 440–453. https://doi.org/10.1016/j.trf.2021.09.008.

Molnar, F.J., Marshall, S.C., Man-Son-Hing, M., Wilson, K.G., Byszewski, A.M., Stiell, I., 2007. Acceptability and concurrent Validity of measures to predict older driver involvement in motor vehicle crashes: an Emergency Department pilot case-control study. Accid. Anal. Prev. 39 (5), 1056–1063. https://doi.org/10.1016/j.aap.2007.02.003.

Muela, I., Chica, A., Garcia-Fernandez, P., Castro, C., 2021. Visual attention in realistic driving situations: Attentional capture and Hazard Prediction. Appl. Ergon. 89, 103235. https://doi.org/10.1016/j.apergo.2020.103235.

Nagarajan, N., Assi, L., Varadaraj, V., Motaghi, M., Sun, Y., Couser, E., Ehrlich, J.R., Whitson, H., Swenor, B.K., 2022. Vision impairment and cognitive decline among older adults: a systematic review. BMJ open 12 (1), e047929. https://doi.org/10.1136/bmjopen-2020-047929.

Ortiz-Peregrina, S., Ortiz, C., Casares-López, M., Castro-Torres, J.J., Jiménez Del Barco, L., Anera, R.G., 2020. Impact of Age-Related Vision changes on Driving. Int. J. Environ. Res. Public Health 17 (20), 7416. https://doi.org/10.3390/ijerph17207416.

Owsley, C., Lacherez, P., Gretarsdottir, E.M., et al., 2012. *Useful Field of View predicts driving in the presence of distracters*. Optom. Vis. Sci. 89 (4), 333–339.

Pae, G., Davis, J., Cavanaugh, J., Zhu, M., Hamann, C., 2025. Predictors of driving errors contributing to crashes in older adults across age groups, 2010 to 2020. J. Saf. Res. 92, 40–47. https://doi.org/10.1016/j.jsr.2024.11.010.

Papandonatos, G.D., Ott, B.R., Davis, J.D., Barco, P.P., Carr, D.B., 2015. Clinical Utility of the Trail-making Test as a Predictor of Driving Performance in older adults. J. Am. Geriatr. Soc. 63 (11), 2358–2364. https://doi.org/10.1111/jgs.13776.

Partington, J.E., Leiter, R.G., 1949. Partington's pathways test. Psychological Service Center Journal 1, 11–20.

Peng, Q., Wu, Y., Qie, N., Iwaki, S., 2022. Age-related effects of executive function on takeover performance in automated driving. Sci. Rep. 12 (1), 5410. https://doi.org/10.1038/s41598-022-08522-4.

Pierce, R.S., Andersen, G.J., 2014. The effects of age and workload on 3D spatial attention in dual-task driving. Accid. Anal. Prev. 67, 96–104. https://doi.org/10.1016/j.aap.2014.01.0.

Pollatsek, A., Romoser, M.R.E., Fisher, D.L., 2012. *Identifying and remediating failures of selective attention in older drivers*. Curr. Dir. Psychol. Sci. 21 (1), 3–7.

Posner, M.I., 1980. Orienting of attention. Q. J. Exp. Psychol. 32 (1), 3–25. https://doi.org/10.1080/00335558008248231.

Rao, P., Munoz, B., Turano, K., Munro, C., West, S.K., 2013. The decline in attentional visual fields over time among older participants in the Salisbury Eye Evaluation Driving Study. Invest. Ophthalmol. Vis. Sci. 54 (3), 1839–1844. https://doi.org/10.1167/iovs.11-8874.

R Core Team, 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing.

Reitan, R.M., Wolfson, D., 1985. *The Halstead–Reitan Neuropsycholgical Test Battery: Therapy and clinical interpretation*. Neuropsychological Press, Tucson, AZ.

Richardson, E.D., Marottoli, R.A., 2003. Visual attention and driving behaviors among community-living older persons. J. Gerontol. A Biol. Sci. Med. Sci. 58 (9), M832–M836. https://doi.org/10.1093/gerona/58.9.m832.

Robbins, C.J., Allen, H.A., & Chapman, P., (2019). Comparing drivers' visual attention at junctions in real and simulated environments. *Applied Ergonomics, 80*, 89–101. https://doi. org/10.1016/j.apergo.2019.1028.

Robertsen, R., Lorås, H.W., Polman, R., Simsekoglu, O., Sigmundsson, H., 2022. Aging and Driving: a Comparison of Driving Performance between older and Younger Drivers in an On-Road Driving Test. SAGE Open 12 (2). https://doi.org/10.1177/21582440221096133.

Rolison, J.J., Moutari, S., 2018. Risk-Exposure Density and Mileage Bias in Crash Risk for older Drivers. Am. J. Epidemiol. 187 (1), 53–59. https://doi.org/10.1093/aje/kwx220.

Roy, M., Molnar, F., 2013. Systematic review of the evidence for Trails B cut-off scores in assessing fitness-to-drive. Canadian Geriatrics Journal: CGJ 16 (3), 120–142. https://doi.org/10.5770/cgj.16.76.

Rubin, G.S., Ng, E.S., Bandeen-Roche, K., Keyl, P.M., Freeman, E.E., West, S.K., 2007. A prospective, population-based study of the role of visual impairment in motor vehicle crashes among older drivers: the SEE study. Invest. Ophthalmol. Vis. Sci. 48 (4), 1483–1491. https://doi.org/10.1167/iovs.06-0474.

Sasaki, T., Yamada, K., Obuchi, H., & Yamada, T. (2025). The development and Validation of a Japanese hazard perception task. *Traffic injury prevention*, 1–9. Advance online publication. doi: 10.1080/15389588.2024.2449255.

Schneider, W., Eschman, A., Zuccolotto, A., 2002. E-Prime (Version 2.0). [Computer software and manual]. Psychology Software Tools Inc., Pittsburgh, PA.

Seiffert, S., Weber, S., Sack, U., Keller, T., 2024. Use of logit transformation within statistical analyses of experimental results obtained as proportions: example of method validation experiments and EQA in flow cytometry. Front. Mol. Biosci. 11, 1335174. https://doi.org/10.3389/fmolb.2024.1335174.

Sekuler, A.B., Bennett, P.J., Mamelak, M., 2000. Effects of aging on the useful field of view. Exp. Aging Res. 26 (2), 103–120. https://doi.org/10.1080/036107300243588.

Seong-Youl, C., Jae-Shin, L., A-Young, S., 2014. Cognitive test to forecast unsafe driving in older drivers: meta-analysis. NeuroRehabilitation 35 (4), 771–778. https://doi.org/10.3233/NRE-141170.

Specka, M., Weimar, C., Stang, A., Jockel, K.H., Scherbaum, N., Hoffmann, S.S., et al., 2021. Trail making test normative data for the german older population. Arch. Clin. Neuropsychol. 37, 186–198. https://doi.org/10.1093/arclin/acab027.

Stefanidis, K.B., Mieran, T., Schiemer, C., Freeman, J., Truelove, V., Summers, M.J., 2023. Cognitive correlates of reduced driving performance in healthy older adults: a meta-analytic review. Accid. Anal. Prev. 193, 107337. https://doi.org/10.1016/j.aap.2023.107337.

Swan, G., Shahin, M., Albert, J., Herrmann, J., Bowers, A.R., 2019. The effects of simulated acuity and contrast sensitivity impairments on detection of pedestrian hazards in a driving simulator. *Transportation research. Part F*. Traffic psychology and behaviour 64, 213–226. https://doi.org/10.1016/j.trf.2019.05.003.

Takahashi, R., Kobayashi, M., Sasaki, T., Yokokawa, Y., Momose, H., Ohhashi, T., 2017. Driving simulation test for evaluating hazard perception: elderly driver response characteristics. Transport. Res. F: Traffic Psychol. Behav. 49, 257–270. https://doi.org/10.1016/j.trf.2017.07.003.

Toepper, M., Falkenstein, M., 2019. Driving Fitness in Different Forms of Dementia: an Update. J. Am. Geriatr. Soc. 67 (10), 2186–2192. https://doi.org/10.1111/jgs.16077.

Underwood, G., Ngai, A., Underwood, J., 2013. Driving experience and situation awareness in hazard detection. Saf. Sci. 56, 29–35. https://doi.org/10.1016/j.ssci.2012.05.025.

Unsworth, C.A., Baker, A., 2014. Driver rehabilitation: a systematic review of the types and effectiveness of interventions used by occupational therapists to improve on-road fitness-to-drive. Accid. Anal. Prev. 71, 106–114. https://doi.org/10.1016/j.aap.2014.04.017.

Urwyler, P., Gruber, N., Müri, R.M., et al., 2015. Age-dependent visual exploration during simulated day- and night driving on a motorway: a cross-sectional study. BMC Geriatr. 15, 18. https://doi.org/10.1186/s12877-015-0015-2.

Ventsislavova, P., Crundall, D., Baguely, T., Castro, C., Gugliotta, A., Garcia-Fernandez, P., Zhang, W., Ba, Y., Li, Q., 2019. A comparison of hazard perception and hazard prediction test across China, Spain and the UK. Accid. Anal. Prev. 122, 268–286. https://doi.org/10.1016/j.aap.2018.10.010.

Vertesi, A., Lever, J.A., Molloy, D.W., Sanderson, B., Tuttle, I., Pokoradi, L., Principi, E., 2001. Standardized Mini-Mental State Examination. use and interpretation. Can. Fam. Physician 47, 2018–2023.

Vlakveld, W., Romoser, M., Mehranian, H., Diete, F., Pollatsek, A., Fisher, D., 2011. Do crashes and near crashes in simulator-based training enhance novice drivers' visual search for latent hazards? Transportation Research Record: Journal of the Transportation Research Board 2265, 153–160. https://doi.org/10.3141/2265-17.

Wells, P., Tong, S., Sexton, B., Grayson, G., & Jones, E., (2008). *Cohort II: A Study of Learners and New Drivers*, Vol. Road Safety Research Report No. 81. Department for Transport, London.

WHO (2023). *Global status report on road safety*. https://iris.who.int/bitstream/handle/10665/375016/9789240086517-eng.pdf?sequence=1.

Wolinsky, F.D., Mahncke, H.W., Kosinski, M., Unverzagt, F.W., Smith, D.M., Jones, R.N., Stoddard, A., Tennstedt, S.L., 2009. The ACTIVE cognitive training trial and predicted medical expenditures. BMC Health Serv. Res. 9, 109. https://doi.org/10.1186/1472-6963-9-109.

Wood, J.M., Black, A.A., Anstey, K.J., Horswill, M.S., 2021. Hazard perception in older drivers with eye disease. Transl. Vis. Sci. Technol. 10 (1), 31. https://doi.org/10.1167/tvst.10.1.31.

Xu, J., Bowers, R.A., 2024. Hazard warning modalities and timing thresholds for older drivers with impaired vision. Accid. Anal. Prev. 202, 107599. https://doi.org/10.1016/j.aap.2024.107599.

Yantis, S., Jonides, J., 1990. Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. J. Exp. Psychol. Hum. Percept. Perform. 16, 121–134. https://doi.org/10.1037/0096-1523.16.1.121.

Zahabi, M., Machado, P., Pankok, C., Lau, M.Y., Liao, Y.-F., Hummer, J., Rasdorf, W., Kaber, D.B., 2017. The role of driver age in performance and attention allocation effects of roadway sign count, format and familiarity. Appl. Ergon. 63, 17–30. https://doi.org/10.1016/j.apergo.2017.04.001.

Zhang, C.T., Bowers, A.R., Savage, S.W., 2020a. The effects of age, distraction, and simulated central vision impairment on hazard detection in a driving simulator. Optometry and Vision Science: Official Publication of the American Academy of Optometry 97 (4), 239–248. https://doi.org/10.1097/OPX.0000000000001501.

Zhang, Y., Zhou, M., Shao, Y., 2020b. mvnormalTest: Powerful Tests for Multivariate Normality. R Package Version 1. https://CRAN.R-project.org/package=mvnormalTest.

Zhuravleva, T.Y., Alperin, B.R., Haring, A.E., Rentz, D.M., Holcomb, P.J., Daffner, K.R., 2014. Age-related decline in bottom-up processing and selective attention in the very old. Journal of Clinical Neurophysiology: Official Publication of the American Electroencephalographic Society 31 (3), 261–271. https://doi.org/10.1097/WNP.0000000000000056.