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Factors that predict hazard perception in older adult road-users: A systematic review

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ABSTRACT

Background: Older adults are more likely to be at-fault and killed in road crashes, and this has been argued to be due to their declining hazard perception (HP). There has been no comprehensive review on what factors predict this decline in HP ability for older adults. *Objectives:* The aim of this systematic review is to identify any predictors of HP in older adults across all road-user types. *Data Sources:* The search was indexed in the Medline, PsycINFO, and Scopus during January 2022. Studies had to be peer reviewed and written in English language. Participants had to be road-users over the age of 60. Studies had to investigate a relationship between a predictor and HP. *Results:* 21 articles met the inclusion criteria, 20 for drivers and one for pedestrians. Seven predictors were examined. Results suggested that driving experience and auditory distraction were the most consistent predictors of HP. HP training for drivers significantly improved HP. Results were mixed for visual abilities, cognitive abilities, and age. Training for pedestrians was not a significant predictor of HP. *Limitations:* Grey literature was not reviewed. *Conclusions:* Whilst results related to age were mixed, most studies suggested that advancing age is associated with HP decline. Driving experience appeared to be a protective factor against decline in HP. Contrast and motion sensitivity may be important in identifying at-risk drivers. Cognitive function was not a consistent predictor of HP. Auditory distractors consistently negatively impacted HP. Results indicated that there could be potential benefits of HP training. There is a dearth of research into HP in vulnerable road user types. *Implications:* By identifying the predictors of HP, road safety strategies such as holistic training programs could be developed to assist with keeping older adult road-users safe. Future research is necessary to explore HP in older pedestrians, cyclists, and motorcyclists.

1. Introduction

Older adults experience functional decline as a consequence of ageing (Bromberg et al., 2012). There is currently no set definition for what age determines older adulthood with cut-offs ranging from 60 years (Bromberg et al, 2012) to 65 years (Erber, 2012) and can include different subgroupings such as old (75–84 years) and oldest old (85 + years; Borglin et al., 2005). Regardless there is consensus that older adulthood is associated with normal age-related changes that typically begin in ones 60′s and involve a decline in cognitive, physical, auditory, and visual abilities (Bromberg et al., 2012, Salthouse, 2009). These abilities are critical to enable safe interactions with the roadway environment, with this age-related decline argued to be a cause of older adults increased risk of harm on the roads

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(Anstey et al., 2005; Bureau of Infrastructure, Transport and Regional Economics [BITRE], 2013). Older adults are therefore categorised as vulnerable road-users, whether they are drivers, pedestrians, cyclists, or motorcyclists. Older pedestrians account for 40% of pedestrian crash fatalities despite only making up around 18% of the population (BITRE, 2019). Not only are they more likely to be involved in crashes, they are also more likely to be at-fault, with older drivers being responsible in 84% of their fatal road crashes (Department for Infrastructure and Transport, 2020). It has been argued that a key reason older adults are often at-fault in crashes is because they have poorer hazard perception (HP) abilities compared to younger age groups (Borowsky et al., 2010).

1.1. Hazard perception

Hazard perception (HP) is defined as the ability to selectively attend to, perceive, localise and anticipate a potential roadway hazard (Barragan et al., 2021). The evidence from drivers suggests that HP is a core safety skill, with individuals who have poorer HP having a higher likelihood of being involved in crashes (Horswill & McKenna, 2004). Whilst HP has traditionally been studied in the context of drivers, it is argued to apply to all road-user groups, as all road-users need good HP skills to safely interact with the roadway (Moran et al., 2019). HP is typically examined by presenting potential roadway hazards to respondents and measuring responses to those hazards via response time (RT), spatial measures such as verbal identification or eye tracking and visual search strategies (Moran et al., 2019). HP Tests (HPT) measuring RT's to potential hazards are included in driver licensing for younger inexperienced drivers in some countries (e.g., Australia, the United Kingdom).

To legally drive independently, novice drivers must demonstrate that they have adequate HP skills by passing a HPT (Department of Transport NSW, 2021). Licencing schemes do not continue to test HP ability to ensure drivers remain safe across the lifespan, despite evidence suggesting that as we transition into older adulthood, HP ability deteriorates (Horswill et al., 2008). This is problematic as evidence shows that older adults experience crash rates comparable to their younger (<25 years) counterparts (BITRE, 2019). Given the importance of HP, it is important to better understand the relationship between age and HP, and the other factors that might predict HP in older adults. By identifying these factors, they could be used to develop road safety strategies to assist with keeping older adult road-users safe.

1.2. Predictors of HP

Age has been consistently argued to be a predictor of HP, with the trajectory of HP following an inverted U-shaped curve. Younger inexperienced drivers have poorer HP that develops into middle adulthood, plateaus, and then declines in older adulthood (Borowsky et al., 2010; Horswill et al., 2009). This trajectory is argued to be due to a combination of age and driving experience (years spent driving). Driving experience (traditionally defined as years spent driving) explains the increase in HP skill from younger drivers to middle-adulthood, for just like any skill, HP abilities improve with more exposure and opportunity to engage in that skill (Borowsky et al., 2010). This does not explain the decline in HP in older adults, because older adults typically have more years of driving experience (this is not an absolute where a variety of factors can influence when individuals learn to drive) and therefore cannot become less experienced. Whilst they cannot become less experienced in terms of years spent driving, they do often reduce the number of kilometres/miles they drive (Ang et al., 2019). This reduction in amount of time spent driving is often argued to be because of decline in capacity as a result of ageing (Anstey et al., 2005). Therefore, other deficits as a consequence of ageing such as in cognitive, physical, visual and auditory abilities could account for why older adults have poorer HP even though they have more driving experience.

It has been posited that cognitive function is a critical skill for safe driving, and therefore may predict HP (Anstey et al., 2012). Cognitive function refers to multiple mental abilities, including language, memory, executive function, perception, attention, and visuo-construction (Koekkoek et al., 2014). Research has shown that cognitive function increases until the early 30′s, at which point it peaks and then plateaus, until around the age of 60 when there is an accelerated decline (Salthouse, 2009). This inverted U-shape of cognitive development matches the trajectory of HP skill. For younger drivers, two studies have demonstrated a relationship between HP RT and the cognitive domains of attention and working memory in one study (Wood et al., 2016) and executive function, visuo-construction and global functioning in the other (Moran et al., 2020). In both studies, poorer cognitive function was associated with slower RT. It is unknown whether a similar pattern of findings holds for older adults and HP. Conducting a review of the literature could elucidate the exact nature of a relationship between cognition and HP in older adult road users.

Older adults can experience declines in physical functioning leading to frailty and medical conditions (Anstey et al., 2005). Decrements in physical function like decreased muscle and grip strength as well as declines in motor speed, endurance and flexibility have been argued to result in poorer driving ability (Alonso et al., 2016). A study by Anstey et al. (2005) found that the only significant relationship for physical functioning was found between neck rotation and risk of crashing. This suggests that to identify hazards throughout the roadway environment elements of physical functioning are vital. Based on this evidence, there could be a relationship between declines in physical functioning and HP and therefore needs to be examined. Furthermore, the focus of the literature has been on older drivers. Physical function could potentially have a greater impact on the HP ability of other road-users, such as pedestrians, that are more physically demanding. The existence of research into physical function and HP across road-user groups needs to be investigated.

Vision loss is the most commonly reported factor that declines with age (Edwards et al., 2016). To attend to and perceive potential roadway hazards, good vision is necessary. Owsley and McGwin (2010) conducted a review on visual functioning in young drivers. Results revealed that, in terms of predicting driving safety, visual acuity is less essential than other aspects of visual function. A study by Lacherez et al., (2012), revealed that visual acuity, merged binocular visual fields, and measures of motion sensitivity were significantly associated with HP RT, however contrast sensitivity was not significantly associated with HP RT. Together these findings suggest a lack of clarity on the most important aspects of visual functioning for safe HP. Given how prevalent visual decline is in older populations it is important to gain a better understanding of how visual decline might impact safety.

Auditory deficits are also common in older adults (Edwards et al., 2016). Auditory skills are important to road safety for providing information about incoming vehicles and potential hazards (Edwards et al., 2016). In the presence of hearing impairment, the noise of an approaching hazards and signals might not be heard for a safe and timely response (Edwards et al., 2016). To date, there has been no thorough review on the literature relating to how these auditory deficits might impact on HP for older road-users.

1.3. Rationale and aim

Taking this together, older adults are more at-risk of being at-fault and killed in road crashes across all road-user types. Declining HP ability as a result of being an older adult is argued to be one of the causes of this increased risk, but to date there has been no comprehensive review on what predicts this decline in HP ability. This is important to understand given that experience is meant to be a protective factor for HP, and older adults are arguably the most experienced road-users. Suggestions from previous reviews into driving safety for older adults have suggested that age-related decline such as cognitive, physical, visual and auditory decline (Anstey et al., 2005), however a review on whether these factors (or any additional factors) explain the decline in the core safety skill of HP has not yet been conducted. Identifying the factors that predict HP in older adults is important so that we can develop appropriate road safety strategies to compensate for these factors, train and improve them or screen for them in fitness to drive assessments. Therefore, the aim of the current review is to do a systematic search of the literature to identify any predictors (not limited to those of previous reviews) of HP in older adults (aged 60 years and older to be inclusive of all potential definitions of older adulthood) across all road-user types, so that we can use that information to assist in tailoring programs to keep older adults safer.

2. Method

2.1. Information sources and search terms

This systematic review was conducted in accordance with PRISMA guidelines (Page et al., 2021) to examine the factors that predict HP in older adult road-users over the age of 60 years. We have opted to set age at 60 + years to be inclusive of studies which may examine older adulthood using different definitions. The search was conducted in the Medline, PsycINFO, and Scopus during January 2022. To focus the search on HP and older adult road-users, a combination of search terms was used. A list of the search terms can be found in Appendix A. The initial title search was completed by one author, with all authors reviewing all articles at the abstract and full text stage. Discrepancies were resolved through consensus.

2.2. Study Selection and eligibility criteria

Studies were screened for eligibility against the following criteria: Articles could not be abstracts, reviews, case reports or dissertations due to not being peer reviewed or not providing enough data. Unpublished studies were excluded due to difficulties with locating grey literature. Studies not in English were also excluded due to limitations with interpretation of scientific studies. Further, participants had to be road-users (i.e., drivers, pedestrians, motorcyclists and cyclists) and over the age of 60 years. Studies had to include a measure of HP and there had to be a relationship between a predictor (e.g., age, cognitive function, etc.) and HP.

2.3. Data extraction

Data from selected studies were entered into a spreadsheet with information relevant for extraction determined a-priori. Data extraction was completed by the authors. Relevant data included: sample characteristics including age (mean, standard deviation, and range) and gender, road-user population (i.e., driver, pedestrian), measures of HP (i.e., type of task and dependent variable), predictors of HP and their measures, and summary sentences of the relevant findings. Effect sizes were examined to determine the feasibility of conducting a *meta*-analysis however due to the combination of the variety of analyses completed, insufficient data presented, and the limited number of studies under the different predictor groupings, a *meta*-analysis was not feasible.

2.4. Quality assessment tool

A 15-item amended version of the 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) checklist (von Elm et al., 2007) was utilised for this study. The amended version was taken from a systematic review by Depestele et al., (2020) which examined the relationship between driving performance and cognitive for older adults. It was chosen in preference to the full version as it was deemed more relevant for this area of research and would allow for comparisons across reviews in this field. The 15 items are broken into three categories; introduction, method and results, and discussion. Each item was awarded a score out of 2, with 0 (negative), 1 (mediocre) and 2 (positive). Each reviewer assesses each study against the criteria to determine whether the paper sufficiently addresses that criteria and awards a score out of 2 per item. Total scores could therefore range between 0 and 30. A score of 22 or less represents a rating of poor-quality, between 23 and 25 was rated medium-quality and 26 or higher was rated high quality. All authors independently reviewed the articles against the criteria with discrepancies resolved via consensus.

3. Results

3.1. Study search

Fig. 1 displays the summary of the study search. Results from the three databases were combined and duplicate records were removed. The articles were firstly screened by titles, with 74 articles identified to be further screened. Following abstract and full text screens, 19 articles met eligibility criteria. Additionally, two studies were found through searching the reference lists of these included articles. This brought the total number of studies to be included to 21.

3.2. Study characteristics

Table 1 displays the characteristics of the included studies. All studies were published since 2005, the majority of which were conducted in Australia ($n = 10$), three in Israel, four in the USA, two in Japan, and one study in each the UK and Canada. Across the studies, 1307 older adults between the ages of 60 and 96 years were examined. Of the 21 studies, 20 were related to HP in older drivers, with only one examining HP in older pedestrians. There were no studies examining the factors that predict HP in older motorcyclists or cyclists.

For studies that measured HP in older adults, the following types of HPT were used. A button-press task to measure RT was utilised in 81% of the studies ($n = 17$). Some of studies using a button-press task to measure RT also measured additional types of responses; 33% of studies ($n = 7$) also used the button-press task to measure number of responses, and 24% of studies ($n = 5$) used eye-tracking to

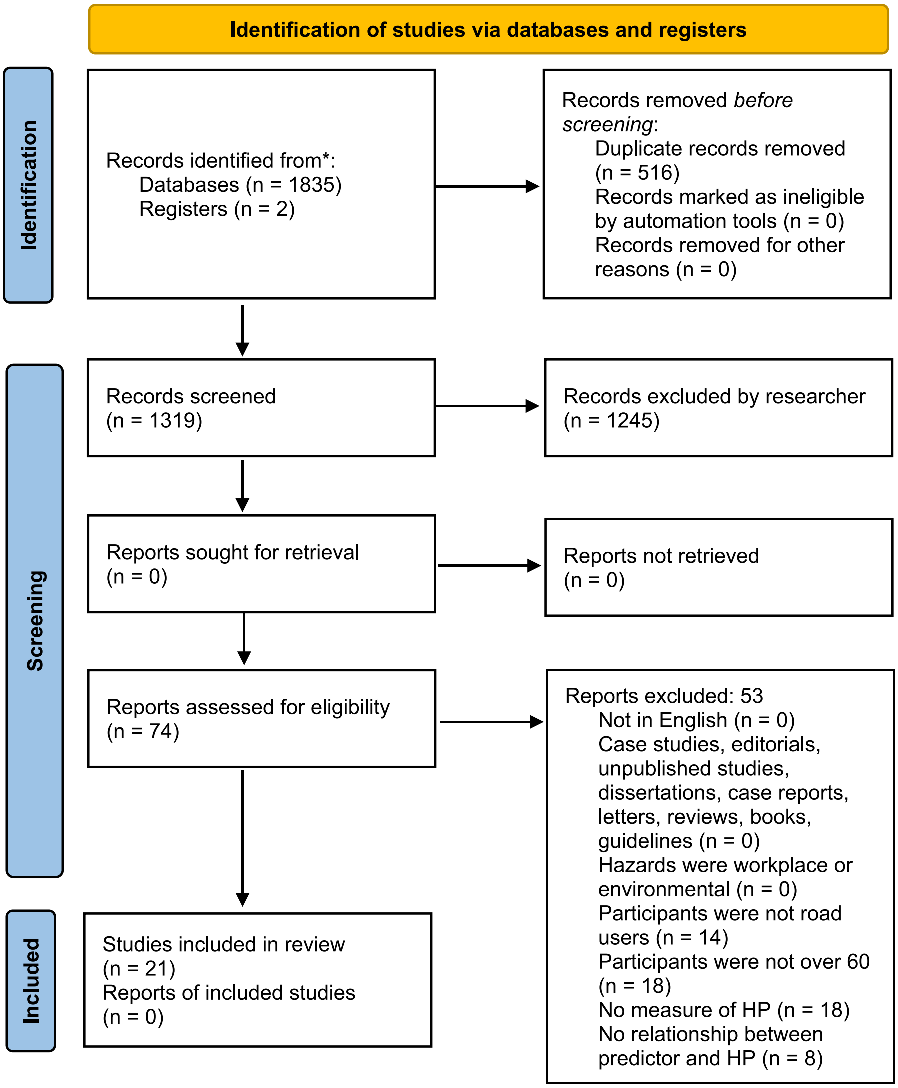

Fig. 1. PRISMA Flowchart for the Study Selection Process.

Table 1
Characteristics of Studies Assessing Predictors of HP in Older Adults.

Author, Year (Country)	Older adults: *N*	Age: Range, *M* (*SD*)	Older male %	HP measure: Dependent variable	Predictors of HP	Key Conclusions	Quality
Drivers							
Anstey et al., 2012 (Aus)	297	65–96, *75.10 (7)*	66.20%	Button-press real-life videos HP Test (HPT): Response time (RT)	Cognitive abilitiesand visual abilities. Measured by a range of cognitive and visual tests	Speed/executive function and spatial ability were positively associated with HP. Visual function was positively associated with HP. Visual closure and working memory were not associated with HP.	High
Borowsky et al., 2010 (Israel)	21 Young19 Experienced 16 Older	Young: 17–18 Experienced: 22–30 Older: 65–72	NR	Button-press real-life videos HPT: RT and Eye tracking (ET)	Age and driving experience	More years of driving experience improves HP. Advanced age does not predict HP.	Poor
Bromberg et al., 2012 (Israel)	22 Experienced 20 Elderly experienced	Experienced: 28–40, *31 (4)* Elderly experienced: 65+, *68 (3)*	80%	Button-press, real-life videos and simulated videos HPT: RT and number of responses Simulated videos, driving simulator HPT: lane-change manoeuvres, brake responses and speeding were measured	Age	Overall, no differences in number of responses between groups. However, there were some significant differences in number of responses on specific hazards presented. Older adults drove significantly slower than younger adults. RT were significantly slower for older adults.	Medium
Eramudugolla et al., 2017 (Aus)	48	65–87, *71.91 (4.47)*	57%	Button-press, real-life videos HPT: RT	Speed of processing (SOP) training	SOP training was associated with significant slowing of RT's in the HPT indicating HP was worse after training.	High
Feng et al., 2018 (Canada)	16 Younger 21 Older	Younger: 21–30, *24.4* Older: 65–79, *70.6*	42%	Button-press, simulated driving scenes (static images) HPT: RT and number of correct responses	Age	Older drivers had less accurate and slower RT than younger drivers. Older drivers were more likely than younger drivers to report a hazard when it was absent, therefore having a lower percentage of correct responses.	Poor
Hirth et al., 2007 (USA)	18	65–87, *72.3 (6.5)*	NR	Button-press, real-life videos HPT: RT and brain activation	Cognitive performance and neural correlates. Measured by functional magnetic resonance imaging (fMRI)	Right inferior frontal gyrus and bilateral regions of the lateral occipital cortex appear to be involved with hazard detection. Intensity of brain activation when a hazard was present was correlated with RT.	Poor
Horswill et al., 2008 (Aus)	118	65–84, *73.23 (5.66)*	56.78%	Button-press, real-life videos HPT: RT	Age Cognitive and visual abilities. Measured by a range of cognitive and visual tests	Significant positive correlation between age and RT. Significant positive correlation between visual acuity and RT, and simple reaction time and RT. Significant negative correlation between contrast sensitivity and RT, and UFoV and RT.	High

(*continued on next page*)

Table 1 (*continued*)

Author, Year (Country)	Older adults: *N*	Age: Range, *M* (*SD*)	Older male %	HP measure: Dependent variable	Predictors of HP	Key Conclusions	Quality
						Correlations between HP RT and all other measures of cognitive abilities were non-significant.	
Horswill et al., 2009 (Aus)	22 Middle Aged (35–55) 34 Young old (65–74) 23older old (75–84)	35–55, 65–74, 75–84,	31.6%	Button-press, real-life videos HPT: RT	Age	There was no difference in RT between young-old and middle aged however older-old had significantly slower RT to hazards than the other groups.	Poor
Horswill et al., 2010 (Aus)	12 Trained, 12 Control	Trained: 67–94, *74.33 (7.56)* Control: 65–90, *76.33 (8.31)*	41.67%	Button-press, real-life videos HPT: RT	HP training	Compared to RT pre-intervention, there was a significant improvement in RT's post-intervention. HP RT's between trained group and control (untrained group) post-intervention were significantly faster.	High
Horswill et al., 2015 (Aus)	38 Trained, 37 Control	65–89, *72.48 (5.98)*	54.67%	Button-press, real-life videos HPT: RT	HP training	Significant improvement in RT to hazards following training and was retained at the 3 month follow up compared to control group who had no significant differences in RT.	High
Lacherez et al., 2013 (Aus)	9 Young (20–39) 9 Old (67–82)	Young: 20–29, *31.4* Old: 67–82, *74.6*	NR	Button-press, real-life videos HPT: RT	Age, and Yellow eye-glass filters	Older adults have significantly slower RT compared to younger adults in both the yellow filter and non-yellow filter conditions. Yellow filters did not significantly improve RT for older adults.	Poor
Lee et al., 2016 (Aus)	20 Young20 Old	Young: *27.1 (4.6)* Old: *73.3 (5.7)*	75%	Button-press, real-life videos HPT: RT, ET, and number of responses	Age, Optical blur, and auditory distractors	There were no significant differences in RT between older and younger adults. However, older adults detected significantly fewer hazards and had poorer ET for hazards than younger adults. Auditory distractors resulted in significantly delayed RT and fewer hazards detected, but not poorer ET for older adults.	High
Lee et al., 2017 (Aus)	55	*71.5 (7)*	40.5%	Button-press, real-life videos HPT: RT and ET	Glaucoma, visual and cognitive measures	Participants with glaucoma had delayed RT compared with controls. However, the detrimental effects of glaucoma on RT was not reflected in eye movement patterns. Motion sensitivity, UFOV, and worse-eye visual field mean deviation (MD) were	Medium

(*continued on next page*)

Table 1 (*continued*)

Author, Year (Country)	Older adults: *N*	Age: Range, *M* (*SD*)	Older male %	HP measure: Dependent variable	Predictors of HP	Key Conclusions	Quality
						predictors of delayed RT.	
Pradhan et al., 2005 (USA)	24 Novice24 Younger 24 Old	Novice: 16–17, *16.3 (0.4)* Younger: 19–29, *21.3 (2.2)* Old: 60–75, *66.5 (6.4)*	NR	Driving simulator, real-life videos HPT: ET	Age and driving experience	Significant age-related differences in eye movement behaviour. Specifically, older drivers had better risk recognition compared to both novice and younger drivers.	Poor
Sasaki et al., 2019 (Japan)	63 S patients67 controls	Stroke: *66.4 (10.2)* Control: *67.2 (4.8)*	Control: 47.76% Stroke: 80.95%	Button-press, real-life videos HPT: RT and number of responses	Stroke and lesion side	Stroke patients had fewer responses and slower RT on HP task than controls for behavioural prediction hazards (difference not affected by lesion side). No differences in RT between stroke and control groups for types of HP scenarios: environmental prediction hazard and Driving and Focusing Attention hazard for RT or number of responses.	Medium
Takahashi et al., 2017 (Japan)	52	60–85, *70.2 (6.1)*	44.23%	Driving simulator, simulated videos HPT: Steering wheel, accelerator and brake responses were measured	Cognitive function measured by MMSE and TMT	Two participants who were suspected of having decreased cognitive function made more errors on the simulator.	Medium
Underwood et al., 2005 (UK)	12 Younger 12 Older	Younger: 31–44, *37.8* Older: 60–75, *68.4*	NR	Button-press, real-life videos HPT: RT, number of responses and ET	Age	Older adults made significantly more responses than younger adults.No reliable differences between the two age groups in RT and ET.	Poor
Wood et al., 2021 (Aus)	Control: 118Eye-disease: 99	65+ Control: *72.2 (5.5)* Eye-disease: *75.4 (6.4)*	Eye-disease: 68% Control: 63%	Button-press, real-life videos HPT: RT	Eye-disease: Glaucoma, Cataracts and Age-Related Maculopathy	Participants with eye-disease and glaucoma had delayed RT compared to controls. Poorer motion sensitivity, visual acuity, better-eye mean defect, and worse-eye mean defect associated with delayed RT.	Medium
Yuan et al., 2021 (USA)	9 Active training 9 passive training8 control	66–86, Active training: *77.1 (5.2)* Passive training: *74 (6)* Control: *71.3 (7)*	Active training: 44.4% Passive training: 44.4% Control: 50%	Driving simulator, images HPT. Button press, steering and pedal responses: Number of responses, driving responses	HP training	Participants in the active training group demonstrated significant improvements in HP with less errors. The passive training group showed marginal improvement with less errors but was non-significant. There were no significant differences between pre- and post-testing of HP in the control group.	Poor

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Table 1 (*continued*)

Author, Year (Country)	Older adults: *N*	Age: Range, *M* (*SD*)	Older male %	HP measure: Dependent variable	Predictors of HP	Key Conclusions	Quality
Zhang et al., 2020 (USA)	16 Younger16 Older	Younger: 22–37, *27 (6.7)* Older: 60–82, *67 (4.9)*	50%	Driving simulator, simulated videos HPT: RT and safe response rates measured by number of correct responses, brake responses, speed, and horn presses	Age, simulated vision impairment (SVI), and auditory distractors	Older adults had significantly slower RT compared to younger adults. However, there was no significant difference between older and younger in safe detection rates. Older adults have delayed RT with SVI compared to younger group. Older adults with SVI made more unsafe detections. There were no significant differences in RT between older and younger drivers in the auditory distractor condition. However, older adults seemed to compensate for the auditory distraction by driving more slowly.	High
Pedestrians							
Nissim et al., 2020 (Israel)	13 Aquatic intervention, 14 on-land physical intervention, 15 non-intervention	65–89, *74.4 (6.65)*	28.57%	Button-press, real-life videos HPT: RT	Type of training: aquatic physical intervention based on Qigong and Tai-Chi, on-land physical intervention, non-physical intervention using guided imagery	Differences in RT for pedestrians scores between the baseline measurement and after 12 weeks of intervention between the training groups were marginally significant.	High

Note. HP = Hazard perception, HPT = Hazard perception test, RT = Response time, ET = Eye tracking, SVI = Simulated vision impairment.

measure gaze patterns. Two studies utilised both a button-press task and driving simulator to measure HP (Bromberg et al., 2012; Yuan et al., 2021). Five studies (23%) used driving simulators to measure HP responses. Acceleration and braking patterns in responses to hazards was measured in all five, however lane change manoeuvres was measured in one study (Bromberg et al., 2012) and wheel turning behaviours was measured in two studies (Takahashi et al., 2017; Yuan et al., 2021).

3.3. *Relationship between HP and various predictors*

Table 2 displays the associations between the predictors of HP and HP performance. Across the studies, seven different types of predictors of HP in older adults were examined, these were: age, driving experience, cognitive function, visual abilities, auditory distractors, HP training for drivers, and HP training for pedestrians. Some of these predictors were further divided into subgroups. Cognitive function includes visual attention, executive function, processing speed, working memory, mental status, spatial ability, visual closure, simple reaction time, fluid intelligence, crystallised intelligence, brain region, and stroke and lesion side. Visual abilities include eye-sight disorders, vision tests, simulated vision impairment, yellow filters, mean deviation of field, and motion sensitivity. Table 2 presents all individual findings for each specific predictor and HP dependent variable from each study. Findings have been grouped into columns to display studies that demonstrated a significant association and studies that demonstrated a non-significant association. No comment is made on effect size of these relationships due to the considerable variability in the statistical information presented in the different studies. Table 3 displays the results related to specific HP dependent variables for each of the predictors of HP. The association between HP dependent variables and predictors of HP seems to be dependent on which HP measure was used. This will be discussed below.

3.3.1. *Age*

Age was the most examined predictor of HP with 10 studies exploring the relationship between age and HP performance. Of those, nine studies assessed age by comparing between age groups. Of those studies, 61.54% of findings showed that older adults demonstrated poorer HP than younger adults across the variety of HP dependent variables. However, 34.62% of findings revealed that there was no significant relationship between age and HP. The remaining 3.85% of findings found in the opposite direction with younger adults performing worse on eye-tracking measures than older adults (Pradhan et al., 2005). One study (Horswill et al., 2008) examined

Table 2
Associations Between Predictors of HP and HP Performance.

Predictors of HP	Significant	Non-Significant
Age		Borowsky et al., (2010) – Response time (RT)
		Borowsky et al., (2010) – Eye-tracking (ET)
		Bromberg et al., (2012) – Number of responses (NOR)
	Bromberg et al., (2012) – RT	
	Bromberg et al., (2012) – Driving controls on a driving simulator (DC)	
	Feng et al., (2018) – RT	
	Feng et al., (2018) – NOR	
	Horswill et al., (2008) - RT	
	Horswill et al., (2009) - RT	
		Horswill et al., (2009) - RT
	Lacherez et al., (2013) - RT	
	Lacherez et al., (2013) - RT	
		Lee et al., (2016) – RT
	Lee et al., (2016) – NOR	
	Lee et al., (2016) – ET	
	Lee et al., (2016) – ET	
	Lee et al., (2016) – ET	
	Lee et al., (2016) – ET	
	Pradhan et al., (2005) – ET	
		Underwood et al., (2005) RT
		Underwood et al., (2005) ET
	Underwood et al., (2005) – NOR	
	Zhang et al., (2020) - RT	
		Zhang et al., (2020) –NOR
		Zhang et al., (2020) –DC
		Zhang et al., (2020) – RT
Driving experience	Borowsky et al., (2010) RT	
	Borowsky et al., (2010) ET	
	Pradhan et al., (2005) - ET	
Cognitive abilities		
Visual attention/		Horswill et al., (2008) – TMT-A – RT
Processing Speed	Horswill et al., (2008) – Useful field of view (UFOV) – RT	
	Lee et al., (2017) – UFOV – RT	
	Takahashi et al., (2017) TMT-A – DC	
		Wood et al., (2021) – UFOV – RT
	Horswill et al., (2008) – UFOV RT	
		Wood et al., (2021) – UFOV – RT
	Lee et al., (2017) – UFOV divided and selective attention associated with delayed RT	
Executive function	Anstey et al., (2012) – RT	
	Takahashi et al., (2017) – TMT-B – DC	
		Horswill et al., (2008) – TMT-B - RT
Working memory		Anstey et al., (2012) – Digit-span backwards/visual working memory task/lettersets task - RT
		Horswill et al., (2008) - Digit-span and digit-symbol subtests of WAIS - RT
Mental status		Horswill et al., (2008) – MMSE - RT
	Takahashi et al., (2017) – MMSE - DC	
Spatial ability	Anstey et al., (2012) - Card rotation/paper folding - RT	
Visual closure		Anstey et al., (2012) – Gestalt completion/Snowy pictures/ Concealed words - RT
Simple reaction time	Horswill et al., (2008) - RT	
Fluid intelligence		Horswill et al., (2008) – Matrix Reasoning subtests of WAIS - RT
Crystallised intelligence		Horswill et al., (2008) – Vocabulary subtests of WAIS - RT
Brain region	Hirth et al., (2007) – RT	
Stroke and lesion side	Sasaki et al., (2019) – Behavioural prediction (BP) - RT	
		Sasaki et al., (2019) – Environmental prediction (EP) – RT
		Sasaki et al., (2019) – Driving and focusing attention (DF) – RT
		Sasaki et al., (2019) – Brain region - RT
	Sasaki et al., (2019) – BP – NOR	
		Sasaki et al., (2019) – EP – NOR
		Sasaki et al., (2019) – DF – NOR
		Sasaki et al., (2019) – Brain region - NOR
Visual abilities		
Eye-sight disorders	Lee et al., (2017) – Glaucoma – RT	
	Lee et al., (2017) – Glaucoma – RT	
	Lee et al., (2017) – Glaucoma – RT	

(*continued on next page*)

Table 2 (*continued*)

Predictors of HP	Significant	Non-Significant
	Lee et al., (2017) – Glaucoma – ET	
	Lee et al., (2017) – Glaucoma – ET	
		Lee et al., (2017) – Glaucoma – ET
		Lee et al., (2017) – Glaucoma – ET
		Lee et al., (2017) – Glaucoma – ET
		Lee et al., (2017) – Glaucoma – ET
		Lee et al., (2017) – Glaucoma – ET
		Lee et al., (2017) – Glaucoma – ET
	Wood et al., (2021) – Glaucoma – RT	
	Wood et al., (2021) – Eye disease total – RT	
		Wood et al., (2021) – Cataracts – RT
		Wood et al., (2021) – Age-related maculopathy – RT
Vision tests	Anstey et al., (2012) – contrast sensitivity - RT	
	Anstey et al., (2012) – visual acuity - RT	
	Horswill et al., (2008) – contrast sensitivity - RT	
	Horswill et al., (2008) – visual acuity - RT	
	Wood et al., (2021) – visual acuity - RT	
		Wood et al., (2021) – contrast sensitivity - RT
Simulated vision impairment	Lee et al., (2016) - ET	
		Lee et al., (2016) – ET
	Zhang et al., (2020) - RT	
	Zhang et al., (2020) – DC	
	Zhang et al., (2020) –NOR	
	Zhang et al., (2020) –DC	
Yellow filters		Lacherez et al., (2013) - RT
Mean deviation of visual field	Wood et al., (2021) – RT	
	Wood et al., (2021) – RT	
Motion sensitivity	Wood et al., (2021) – RT	
Auditory distractors	Lee et al., (2016) – RT	
	Lee et al., (2016) – NoR	
	Lee et al., (2016) – NoR	
	Lee et al., (2016) – RT	
	Zhang et al., (2020) - DC	
Training for drivers	Eramudugolla et al., (2017) –RT going in the wrong direction (slowing post-intervention)	
	Horswill et al., (2010) - RT	
	Horswill et al., (2015) – RT	
	Yuan et al., (2021) – NoR active training group	
	Yuan et al., (2021) – DC active training group	
		Yuan et al., (2021) – NoR passive training group
		Yuan et al., (2021) – DC – passive training group
Training for pedestrians		Nissim et al., (2020) - RT

Note. RT = Response time, ET = Eye tracking, NOR = Number of responses, DC = Driving controls on a driving simulator, Useful field of view = UFOV, Trail-Making Test Part A = TMT-A, Trail-Making Test Part B = TMT-B, Mini-Mental Status Exam = MMSE, Behaviour prediction = BP, Environmental prediction = EP, Driving and focusing attention = DF.

Table 3
Results of Predictors of HP in Relation to Specific Dependent Variables.

	HP Response time		Number of responses		Eye-tracking		Driving controls		Total	
	k	Sig	*k*	Sig	*k*	Sig	*k*	Sig	*k*	Sig
Age	12	58.33%	5	60.00%	7	71.42%	2	50.00%	26	61.54%
Driving experience	1	100.00%	–	–	2	100.00%	–	–	3	100.00%
Cognitive function	22	40.90%	4	25.00%	–	–	3	100.00%	29	44.83%
Visual abilities	18	77.77%	1	100.00%	10	30.00%	2	100.00%	31	64.52%
Auditory distractors	2	100.00%	2	100.00%	–	–	1	100.00%	5	100.00%
Training for Drivers	3	100.00%	2	50%	–	–	2	50%	7	66.66%
Training for pedestrians	1	0.00%	–	–	–	–	–	–	1	0.00%
Total	59	61.02%	12	66.66%	19	52.63%	8	87.50%		

Note. k = number of findings.

age as a continuous variable. Findings showed a negative relationship between age and RT, with HP performance decreasing as age increased. The relationship between age and HP does not appear to be moderated by the HP dependent variable with over between 50 and 71% of all findings significant regardless of dependent variable.

3.3.2. Driving experience

Two studies (Borowsky et al., 2010; Pradhan et al., 2005) assessed years of driving experience as a predictor of HP. Both studies found that driving experience was a significant positive predictor of HP in older adults. It was found that older drivers with a range of 32.5–37.5 years of driving experience were found to have significant better HP than novice drivers with a range of 6.5–7.3 years of driving experience.

3.3.3. Cognitive function

Cognitive functions were assessed in seven studies. Of those seven studies, five examined visual attention, three examined processing speed, three examined executive function, two examined mental status, and two examined working memory. Also, one study examined each of the following: spatial ability visual closure, brain region, fluid intelligence, crystallised intelligence, simple reaction time, and stroke. It was revealed that 44.83% of findings indicated that cognitive abilities were significantly associated with HP abilities in older adults. Specifically, as cognitive function decreased, HP abilities also decreased. The relationships appear to be domain specific findings with all findings related to simple reaction time and spatial ability were significant. Additionally, all findings assessing visual closure, working memory, and fluid and crystallised intelligence were non-significant. Moreover, as demonstrated in Table 3, these relationships also appear to be dependent on how HP was measured, with 100% of findings that were driving responses on a driving simulator being significant and less than half of findings measured by RT being significant.

One study (Hirth et al., 2007) observed brain region as a predictor of HP in older adults. Results revealed that there was a significant association between HP and activation in the right inferior frontal gyrus and bilateral regions of the lateral occipital cortex. There was a significant association between RT and brain activation. In particular, RT's were faster when these brain regions were activated.

One study (Sasaki et al., 2019) observed stroke and lesion side of stroke as predictors of HP abilities in older adults. Stroke patients had slower RT's and fewer number of responses than controls in the Behavioural Prediction Hazard measure of HP. There was no significant relationship between stroke and HP in the Environmental Prediction Hazard measure and the Driving and Focusing Attention Hazard measure. Additionally, it was revealed that lesion side did not matter.

3.3.4. Visual abilities

There were seven studies that assessed visual abilities of older adults as a predictor of HP. In these seven studies, seven visual aptitudes were measured. Three assessed contrast sensitivity, three examined visual acuity, two assessed worse-eye field mean deviation, two assessed motion sensitivity, two studies examined eye-sight disorders disease (two assessed glaucoma, and one study examined cataracts disease and Age-Related Maculopathy. Two studies assessed simulated vision impairment. Further, one of each of the following was assessed: yellow eye filter, mean deviation of visual field, and motion sensitivity. It was established that 64.65% of findings suggested that visual abilities in older adults are a significant predictor of HP abilities. Specifically, that as visual abilities decreased, HP abilities decreased as well. Simulated vision impairment and vision tests (visual acuity and contrast sensitivity) has the most consistent significant relationships with HP. The way that HP was measured appears to affect whether a relationship was found between HP performance and visual abilities. When HP was measured by number of responses to hazards and using driving controls, all findings demonstrated that visual abilities were a significant predictor of these skills. However, a significant relationship between eye-tracking and visual abilities appeared to only be demonstrated in 30% of findings.

3.3.5. Auditory distractors

Two studies (Lee et al., 2016; Zhang et al., 2020) investigated the impact of auditory distractors on HP performance. Both studies found that the presence of auditory distractors inhibited HP abilities in terms of delayed RT and fewer number of responses compared to when auditory distractors were absent.

3.3.6. Training for drivers

Four studies examined different types of training as a predictor of HP ability for drivers. These included three studies examining HP training and one study assessing speed of processing training. Of those four studies, 66.66% of findings demonstrated training to be a significant predictor of HP outcomes for older adults. Two studies (Horswill et al., 2010; Horswill et al., 2015) found HP training improved HP RTs and one study (Yuan et al., 2021) found active HP training decreased the number of incorrect responses and incorrect DC responses. However, one study (Eramudugolla et al., 2017) that examined speed of processing training found following training HP RT decreased.

3.3.7. Training for pedestrians

There was one study (Nissim et al., 2020) that examined aquatic physical training as a predictor of HP ability for pedestrians. Results found that any differences between pre- and post-intervention were marginally significant (technically non-significant) at improving HP for pedestrians. Specifically, there was a marginally significant increase in RT for pedestrians in the aquatic physical intervention group compared to controls who received non-physical interventions.

3.4. Quality assessment

The overall STROBE quality assessment score per study can be found in Table 1. For drivers, seven studies were found to be of high quality, five of medium quality, and eight of poor quality. The only study for pedestrians was of high quality. All studies clearly described the scientific background of the study, the study outcomes and the methods employed. Across the studies, the most common limitation was a failure to describe drop-out (or lack thereof), followed by not addressing potential sources of bias. Furthermore, only six studies had a sufficient sample size for their analysis. When examining the pattern of findings for drivers, there appears to be no bias in the pattern of the findings for the relationship between predictors and HP. For example, for age, out of the 26 findings, 16 were significant of which seven were from high quality studies, two were from medium quality studies, and seven were from poor quality studies. The quality was equally mixed for the non-significant findings with four were from high quality studies, one was from a medium quality study, and five from poor quality studies. Together this suggests that the relationship between age and HP is not dependent on quality of the study. The same pattern holds for the other predictors. For pedestrians, bias in the results was not examined as there was only one study.

4. Discussion

The aim of the present review was to synthesise the literature on the predictors of HP in older adult road-users. Understanding the factors that predict HP in older adults is important given that it is argued that poorer HP could explain why older adults are more likely to be involved in and at-fault in road crashes (Department for Infrastructure and Transport, 2020). This systematic review yielded 21 studies, of which 20 assessed HP in older drivers and one assessed HP in older pedestrians. No studies were found which examined predictors of HP in older cyclists or motorcyclists. Across the studies, the following seven possible predictors of HP were investigated; age, driving experience, cognitive function, visual abilities, auditory distractors, HP training for drivers, and HP training for pedestrians. The relationships between each predictor and HP will be discussed in more detail.

4.1. Age

Increasing age has been argued to be a predictor of poorer driving performance given that older adults are more likely to be involved in and at-fault in crashes (Skyving, Möller & Laflamme, 2023). Given this, it has often argued that older adults poorer HP could explain their increased risk (Bromberg et al., 2012). However, results of this review reveal that it is not that straightforward, with findings related to age mixed. Specifically, only 61.54% of findings demonstrated a significant relationship between advancing age and poorer HP performance. This inconsistency in findings could potentially be explained by the different age groupings employed in the studies. Most studies treated older adults as a homogenous group, however Horswill et al., (2009) found that older adults may not be a homogenous group in terms of HP performance with older-old (75–84 years) have significantly poorer HP than younger-old adults (65–74 years). This serves as a potential explanation for the inconsistencies in the findings in this review as the age of the participants in the sample may determine whether differences are found in HP. It could also be simply that increasing age is not a sufficient enough predictor of HP performance, with some researchers arguing that older adults as a cohort cannot be classified as more at-risk drivers, but rather we should investigate individual differences in a variety of skills when determining safety (Andysz & Merecz, 2012).

4.2. Driving experience

Increased driving experience has been demonstrated to reduce crash rates (Curry et al., 2015) and impact risk perception (Machado-León et al., 2016). HP has been argued to be a skill that improves with experience (Borowsky et al., 2010). Only two studies investigated driving experience in older adults with both studies revealing that adult with more driving experience had better HP abilities, suggesting that experience is a protective predictor of HP. This is consistent with research in younger adults that experience matters (Pradhan et al., 2005). Perhaps the reason declines in HP are not observed until a certain point is reached in the ageing process is due to driving experience acting as a protective factor. However, there appears to come a point in ageing when age-related decline overrides the protectiveness of driving experience. This may coincide with when there is a decline in other potential measures of driving experience. The limitation of examining experience only as years spent driving is that it does not consider current driving behaviours which may also influence HP performance. Research has demonstrated that when experience is examined as number of miles driven over the past three years, there are differences in the perception of risk for certain driving behaviours (Machado-León et al., 2016). Research has found that older adults are much more likely to reduce the number of hours and the number of kilometres/ miles they spend driving (Ang et al., 2019). It would be useful to determine whether this reduction in amount of driving co-occurs with or impacts on declining HP performance. If so, it could provide a potential explanation for the reason that driving experience ceases to be a sufficient as a protective factor.

4.3. Cognitive function

Cognitive function has been argued to be one of the most important determinants of driving capacity for older adults (Anstey et al., 2005). Only 52.83% of findings indicated that cognitive function across a range of domains was a significant predictor of HP abilities in older drivers. These findings suggested that as cognitive abilities decline, HP abilities also decline. The fact that only half of the findings revealed significant relationships was an unexpected result given suggestions by Anstey et al. (2005) of the importance of cognition for safe driving for older adults. This is also at odds with a recent study into cognitive function as a predictor of HP performance in young drivers (Moran et al., 2020). To try to understand why these mixed findings occurred, study methodologies were examined. The findings related to executive function, attention, and processing speed were mixed across the same tests. For example, both Horswill et al., (2008) and Takahashi et al., (2017) utilised the Trail Making Test B to assess executive function, yet only one finding was significant. This occurrence was also found across the domains of attention and processing speed with the Trail Making Test A and

UFOV test. This inconsistency between individual tests and across domains matches findings in reviews on the relationship between cognitive function and driving for individuals with dementia (Bennett et al., 2016). Bennett et al. (2016) argued that to improve understanding on the relationship between cognitive function and driving performance, composite batteries of cognitive tests across the various domains should be used. It is unclear whether the inconsistency in the findings is because of limitations with the reliability of the individual tests or a lack of sensitivity of the individual domains. The limited sample sizes in the studies included could also have accounted for the inconsistency of results.

Structural and functional neurological changes have been demonstrated to impair an older adults ability to perform the complex mental and physical actions required for safe driving leading to a higher incidence of road crashes (Aksan et al., 2015; Renge et al., 2020). This reviewed aimed to determine whether neurological changes were a potential explanation for poorer HP performance with mixed results. In one study by Sasaki et al., (2019) stroke was examined, and found to be a significant predictor of the behavioural prediction, but not environmental or driving and focusing attention. Of note, the region in the brain that was impacted did not appear to affect the outcome. Alternatively, a study by Hirth et al., (2007) seemed to suggest that activation in certain brain regions were associated with HP performance. Whilst there is growing evidence that specific brain regions are associated with safe driving (Renge et al., 2020; Yamamoto et al., 2020) it is unclear which brain regions/structures might be associated specifically with the skill of HP. As such the relationship between brain structure and brain regions, and HP is unclear.

4.4. Visual abilities

Visual abilities are known to decline with increasing age and are considered essential to examine when determining fitness to drive for older adults (Karthaus & Falkenstein, 2016). Visual abilities have been demonstrated to have a differential impact on different driving behaviours (Merickel et al., 2019). With regards to the impact of visual abilities on HP this review found that 64.65% of findings found vision to be a significant predictor of HP abilities in older adult drivers. This is incongruent with the realities of visual decline in older adults (Anstey et al., 2005). These inconsistencies may be attributable to the diverse results of the relationship between HP and glaucoma. Specifically, the definition of HP highlights the necessity of proficient vision to be able to perceive and attend to hazards. Therefore, it might be expected that those with the glaucoma may perform more poorly on an HPT. It has been suggested that the lack of relationship between HP and glaucoma might be explained by the possibility of compensatory behaviours in individuals with glaucoma (Lee et al., 2017). For example, increasing saccade amplitudes in adjusting to glaucomatous visual field deficits may have improved response time (Lee et al., 2017), therefore making the difference between controls non-significant.

Regardless, the significant findings this review suggest that as decline in visual abilities due to age, can result in a threat to safety when driving. The visual deficits that this review identified to be problematic were eye-sight disorders, contrast sensitivity, visual acuity, and motion sensitivity. Whilst eye-sight disorders are a medical fitness to drive issue which are reviewed by practitioners, current eye-sight tests for licensing only involve visual acuity and exclude contrast sensitivity and motion sensitivity (Department of Transport NSW, 2021). Findings suggest that including contrast and motion sensitivity into the licencing scheme for older drivers may be important to identify at-risk drivers. This is in line with suggestions by Karthaus and Falksenstein (2016) that assessments need to be more comprehensive than visual acuity alone, and should also include mesopic and peripheral vision.

4.5. Auditory distractors

Auditory distraction in older drivers was found to have a significant negative effect on HP in 100% of findings. This is consistent with the litany of research into driver distraction which shows that distraction has a negative impact on driving performance (Regan Victor & Lee, 2013). Older adults have been demonstrated to be more greatly affected by auditory distractions (Karthaus et al., 2020). Whilst there is no evidence on whether older adults are engaged in a secondary audio task when they are involved in real life crashes, the findings from this review suggest that auditory distractions such as listening to the radio might impair their HP and increase their chances of being involved in crashes.

4.6. Training for drivers

Reviews into HP for drivers has found that training if effective at improving drivers HP skills (Cao et al., 2022). Training was found to be a significant predictor of HP abilities in older drivers. Two studies (Horswill et al., 2010; 2015), which examined HP training found that by implementing a targeted HP training program for older drivers, their HP performance improved, and this improvement was maintained three months later. General training however was found to have a detrimental impact on HP performance with speed of processing training (Eramudugolla et al., 2017) being found to reduce HP RT. These findings suggest that it is more beneficial to implement targeting HP training rather than just training a general skill such as speed of processing. This is a promising finding which suggests that HP training can act to ameliorate the effects of age-related decline on this critical safety skill. This is in line with a recent review which suggests that HP training courses are needed consistently for all drivers (Habibzadeh, Yarmohammadian & Sadeghi-Bazargani, 2023).

4.7. Training for pedestrians

This review revealed that the predictors of HP in pedestrians was understudied. This is consistent with a review into HPT methodologies which found that research into vulnerable road users is significantly understudied (Moran et al., 2019). Only one study investigated HP training in relation to pedestrians, with results suggesting that aquatic physical training may improve HP in older pedestrians as the study found borderline significant improvements in HP following training. Research into HP training for child pedestrians has found that training can improve outcomes for children (Meir, Oron-Gilad & Parmet, 2015), it is likely that it may also be effective for older adults, however more research is needed. Other predictors are however unknown and future research is essential for understanding HP in older pedestrians. There is the likelihood that factors that are predictors of driving HP such as increasing age, visual function and auditory distractors may also be equally relevant for determining HP for all road user types.

4.8. HP dependent variables

This study examined the impact that HP dependent variable might have had on the pattern of the results. A recent review by Moran et al., (2019) highlighted the considerable heterogeneity that exists in HP methodologies and so it was important to consider the impact that these measures might be having on understanding HP performance for older adults. RT was the most commonly employed HP dependent variable which is not surprising given that button-press HPT are commonly employed both in research and driver licencing (Moran et al., 2019). Whilst RT might be the most common, the findings from the current review suggest that it may not be the most sensitive measure to use to elucidate relationships between predictors and HP for older adults. Driving controls was found to elicit a relationship between a predictor in 87.5% of findings compared to only 61% of findings for RT, and 52% for eye tracking. An important caveat to this however is that only eight findings have examined driving controls compared to 59 with RT and 19 for eye tracking, and as such this greater sensitivity for driving controls could be due to the amount of findings examined and also the predictors that have been examined. It is therefore worth conducting further research to examine which HP dependent variable might be better to employ as a measure of HP skill for older adults. If this can be determined in a comparative study, it will help determine which is the 'gold standard' measure to use when trying to understand the factors that predict poorer driving safety in this population, and what might be suitable if HP testing was to be used in fitness to drive assessments.

4.9. Strengths and limitations

The current review was the first to examine the factors that predict HP performance in older adulthood. A strength of this study was that by using a more inclusive age-criteria of 60 years old as opposed to 65 + years, this review was able to include an additional four studies. The use of this more inclusive criteria allowed for a more thorough investigation of the predictors of HP for this cohort. A further strength of this review was the examination of the impact that the differing HP dependent variables has on our understanding of the relationships between predictors and HP performance. Given that there has been significant heterogeneity in the way that HP skills have been measured (Moran et al., 2019), it is useful to determine how this heterogeneity impacts on our understanding of this critical safety skill. By breaking down the findings according to the way HP was measured, this review provides a more nuanced understanding on how certain predictors influence specific aspects of HP performance.

There were limitations in the studies included in this review as well as in the review itself. The methodological quality of the included studies were mixed, with over half of the included studies in the review falling into the 'poor' methodological quality. Studies would benefit from the use of reporting checklists such as those outlined by the EQUATOR toolkit to improve the quality of their reports. This would overcome common limitations of failing to report on eligibility criteria, dropout rates etc. The limitation around the lack of adequate sample sizes needs to be addressed by authors to ensure that patterns of non-significant findings represent null findings in the population and are not an artefact of underpowered analyses.

Limitations of the current review include the lack of inclusion of studies not in English and failing to conduct a search of the grey literature. No studies were excluded on the basis of not being in English therefore it is unlikely that this affected the findings of the review. The grey literature not being searched however could have resulted in potential bias in these findings. Governing bodies conduct an expansive amount of grey literature in the domain of road safety. Therefore, it is possible that an understanding of the broader topic is lacking, including studies with non-significant results.

4.10. Conclusion

In conclusion, this review aimed to synthesise the literature on the predictors of HP in older road-users. It is imperative to understand these factors that predict HP as it is argued that having poor HP could account for why older adults are more likely to be at-fault in road crashes. For older drivers, the most consistent protective predictors appear to be experience and training, with more experience and engagement in HP training improving HP performance. Understanding how much protection experience offers and when the shift occurs is essential. Furthermore, it would be useful to determine whether it is simply experience in years spent driving, or continued driving exposure in say hours spent driving per week or miles drivers that is the more protective factor. Training was found to be effective however more research is required to understand which type of HP training for drivers and pedestrians is more effective and the long-term effects of this HP training. The presence of auditory distractors was a consistent negative predictor of HP, however research is needed to further identify the link between auditory distraction, HP and increased crash risk.

Unexpectedly the findings related to age, impairments in vision, cognitive function and brain regions was mixed. Before discounting any of these predictors, more research is needed. The relationship between HP and age needs a more nuanced approach as the varying age groupings that have been used across the literature could have contributed to the mixed results. Given that the predominate finding is however that advancing age is associated with declining HP, it would be prudent to either examine age on a continuum or to conduct more nuanced research into different age groupings with a narrower age range to determine the age at which

HP more clearly starts to decline. This age cut-off could then be employed as a guide for when closer examination of fitness to drive for older adults might be necessary, and whether HP testing might be a sensitive measure to use to test their driving capacity similarly to younger drivers.

For cognitive function, future research should investigate using composite batteries of cognitive testing across multiple domains. This is useful to determine as it will provide greater levels of guidance on the tests that practitioners should employ if they are to use cognitive testing to determine fitness to drive in-office. More research is needed to determine whether specific areas are more or less involved in HP and if these regions are impacted by neurological and neurodegenerative conditions such as stroke, will there also be a resulting impact on HP. Understanding the relationship between brain structure and brain regions and safe driving in older adults would be beneficial as it will allow for neuroimaging outcomes to be used as in-office screening tools for fitness to drive for this population. Additionally, although the majority of results indicated a significant relationship between vision and HP, additional research should investigate how compensatory behaviours can influence HP performance for individuals with glaucoma. Future research should also aim to identify the thresholds for when visual deficits are likely to result in crashes so tests can be used as screening measures.

Results overwhelmingly highlighted the dearth of research into predictors of HP in older pedestrians, cyclists, and motorcyclists. This is an essential area for future research, as older adults are more likely to utilise alternate forms of transport. It is important to note that there was a complete absence of studies that looked at HP in older cyclists and motorcyclists. This is a critical area for future research, as older adults are more likely to give up driving and begin to rely on other forms of transportation such as walking, cycling, motorised scooters, or even motorcycles (Department for Infrastructure and Transport, 2020). This makes them immensely vulnerable as there is lack of protection that a car would provide and they are increasingly fragile (World Health Organisation, 2018). Therefore, to protect this vulnerable population, it is critical that research is conducted in the area of HP in older alternative road-users. Continuing research into the relationships between predictors and HP in older adults is important as it will enable the development of appropriate guidelines and screening tools for determining fitness to drive and programs for improving road safety in this at-risk population.

Author contributions

All of the listed authors contributed significantly to the development, research and written components of the presented manuscript. The weight of the contribution is signified by the order in which the authors names have been presented. The primary author (MF) completed the initial title screen of the papers and the initial data extraction. The secondary author (JMB) completed the screening of all papers at the abstract and full text stage, and cross checked all data extraction.

CRediT authorship contribution statement

Michela Folli: Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing. **Joanne M. Bennett:** Supervision, Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

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.

Data availability

No data was used for the research described in the article.

Appendix A. Search Term Combinations

Search terms for review. The two concepts were combined with an 'AND' Boolean operator.

Concept 1 **Hazard Perception**	**Concept 2** **Road Users**	**Concept 3** **Older Adults**
"Hazard perception" OR "hazard perception test" OR "hazard perception task" OR "hazard perception assessment" OR "hazard prediction" OR "hazard prediction test" OR "hazard prediction task" OR "hazard prediction assessment" OR "hazard anticipation" OR "hazard anticipation test" OR "hazard anticipation task" OR "hazard anticipation assessment" OR "hazard detection"	*"driv*" OR "vehicle*" OR "car*" OR "automobile*" OR "motor*" OR "road*" OR "motorway*" OR "bicyclist*" OR "cyclist*" OR "pedestrian*" OR "motorbike*" OR "motorcyclist*"*	*"elderly" OR "old*" OR "aging" OR "ageing" OR "dementia*" OR "mild cognitive impairment" OR "MCI" OR "Alzheimer*" OR "fronto-temporal" OR "Lewy body" OR "vascular" OR "neurodegen*" OR "cognitive decline"*

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Concept 1 Hazard Perception	Concept 2 Road Users	Concept 3 Older Adults
OR "hazard detection test" OR "hazard detection task" OR "hazard detection assessment" OR "risk awareness" OR "risk awareness test" OR "risk awareness task" OR "risk awareness assessment" OR "risk perception" OR "risk perception test" OR "risk perception task" OR "risk perception assessment" OR "HPT" OR " traffic conflict" OR "traffic conflict test" OR "traffic conflict task" OR "traffic conflict assessment"		

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*N.B. References marked with an * were included the systematic review.*

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