• **Title.** An Investigation of the Effects of Driver Age when using Novel Navigation Systems in a Head-Up Display

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Abstract

Although drivers gain experience with age, many older drivers are faced with age-related deteriorations that can lead to a higher crash risk. Head-Up Displays (HUDs) have been linked to significant improvements in driving performance for older drivers by tackling issues related to aging. For this study, two Augmented Reality (AR) HUD virtual car navigation solutions were tested (one screen-fixed, one world-fixed), aiming to improve navigation performance and reduce the discrepancy between younger and older drivers by aiding the appropriate allocation of attention and easing interpretation of navigational information. Twenty-five participants (12 younger, 13 older) undertook a series of drives within a medium-fidelity simulator with three different navigational conditions (virtual car HUD, static HUD arrow graphic and traditional head-down satnav). Results showed that older drivers tended to achieve navigational success rates similar to the younger group, but experienced higher objective mental workload. Solely for the static HUD arrow graphic, differences in most workload questionnaire items and objective workload between younger and older participants were not significant. The virtual car led to improved navigation performance of all drivers, compared to the other systems. Hence, both AR HUD systems show potential for older drivers, which needs to be further investigated in a real-world driving context.

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1. Introduction

Over time, drivers gain valuable experience on the road, which leads to more efficient visual scanning behaviours (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Konstantopoulos, Chapman, & Crundall, 2010), better anticipation (Bellet, Bailly, Mayenobe, & Georgeon, 2007) and less aggressive behaviours (Shinar & Compton, 2004). Indeed, drivers over 50 years old account for 44.1% of the driving population in the US in 2015 (FHWA, 2016). However, with rising age, drivers are faced with visual and cognitive deteriorations that can increase crash risk. Such age associated deterioration – whether physical or cognitive – can have a negative impact on a driver's ability to safely control their vehicle (Koppel, Charlton, & Fildes, 2008) with crash rates being found to rise significantly from the age of 70, according to an analysis of US crash and fatality data by Li at al. (2003).

An increasing body of research has investigated the ways in which age affects driving behaviour. For example, Rogé, Pébayle, Lambilliotte, Spitzenstetter, Giselbrecht, & Muzet (2004) found in a driving simulator study that, in comparison to younger drivers, the useful visual field of older drivers deteriorates. In particular, older drivers tend to miss more peripheral cues, suggesting a greater susceptibility to tunnel vision, possibly as they suffer more from reductions in alertness during monotonous driving. In addition, older drivers tend to experience higher mental workload in difficult manoeuvres, which can support better cognitive adjustments to situational driving demands (Foy, Runham, & Chapman, 2016). However, Cantin, Lavallière, Simoneau, & Teasdale (2009) conducted a study with drivers ranging from 65 to 75 years and noted not only increases in workload, but also reaction times to secondary stimuli. Craik and Simon (1980) theorise that many age decrements can be attributed to shortfalls in attention and a reduced depth of information processing, or, as Craik (2002) discussed later, detriments in the consolidation of cognitive operations, thus memorising. However, the idea of attenuated processing 'depth' with age is further supported by an investigation by Johnson (1990) in which older participants used lower-demand searching strategies and reviewed less information during a decision-making process. It has been shown that older drivers are often aware of their deteriorations and actively compensate for them for example by driving more slowly (Cantin et al., 2009; Szlyk, Seiple, & Viana, 1995), increasing their eye movements (Szlyk et al., 1995) and driving at quieter times (Ball, Owsley, Stalvey, Roenker, Sloane, & Graves, 1998).

With the ever increasing presence of Human Machine Interfaces (HMIs) in cars, it is becoming more important to consider how older users can be affected by developments in vehicle technology, especially with regards to driver distraction and performance decrements. One particularly relevant in-vehicle 'secondary' task type is navigation, due to the ubiquity of satellite navigation technology, as well as the excessive distraction by traditional paper maps. Spatial cognition decreases with age, as Aubrey, Li, & Dobbs (1994) found, when they asked people of different ages to interpret 'you are here' maps and make navigation decisions. These impairments also impact the use of in-vehicle navigation systems. Most of such systems require the driver to look away from the road to gather the information needed to make navigation decisions, which distracts the driver and increases workload. On the flipside, it may also be possible to mitigate some age-related performance issues using technological navigation solutions. Goodman, Gray, Khammampad, & Brewster (2004) designed a handheld navigation system for older pedestrians, which increased performance and lowered workload, in comparison to a map. According to the participants' comments, the effects could be traced back to

easily identifiable landmarks, confirmation of locations and a clear set of directions. These findings suggest that, if technology can provide information that is easier to interpret, performance increases in older drivers could be observed.

Head-Up Displays (HUDs) may facilitate navigation solutions that overcome some of the limitations of traditional head-down systems. The overall aim of HUD systems is to make transport safer, more pleasant and to make the visual extraction of information provided by HMIs more convenient (Wickens & Long, 1995). One major advantage is that HUDs include the presentation of information in, or close to the forward driving scene, which should not divert drivers' gaze away from the road. The information presented towards the road scene reduces the required workload by limiting the need for visual accommodation, and subsequently reduces the potential for distraction. Especially when the overlaid information is spatially linked to actual objects in the forward scene, clutter in the forward scene and scanning for HMI information could be minimised (Wickens & Long, 1995).

Though widely used in aviation for years, advancements in the technology have recently increased the popularity of HUDs within the automotive industry. The method of implementing AR into HUDs can take various forms. More than a decade ago, Levy, Dascalu, & Harris (2005) and Narzt, Pomberger, Ferscha, Kolb, Müller, Wieghardt et al. (2006) proposed technologies that project coloured lines onto the road ahead for drivers to follow. Large, Burnett, & Bolton (2017) observed improvements in navigation performance when using AR to highlight landmarks as cues. The benefits of using HUDs for driving and navigation are well documented in the literature (cf. Gabbard, Fitch, & Kim, 2014), with improved navigation and driving performance, as well as reduced reaction times when braking in emergency situations (Kim & Dey, 2009; Liu & Wen, 2004; Medenica, Kun, Paek, & Palinko, 2011). While Liu (2003) controversially attributed these improvements to an increased mental workload resulting in more attentive and cautious driving, subsequent studies have demonstrated the opposite. They indicate stronger personal preference, lower stress levels and easier familiarisation when using a HUD in comparison with a standard head-down system (Liu & Wen, 2004; Medenica et al., 2011). An interesting metaphor facilitated by AR technology is a virtual car, as envisioned by Narzt et al. (2006). Following another vehicle is a well-known navigation method, but a virtual front car might mitigate risky behaviours exhibited when trying to prevent losing sight of a 'real' front car (McNabb, Kuzel, & Gray, 2017).

HUDs have been linked to significant improvements in driving performance for older drivers by tackling age-related issues. Kiefer (1998) found that a HUD display allowed older drivers to more quickly and reliably detect pedestrians than with a standard head-down system. Additionally, Mourant, Tsai, Al-Shihabi, & Jaeger (2001) demonstrated older users' ability to maintain driving performance while obtaining information was improved when using a HUD in comparison with a head-down device. While such improvements in older drivers have been found to be similar to those of younger drivers (Kim & Dey, 2009), the research of Mourant et al. (2001) demonstrates that the increase in performance associated with using a HUD was in fact greater for older users, suggesting the potential to reduce discrepancies in driver performance between different age groups using this technology. A reduction in mental workload can be particularly useful for older drivers, who may generally struggle with higher stress levels (Cantin et al., 2009). A well-designed HUD navigation system can also counteract the need for information interpretation (i.e. counting exits or translating

maps into the driving scene) which may further lead to impaired driving performance (Trawley, Stephens, Rendell, & Groeger, 2017).

1.1   The study

The current study aimed to explore whether the use of a HUD to provide navigational instructions, can help older drivers when navigating a complex road environment. It compares a standard, head-down navigation device ('satnav'), with a conventional static arrow HUD and a novel AR-HUD virtual lead car presentation, using the metaphor of following a friend. It was expected that a world-fixed, animated virtual car would aid navigation by avoiding issues of interpreting abstract information (i.e. judging distances, directions and icons) as highlighted by Narzt et al. (2006). This is particularly relevant to older drivers, where the representation of a real life 'follow-me' setting can avoid issues of reduced spatial cognition (Aubrey et al., 1994) and reduced ability to interpret abstract information due to lower processing capabilities (F.I.M. Craik & Simon, 1980).

To explore this, 25 participants were invited to use three different navigation systems while seated in a fixed-base driving simulator. They were shown simulated routes, as if they were driving along a main road, and were asked to identify the correct turn off the road, using the cues of the navigation systems. The drivers communicated their choice of side road by activating the simulator car's indicator and stating the road's colour code. The focus of this study was on correctness, and timing of navigation decisions, workload scores (objective and subjective) and preference ratings.

The following research questions were tested:

- How do older and younger drivers differ in navigation performance and workload (factor Age)?
- Do the measures differ when using the HUD-based and traditional navigation systems (factor System)?
- Are System effects different between the Age groups (Age x System interaction effects)?

2.   Method

2.1   Materials

The study was undertaken using a medium-fidelity driving simulator, comprising a matte black right-hand drive Audi TT within a 270° curved screen setup, see Figure 1. A custom driving scenario, created using STISIM Version 3 software, was projected onto the screen via three high-definition overhead projectors. To ensure that the display of navigation information corresponded with the required turnings and remained consistent between participants, an automated driving situation was programmed in the simulator.

The 'virtual car' and static HUD navigation cues were created with the Qt graphics software. The animations of the HUD graphics used location information of the participant vehicle in the driving

scene, which was transmitted in real-time from the STISIM driving simulator software. The imagery was displayed using a Pioneer Carrozzeria Laser ND-HUD1 head-up display unit (customised to allow VGA input) affixed in place of the driver's sun visor. Thus, the information presented on the HUD appeared to be superimposed on the driving scene. The traditional satnav was presented on a 7-inch LCD screen located within the vehicle's centre console. To ensure the display corresponded completely with the driving scenario, this was created by recording the driving scenario from an overhead viewpoint then adding navigation information to the resulting video using Adobe After Effects software.

Digital camcorders were unobtrusively located in order to record the driver's responses. Throughout all drives, participants wore a Tactile Detection Task (TDT) device to provide an objective measure of workload. The TDT is an ISO standardised method in which drivers wear a small vibro-tactile motor attached to the lower part of the neck. Periodically (and seemingly randomly), with uniformly distributed time periods in-between, the motor vibrated with a brief low intensity pulse. The task of the participants was to press a button on their index finger against the steering wheel when they noticed the pulse, in order to switch it off. In addition, participants' behaviour and responses were recorded via four digital cameras located unobtrusively within the vehicle.
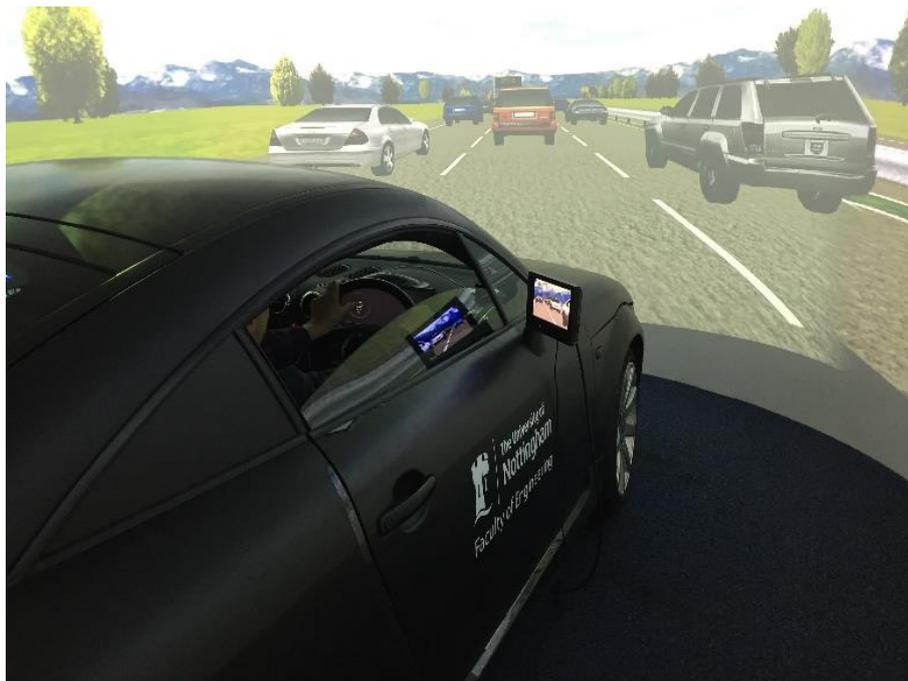

Figure 1: Medium-fidelity fixed-base Driving Simulator

2.2 Driving scenario

To create a challenging environment with considerable navigational uncertainty, the scenario depicted a straight, suburban road with multiple turnings very close to each other (see Figure 2). The simulated participant vehicle operated in an automated mode and maintained a constant 30mph

speed as it proceeded along its route. For each route, drivers had eight navigational decisions to make. Every intersection had five possible turnings and each turning was coloured to aid identification.

Figure 2: Driving scene with coloured side roads

2.3   Design

Two main variables were regarded during the study, Age and System.

IV1 Age: 'Younger' vs. 'Older' (between-subjects):
The participant base consisted of two distinct age groups, the 'younger' group's ages ranged from 20 – 40 years, and the 'older' group required participants to be at least 50 years old.

IV2 System: Virtual Car (VC) vs. Static HUD Graphic (SG) vs. Traditional Satnav (SN) (within-subjects):
The *VC*, Figure 3, condition depicted a car positioned 50ft in front of the driven vehicle and was displayed on the HUD unit. It was programmed to flash its indicators left/right after passing the last side road before the correct turning. It then stopped at the correct side road before disappearing.
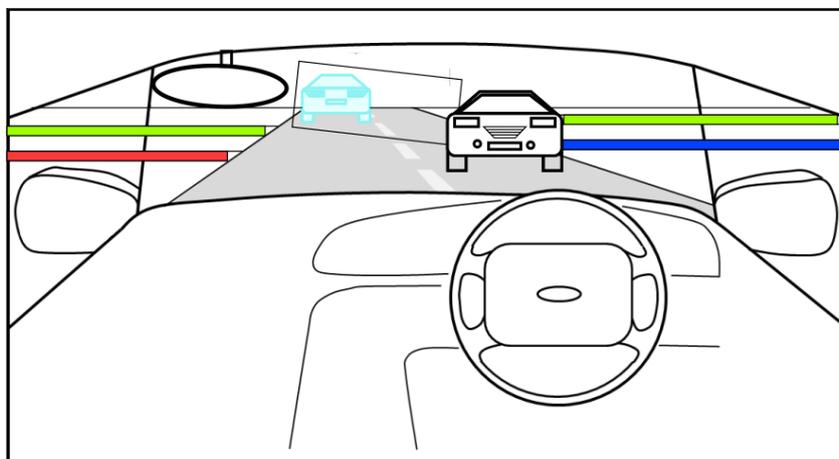

Figure 3 VC system

The SG condition mimics displays commonly seen in modern HUDs already implemented in cars. It consists of a directional arrow which fills up as it approaches the required turning. SG displays the turn direction (utilising a screen-fixed arrow) and distance-to-turn (using a bar) on the bottom right of the HUD display, see Figure 4.
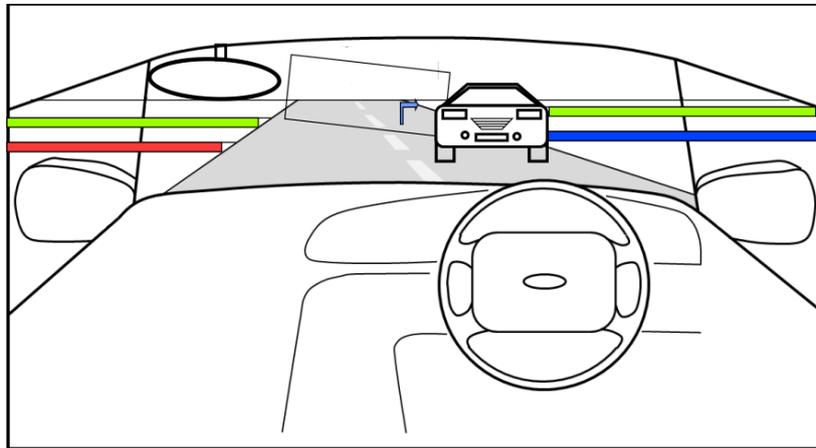

Figure 4 SG system

The *SN* was designed as a separate screen placed onto the centre console of the Audi TT. The screen showed the STISIM driving scenario, without trees, ambient traffic and pedestrians, from a birds-eye perspective from behind the participant car. Figure 5 illustrates how straight lines and arrows were overlaid on the road to guide the drivers.
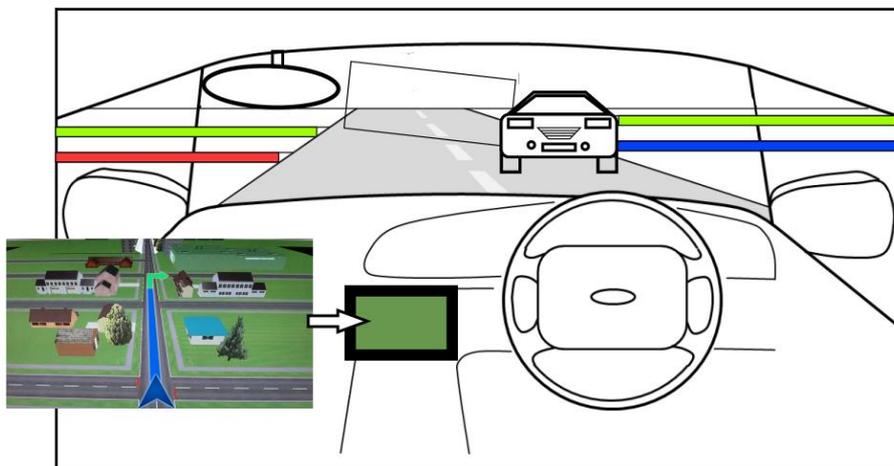

Figure 5 SN system

For all conditions the navigational cue initially appeared 7.95s (350ft) before the required turning. The navigation conditions were counterbalanced to account for order effects.

2.4   Participants

Twenty-five participants were recruited to take part in this study. Twelve participants for the younger (8 males, 4 females) and 13 people for the older age group (9 males, 4 females) took part. The final age ranges for the two groups were 21-37 years (M = 26.33, SD = 4.85) and 51-78 years (M = 61.00, SD = 8.07) respectively. All participants were licensed regular drivers, with 3+ years of driving experience. Drivers' mean annual mileage was 7,416 miles (SD = 4,033) for the younger and 8,692 miles (SD = 3,728) for older group. Additionally, all participants were regular users of satellite navigation systems, with a mean annual mileage driven aided by such a device for younger and older drivers of 3,317 (SD = 1,986) and 4,133 miles (SD = 4,133) respectively. Participants were compensated with a £10 voucher for their time at the end of the study.

2.5   Procedure

To complete the experiment, participants were asked to maintain a standard driving position, but were not actually in control of the vehicle. Participants were asked to use the navigation cues provided to identify the 'correct' turning as quickly as they could while maintaining accuracy. To do this, participants were asked to indicate the desired direction using the vehicle indicator whilst speaking aloud the colour of the road. Following this, a confidence rating on whether the chosen route was correct was required from participants. This took values between 1 and 5, where a rating of 1 indicated the driver was "not at all confident" and 5 meant "very confident". Drivers completed three drives, each with a different method of presenting navigation information – VC, SG and SN. No additional audio cues were given for any condition to ensure participants were solely reliant on visual information. Throughout each drive, participants were asked to complete the secondary TDT (ISO 17488, 2016) to measure cognitive workload. Each drive took 3-4 minutes to complete and following each drive participants completed a NASA-TLX questionnaire (Sandra G. Hart & Staveland, 1988) to quantify the workload they felt each navigation method presented. After all three conditions had been completed, participants were asked to rank them (with 1 being the most preferred and 3 being the least). The entire session lasted 60 minutes and the participants were compensated for their time with £10 shopping vouchers.

2.6   Measures

A range of measures were taken during the study in order to capture the overall effectiveness of the different methods of navigation:

1. Navigational success
The percentage of 'correct' turn selections for the route.
2. Navigational decision time
The time taken between the navigational cue first appearing and the participant activating the indicator.
3. Objective mental workload

Obtained through the secondary tactile detection task and expressed by the success rate and time taken in responding to the stimulus.

4. Subjective mental workload

Obtained using the NASA-TLX questionnaire and expressed as the cumulative sum value for all subscales (i.e. temporal demand, mental demand, mental effort, frustration, physical demand, performance). The value for each subscale ranges from -10 to 10.

5. Driver confidence

Spoken aloud by the driver during the study and expressed as the mean value for each drive. The value ranges from 1 (not confident at all) to 5 (very confident).

6. Participant preference

Obtained using a post-study questionnaire and expressed as the mean ranking. The value ranges from 1 (most preferred) to 3 (least preferred).

2.7   Analysis

The recorded video data files were coded in BORIS, and then exported as text files. These, as well as the TDT data files were processed in Matlab to synchronise them, and to extract the dependent measures. Subsequently, a two-way ANOVA was performed for each measure, comparing Age and the navigation Systems. For violations of the sphericity assumption, the conservative Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) was applied. When assumptions of parametric testing were not met, according to the Kolmogorov-Smirnov test, non-parametric methods were used instead. The Friedman test was applied to identify main effects of System, and the Wilcoxon signed-rank test was utilised to investigate which conditions were significantly different from each other, and whether Age effects occurred for the different System types. All post-hoc pairwise comparisons were Bonferroni-corrected. Statistical significance was accepted at $p < 0.05$. For all measures, all 25 participants have been analysed.

3.   Results

Table 1 shows the values for each measure, split into the younger and older groups. The results of the statistical comparisons for System and Age are reported in the sections below.

Table 1 Results of experiments across all measures showing mean and standard deviation (SD) values with significance level for statistically significant effects

Measure		Navigational success rate (%)		Navigational decision time (s)		TDT success rate (%)		NASA-TLX sum		Confidence level (range 1-5)		Preference ranking (range 1-3)	
Significant effects		System: p = .001		System: p < .001		Age: p = .027 (VC), p = .039 (SN)				System: p = .007			
Younger		M	SD	M	M	M	SD	M	SD	M	SD	M	SD
	VC	94.3	11.7	-11.5	-11.5	92.4	8.1	-11.5	23.6	4.36	0.64	1.75	0.87
	SG	78.4	18.6	-14.6	-14.6	88.2	14.1	-14.6	26.1	3.63	0.75	2.00	0.85

		M	SD	M	M	M	SD	M	SD	M	SD	M	SD
	SN	80.7	25.8	-12.8	-12.8	89.6	9.1	-12.8	26.4	4.27	1.03	2.25	0.75
		M	SD	M	M	M	SD	M	SD	M	SD	M	SD
Older	VC	96.2	7.9	-7.08	-7.08	73.6	24.8	-7.08	19.6	4.19	0.28	2.33	0.99
	SG	71.2	31.2	-2.2	-2.2	80.5	14.9	-2.2	15.0	3.85	0.79	1.92	0.67
	SN	81.7	22.0	-2.7	-2.7	73.1	23.0	-2.7	24.4	4.17	1.01	1.67	0.65

3.1 Navigational success

A Friedman test revealed statistically significant differences in performance between navigational conditions for the overall percentage of correct turn selections, $\chi^2(2, N = 24) = 14.24$, $p = .001$. Both Older and Younger drivers were found to exhibit the highest percentage of correct selections when using the VC condition ($M = 95.31$, $SD = 9.62$). Post-hoc tests revealed statistically significant differences in navigational success between the VC and SG conditions ($Z = -3.06$, $p = .006$) and the VC and SN conditions ($Z = -2.41$, $p = .048$). While older drivers showed higher percentages in the VC and SN conditions (Figure 6), the differences in success rate between Age groups for each condition were found not to be statistically significant.
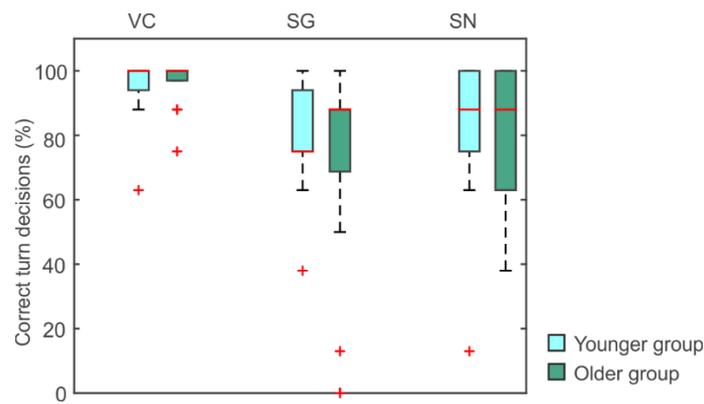

Figure 6 Percentage of 'correct' turn selections

3.2 Navigation decision time

The SG presentation method was associated with the shortest mean decision times, with 3.06 seconds for younger and 3.34 seconds for older drivers, supported by a main effect for System, $F(2, 44) = 16.99$, $p < .001$. Pairwise comparisons clarify that the SG condition led to the quickest mean reaction times for both ages (see Figure 7), significantly different to the VC ($p < .001$) and the SN ($p = .011$). There were no significant effect for Age, $F(1, 22) = 0.35$, $p = .561$), and no interaction effects [$F(2, 44) = 0.81$, $p = .452$)].
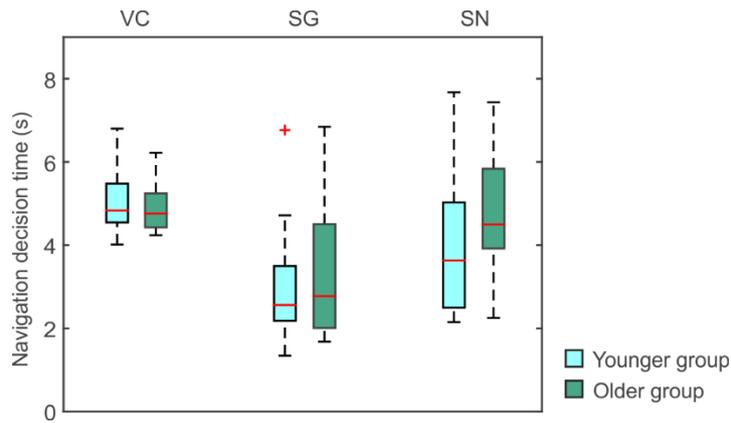
Figure 7 Time from the onset of the navigation cue to the activation of the indicator

3.3 Objective mental workload

A Friedman test with the TDT success rate found no significant difference for the navigational HMIs, $\chi^2(2, N = 23) = 0.023$, $p = .989$). However, objective mental workload was different of the two Age groups, in the case of the VC ($U = 24.50$, $p = .027$) and the SN ($U = 26.00$, $p = .039$), where the younger group showed higher success rates, by 26% and 23%, respectively, see Figure 8. Although the younger group also exhibited a 10% higher TDT hit rate in the SG condition, the difference between Ages for this condition was not significant ($U = 41.00$, $p = .234$).
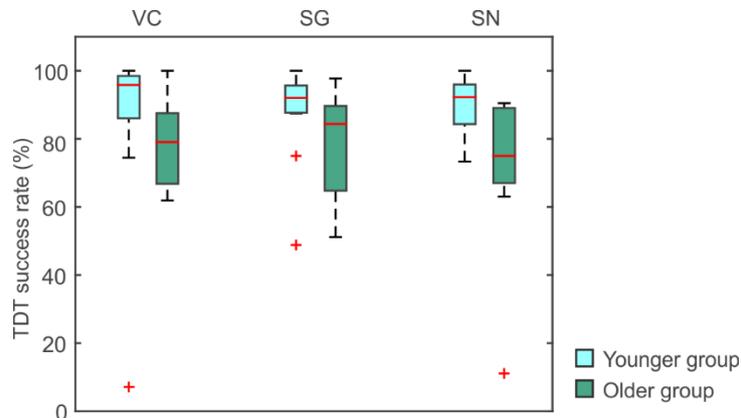

Figure 8 TDT success rate

3.4 Subjective mental workload

A two-way repeated measures ANOVA with the cumulative sum of the NASA-TLX questionnaire did not reveal significant difference between the three navigational conditions [$F(2, 46) = 0.05$, $p = .948$)]. Similarly, differences across Age groups were revealed not to be significant [$F(1, 23) = 1.54$, $p = .228$)], and there were no interaction effects. Solely for the 'temporal demand' item there was a significant effect, an Age*System interaction [$F(2, 46) = 39.71$, $p = .039$]. The older group rated the SG and SN items as more temporally demanding than the younger drivers, but it was the other way around for the VC condition. The younger group found the virtual car to be the most temporally demanding condition.

3.5 Driver confidence

The SG condition was found to have the lowest average confidence rating for both older and younger participants. Following a Friedman test [χ^2(2, N = 23) = 9.85, p = .007] and Bonferroni-corrected post hoc tests, it was revealed that the differences between the SG condition and VC and SN conditions were significant (VC: Z = -2.89, p = .012, SN: Z = -2.44, p = .045). Differences across the two Age categories for the three conditions following a series of Bonferroni-corrected Mann-Whitney U tests were not shown to be significantly different (VC: U = 63.50, p > .999, SG: U = 73.50, p > .999, SN: U = 67.50, p > .999).

3.6 Participant preference

Personal rankings across conditions showed an average overall ranking of VC, SG, SN for younger users and SN, SG, VC for older users. Differences in score across Age groups for the conditions were found not to be significant, and a Friedman test found no significant differences across treatments, χ^2(2, N = 24) = , p = .969).

4. Discussion

The aim of this study was to explore how older drivers can be supported with different navigation methods, compared to younger drivers. The three employed methods of presenting navigation information included an animated virtual car projected via a HUD into the front of the driver, a screen-fixed arrow representation in the HUD, as well as a standard head-down satnav.

Overall Age related comparisons of the navigation performance measures revealed that, not fully in agreement with some prior findings (e.g., Cantin et al., 2009; Kim & Dey, 2009), older drivers did not perform differently than younger drivers in the navigation task. This was indicated by the correctness of turn decisions as well as the timing of the indicator activation. A potential explanation for this lack of discrepancy is compensation – older participants may have chosen to indicate quickly or delayed indicating until they were more certain. Studies such as a survey combined with crash data by Ball et al. (1998) show that older drivers tend to be aware of their limitations and take steps to compensate for performance deteriorations. Also Horberry, Anderson, Regan, Triggs, & Brown (2006) found no effects of Age on secondary task performance and hazard detection, as the older drivers could compensate for any detriments by reducing their speed.

Interestingly, the navigation Systems affected navigation performance in different ways. The VC presentation method led to both, older and younger users, experiencing the greatest navigational success. A possible reason is that this condition required the least interpretation of the navigational information. Using the SN, the participants needed to count turnings and the SG condition required a judgement to be made in terms of the distance represented by the slowly filling arrow. The VC condition is designed to avoid the need for spatial translation by fully integrating navigation information into the road scene to clearly display the required route. Therefore, these findings are in agreement with those of Narzt et al. (2006) in that reducing the need for information processing leads to improved task performance. The SG condition in the HUD was shown to allow users to select their

route fastest, being highlighted as having the lowest decision times for younger and older participants. This is in line to prior studies (e.g., Liu & Wen, 2004) which found HUD methods to allow faster responses.

Workload measures show a slightly different picture. Hit rates in the TDT for the VC and SN conditions were significantly lower for the older drivers, who hit the button about a quarter less than the younger group for both Systems. In the SG condition, older participants hit the buzzer almost 10% less. Although the difference for the SG System was not statistically significant, these results suggest that older drivers generally experienced higher objective mental workload levels, due to their age-related deteriorations. This supports the argument that older users are affected by increases in cognitive load and, as a result, have more difficulty processing information (F.I.M. Craik & Simon, 1980). For younger users, the VC and traditional SN Systems were found to be the least demanding condition, indicating their ease of use for them.

Nevertheless, there were no differences between the younger and older drivers in subjective workload, as measured with the NASA-TLX questionnaire. Other studies too found no adverse effects of Age on NASA-TLX scores, e.g., Otmani, Rogé, & Muzet (2005) with an 'older' group that had a mean age of 49 years, and Shanmugaratnam, Kass, & Arruda (2010) comparing drivers who were under and at least 40 years old, although the latter exhibited clear performance decrements such as traffic violations despite lower speeds. Similarly, the differences between the navigational conditions were not statistically significant in terms of perceived mental workload, except for the perception of the virtual car by the older group as less temporarily demanding and the other systems as more demanding, which was opposed to the ratings by the younger drivers. In a similar study, employing HUD navigation arrows, Bolton, Burnett, & Large (2015) found less significant results in the NASA-TLX score than with navigation performance measures. Especially the 'performance' questionnaire item rendered opposite ratings compared to the objective performance. When Tönnis, Klein, & Klinker (2008) tested automotive HUD navigation arrows with different shapes, they found that some shapes were perceived earlier than others, shown with the timing of indication, but that such difficulties were not reflected in the NASA-TLX questionnaire. Earlier studies found that personal preference can influence subjective workload ratings (e.g., Park, Harada, & Igarashi, 2006), but in the present study, the preference rankings do not mirror the NASA-TLX scores. In fact, Hart (2006) conducted an extensive review of studies employing this questionnaire, found similar dissociations between the constructs and concluded that these should be regarded separately.

Confidence levels were not affected by Age, but the VC presentation method led to both, older and younger users, experiencing the highest mean confidence levels. The SG condition was associated with the greatest degree of uncertainty in both younger and older drivers compared to the other Systems. This mirrors the low navigational success rates and supports the argument for more easily interpretable navigation conditions.

Finally, subjective preference rankings did not present any significant effects of Age or System, which suggests that such preferences can vary strongly across individuals. Comments made by participants

indicated that distance-to-turn information would be appreciated alongside the conditions shown to reassure drivers that their choice of route is correct.

Taken all measures together, the comparison of the navigation systems showed that no single condition could be considered the most suitable for older drivers. With the smallest difference in objective workload between the younger and older drivers, the SG could potentially be the condition that bridges the gap. If this gap was prioritised, systems would be designed that put younger and older drivers closely together at the expense of potentially better performance, particularly for younger people. At the same time, it was shown that the VC improved navigational success of both Age groups and also led to higher confidence levels at the expense of a higher objective workload for the older drivers. The question is whether it is possible that the higher objective workload associated with the VC for older drivers reduces over time. It has been shown that they to need longer to perceive the use of unfamiliar technology as more effortless and successful (Venkatesh, Morris, Davis, & Davis, 2003). It is also promising that the older group rated the VC to be the least temporally demanding system, possibly due to the need for less visual accommodation (Wickens & Long, 1995). If the problem of the objective workload could be decreased, potentially with time and familiarisation, it appears that the VC would be the best system to recommend.

One limitation of this study is that the employed navigation technologies provide some of their cues at different points along the route. Although all systems initially appear at the same distance away from the manoeuvre, the communication of the turn direction and the distance to turn vary. For instance, the indicators of the VC appear after passing the last side road before the turn, whereas the SG shows the direction early on. This way, the SG better supports the preview of the route, but the VC is likely more suitable for the identification of the correct turn when a driver is about to perform the manoeuvre (cf. Burnett, 1998). In order to control for the provision of the distance and direction information, a future study could add flashing lights to the SG graphic, similar to the VC, for example. Vice-versa, the VC could present a distance cue by gradually fading in when approaching the turn. An additional noteworthy consideration to be made in the interpretation of these results is the lack of depth perception in a simulator study. One of the benefits of AR HUD displays is that they limit the necessity for visual accommodation caused by shifting between near and far vision. However, in a simulator this is already limited by the 2D nature of the road scenario projected onto a screen. In a real-world study, differences in performance between conditions may be shown to be more significant and should therefore be investigated further in on-road studies. These would also allow for a more realistic representation of driver behaviour when they are in control of the vehicle as opposed to simply indicating their route. Another limitation is the low participant number. Although smaller sample sizes are common in driving simulator studies (Rapoport & Baniña, 2007), larger numbers, and possibly a wider variety of ages, could shed more light on effects of lower magnitude.

5. Conclusions

This study explored the navigation performance, workload and personal preferences of younger and older drivers, while using three types of HUD and traditional navigation solutions in a driving simulator experiment. The aim was to investigate whether it was possible to improve performance and workload

measures and ultimately reduce the discrepancy between younger and older drivers by providing navigational information projected onto the road. Results showed that older drivers generally tended to exhibit navigational success rates and response times similar to the younger group. The world-fixed virtual car graphic led to the most correct navigation decisions overall, while the screen-fixed arrow facilitated the fastest responses, indicating the reduced need for information processing with HUD graphics. Nevertheless, the older group experienced higher objective, but not subjective, mental workload than younger drivers in the case of the virtual car, which could, however, be mitigated with time and familiarisation. Future research should further investigate measures of distraction using AR-HUD concepts, and consider how drivers' behaviour may differ in a real-world scenario where they are in control of the vehicle and issues of depth-perception associated with simulator environments are more representative. In addition, AR-HUD navigation concepts will be interesting within higher vehicle automation levels in order to increase situation awareness by highlighting elements in the road scene or to communicate the vehicle's intention to the passengers.

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7. References

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