BLIND SPOT WARNING INTERFACE ADAPTED TO OLDER DRIVERS WITH EARLY STAGE VISUAL IMPAIRMENT

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ABSTRACT

Research Question/Objective
Advanced driver assistance systems (ADAS) are found increasingly commonly in modern day cars. These systems should have their interfaces adapted to the target population to be completely effective and help prevent accidents. Our study is focused on the improvement in interface design of Blind Spot Warnings (BSWs). This ADAS is particularly relevant to issues with older driver's physical limitations, errors with blind-spot checking and accident characteristics. However, the standard blind spot detection interface is often designed without taking into account age related visual impairment.

Methods and Data Sources
A BSWs interface adapted to major visual impairment was developed and studied. A driving simulator study was conducted, in which 14 participants aged from 62 to 76 took part, to compare our BSWs interface with a conventional BSWs interface. Participants performed two series of lane change tasks, with potential side collision scenarios, for each interface. Both subjective and objective data (oculometry, vehicle parameters) were collected.

Results
The results show that driving performance and comfort are enhanced by our dedicated interface. Drivers spend more time concentrating on the road with fewer fixations on the interface. It helps the driver keep their vision on the road by providing information in their peripheral vision. It also provides less disturbance while driving and is perceived as more useful.

Discussion and Limitations
The interface has been tested with older drivers with relatively normal vision. As a next step, it will be necessary to test this interface with patients with greater deficits.

Conclusion and Relevance to session submitted
The findings of this research may help interface designers to create ADAS interfaces adapted for the older driver population.

1. INTRODUCTION

Over the past 20 years we have witnessed major technical changes in the field of the automotive industry. More and more vehicles are equipped with advanced driver assistance systems (ADAS). These systems, which enhance security, offer support to the driver by either providing information or taking some control of the vehicle (e.g. adaptive cruise control automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead). Most of the time, only technological capabilities are taken into account in the development of some of these systems [1]. However, it is imperative to define the real needs of drivers, and to adapt these technological solutions, and more specifically the design of the human machine interface, to be completely effective and help prevent accidents [2]. The use of unsuitable assistance can have adverse effects if the behavior and the characteristics of the driver does not correspond to the one anticipated by designers [3].

A category of drivers that can benefit from ADAS is older drivers. It is well known that age□related functional limitations, diseases and disorders can affect the driving performance of older people [2]. Davidse concluded that road safety of older drivers could be improved by an advanced driver assistance systems (ADAS) that signals road users located in the driver's blind spot. However, seniors are also more sensitive to the consequences of a poorly defined ADAS compared to young drivers. An ADAS, adapted to the older driver's population, should therefore be defined on the basis of difficulties that the seniors encounter.

We have developed an interface display for BSWs. We call it ADVISE. This interface has been design to match the needs of older drivers and to compensate for their age related visual, cognitive and motor functional change or deficit. The purpose of the present study was to determine the benefits of our interface. We conducted a comparative evaluation on a driving simulator of our Augmented Reality system versus a standard prototypic blind spot warning system (a BSW pictogram in a wing mirror).

2. BIBLIOGRAPHY

2.1. Older drivers

Older adults represent the fastest growing segment of the driving population in occidental countries [4]. They drive more and more at an older age. They have different age-related motor, cognitive and sensory functional changes relevant to driving [5] and show poorer driving performance [6]. Furthermore, older drivers are more involved in left turn accidents at intersections [7], are 1.46 times more likely to be involved in a high speed lane change crash than younger drivers [8] and are more inconsistent than younger drivers in maintaining headway and lateral lane position [9]. Since older drivers are more fragile, their fatality rates are higher than those of younger drivers [10,11]. Seniors, because of their frailty, are therefore more likely to die from the same accident than other categories of drivers. A significant increase in the number of deaths or serious injuries is expected in the years to come [12].

Taking into account the significant increase of older drivers on the road, their increased accidents and frailty, it is therefore essential for road safety in the upcoming years, to be able to develop efficient ADAS for older drivers. Aging, although very variable in its expression, leads to a decline in functional abilities, at the sensory (vision, hearing, ...), physical (joint disorders, osteoarthritis, ...) and cognitive levels (memory, attention...).

Normal (or physiological) aging affects a wide range of visual functions (for a review see Owsley and McGwin [13]). Visual acuity, visual field and contrast sensitivity are some of the aspects of vision that decline with age. Visual impairment today concerns 2 million people in France and includes several types of pathologies such as cataract, glaucoma and Macular degeneration. At an acute stage, visual deterioration may not be noticed by drivers and thus represents a significant hazard on the road. Drivers may not be able to detect the relevant information both from the road and from the on-board assistance systems. Indeed, these pathologies at an early stage could affect vision through central, peripheral or mixed deficits (central and peripheral). Thus, drivers with a central deficit could fail to identify hazards or read important information, especially small pictograms. Drivers with peripheral deficits could fail to detect hazard in the driving environment inside or outside the car.

In the course of aging, there is a decline in cognitive abilities [14], including executive functioning, selective attention, visuo-spatial and constructive capacities, memory and speed of information processing which have all been related to the involvement in accidents or driving performance [15–19]. Deficits in selective attention have been more particularly related to crash involvement [15,17,19,20] and impaired driving performance [16,21–24]. Executive functions are also important for driving [25]. Inhibition, which concerns one's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary [26], is of particular interest as selective attention relies on inhibitory mechanisms [27,28]. Age-related deficits in inhibitory ability may impact the response times (RTs) of older drivers under pressure. Some studies have used classical inhibition (Stroop test, Incompatibility test, Color Choice Reaction Time). Some studies have also used shifting tests (Trail Making Test B, Wisconsin Card Sorting Test) which concerns switching back and forth between different tasks. Poor performances on these executive tests have been related to crash involvement [15,19] and poorer driving performance [22,29].

Physical limitation can also impact driving performance especially osteoarthritis which can have a detrimental effect on neck, head and trunk mobility. Visual exploration could be affected as restricted neck and trunk mobility decreases eye movement amplitude [30–32]. Age related decreases in head and neck mobility can adversely affects older driver's ability to complete driving tasks. Thus, a limited range of neck motion can affect glancing in mirrors and to the rear and sides of their vehicle to observe blind spots. It can also impact the time of recognition of conflicts during turning and merging manoeuvers at intersections [33].

3. CONSIDERATIONS FOR INTERFACE DEVELOPMENT

3.1. Central vision

The central vision is specialized in the vision of details and colors, thanks to the high density of photoreceptors responsible for these functions: cones. Central vision is generated by the macula, the central area of the retina. The fovea is located in the center of the macula lutea of the retina. We call foveal vision the very limited visual angle (2-4 degrees) around the central axis, which allows excellent spatial discrimination. This capacity is altered by moving away from this point. However, in this type of vision, one can always have a partial recognition of objects in the 20 degrees around the central axis.

3.2. Peripheral vision

According to Strasburger [34] peripheral vision refer to anything outside 2°. Peripheral vision is particularly sensitive to movements and night vision, thanks to a high density of photoreceptors responsible for these functions: Rod cells. For Claverie and Leger [35] careful attention is possible within up to 30° horizontally and 20° vertically in the visual field, while impressions can be collected up to 100° horizontally and 80° vertically and finally only alerting movements are still detected up to 180° horizontally and 125° vertically. Some authors have shown that red, orange, yellow and blue induce a constant sensation up to 60° and up to 80° categorization performance for red and blue is still possible [36,37]. Furthermore, according to Sakurai, surround luminance seems to have no impact on those results.

3.3. Augmented Reality Head-up Display

HUDs provide the advantages of reducing accommodation demands when switching from displays to external targets and vice versa. They also increase "eyes-on-the-road" time. However, the restricted display area means the projection of only small elements is possible. In addition, the overall visibility of the projected elements is highly dependent on the ambient light conditions. Augmented Reality Head Up Displays appear to be particularly useful in overcoming the shortcomings of current systems. Charissis, Papanastasiou, MacKensie and Arafat [38] show that the use of an augmented reality head-up display could reduce both the response time of older drivers and the occurrence of collisions, compared to conventional indicators on the dashboard. It is also imperative to ensure that they do not distract the attention of the driver and do not mask the physical elements of the road.

4. INTERFACE DESCRIPTION

4.1. Current studies

Our aim is to produce a blind spot detection interface that can be detected by peripheral vision through use of a head up display. The interface should take into account older drivers specificities but also general considerations on visual, cognitive and motor aspects.

We decided to develop an interface for Blind Spot Warning (BSW) systems because lane changes are one of the most hazardous situations and represent a challenge not only for older drivers but for all drivers. According to Svenson, Gawron, & Brown [39] 5% of reported car accidents occur during lane changes. To complete a safe lane change, it is essential for the driver to scan a large area around the car. They must pay attention to the front for the current lane but also to the back for the target lane. This action is very difficult for older drivers who may have cognitive deficits. Furthermore, we know that detecting a vehicle present in the blind spot is a particularly challenging situation for older people with neck mobility problems because they are invisible to the driver without a direct visual scan [40]. Existing solutions that have been developed to reduce blind spots are principally localized on or near the wing mirrors. However, those solutions are not fully adapted, and crash risks still remain if the driver's visual attention is not on those mirrors.

4.2. Interface description

Our aim is to produce a signal accessible without moving the head to compensate for age related motor deficits. To compensate for age related inhibition or selective attention deficits the signal should be detected by near peripheral vision, without the help of foveal vision, and should be easily ignored. As visual pathologies at an early stage could affect central or peripheral vision the warning should be detectable whatever the deficit. The signal should use augmented reality principles in a head up display format, to increase “eye-on-the road” time compared to head-down displays. The augmented reality format should facilitate the interpretation and support the age-related decrease of inhibitory function. The information should focus on warning only, be easy to process and the decision making should be easy to take in a critical situation.

4.3. Conception

The Final Advise interface is presented in Figure 1. To help detection we located the warning signals directly on the road scene. The signals are overlaid on the two adjacent lanes to alert for potential hazards. In this way, the interface enhances one’s current perception of reality of the driving situation in real time. It gives the drivers a clear indication of what to do in an intuitive manner. This solution offers a more extensive type of HUD display than those currently offered, i.e. within a horizontal "unbalanced" band on the bottom of the windshield in front of the driver. Head up display interfaces are interesting because they minimize the ocular distance between the display and the driving scene.

The signal covers a surface of approximately 3° height and 16.8° width using a red color to signify the danger. The shape should be large enough to cover a large part of the adjacent lane. In each signal, on the right and left, a yellow blind spot pictogram representing a car with a radar is positioned in the middle of the red area covering a visual angle of approximately 1.15° height and 0.76° width.

The warning signal appears only when a car enters the radar zone and the driver has activated his indicator light. The blind spot pictogram appears first and instantaneously while the red shape appears with a fade in of 0,5 seconds. The signal stays as long as the radar detects the car and disappears instantaneously when the car is no longer detected by the radar.

No sound was added to the warning so as to provide information from the interface alone.

Figure 1. ADVISE interface

5. METHODOLOGY

We would like to test the following hypothesis: compared to a standard interface ADVISE interface, (1) enables the driver to longer keep his foveal vision on the road, (2) improves lateral position on the lane, reduce collisions and (3) improves driving comfort.

5.1. Subjects

We recruited 14 participants (8 men and 6 women) aged from 62 to 76 ($M = 69 \pm 3.84$). Subjects scored high on the Mini Mental State Exam (MMSE) and above the cut off score of 24 indicating intact normal cognitive functioning. Some of them presented early visual impairment. One participant with early Diabetic Retinopathy showed poor contrast sensitivity. Four participants have abnormalities in their peripheral visual field. However, all the participants attained the legal vision requirements to drive in France.

5.2. Apparatus

We used a fixed-based Compact Driving Simulator (OKTAL CDS-650) located at the Institute de la Vision in Paris. The simulator consists of a cockpit, an open cabin-mock-up, containing a force-feedback steering wheel, accelerator, brake pedal, clutch pedal and audio simulated driving sound. This is all placed in front of three 65 inch HD LED display. The driving scene is displayed in front and on both sides of the driver covering a 180 degrees’ physical horizontal field of view. Wing and rear view mirrors are represented on the screens through SCANeR software. Visual scenes presented on the three displays provide the external driving environment (other cars, road, lanes, etc.) and the vehicle cockpit including vehicle dashboards. The driving environment consist of a two-lane motorway.

5.3. Driving Scenario

The driving scenario is inspired by Chun [41]. The driving scenario takes place on a two-lane motorway. The participant was asked to follow a preceding car travelling at a constant speed and at a safe distance. The distance was fixed at 2 seconds with the preceding vehicle and we instructed the subjects to drive as closely as possible to the speed limit. The driver was instructed that the preceding car will change lanes and they will have to position their car on the same lane. The preceding car changes lane every 10-30 seconds assuming the participant is directly behind them.

In addition, two cars followed the participant's car at a time headway of 3,5 seconds. When the participant started to move into another lane to follow the preceding car, the following car situated on the destination lane accelerated by 50 m/s2 to suddenly approach the participant's car and stay in the blind spot zone. This collision event occurred with a probability of 1/3 for each lane change. This probability is equal for both the left lane change situations and the right lane change situations. The participant was instructed to act to avoid collisions as soon as they detected events. The ADVISE, or standard BSW, was show right after a car appeared in the participant's blind spot. The following car stayed in the blind spot zone for 5 seconds and then decelerated to reach the original time headway.

5.4. Collected data

We measured indicators of the drivers' actions (use of the brake, accelerator…) and car dynamics (speed, acceleration…). We also measured driver's eye position with an SMI eye tracker placed on the driver's head and paired with the OptiTrack motion capture system to extend the visual field of the SMI camera. An additional ergonomics questionnaire was given to the participants after each driving session to measure the cognitive load, usability and the user preferences.

5.5. Procedure

All participants gave informed consent to participate in this research study. An ophthalmologic examination was conducted to assess binocular visual acuity, contrast sensitivity and peripheral visual field. They also completed a Mini-Mental State Examination (MMSE). During the driving simulator session, the subjects were accompanied by an experimenter (an ergonomist). To become familiar with the driving simulator the participants were provided with 15 min of free driving time. They were next instructed on the two interfaces and the BSW ADAS. Then, the participants practiced the experimental task of following a preceding car. The conditions were counterbalanced to control for the independent variable "Interface". Thus, half of the participants tested the ADVISE interface first and the standard interface second, and half participants in the reverse order. Each interface was divided into two testing session of 10 minutes each. Finally, all participants completed an ergonomics questionnaire.

6. RESULTS

6.1. Percentage of Gaze duration

Thanks to the coupling of the oculometry system and the motion capture system it is possible to obtain the position of the eye on a large area from the left-wing mirror to the right-wing mirror. we could measure the time spent by foveal vision on the following areas of interest (see figure 2 below): road (red area), ADVISE interface (yellow area), mirrors (blue area) and dashboard (green area). These gaze durations were collected during only one of the sessions for each interface.

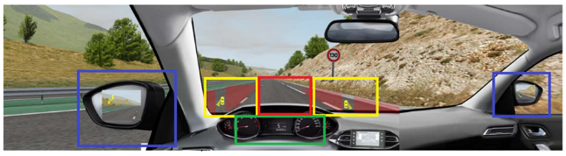

Figure 2. areas of interest: road, ADVISE interface, mirrors and Dashboard.

We summed the duration on each area of interest for all the subjects, for each interface session testing, and calculated from this the percentage of time spent on each area for each left or right lane changing event. We focused here on the four main areas, presented in table 1.

Table 1. Percentage of gaze duration for all areas of interest.

Area of interest	Advise interface testing		Standard Interface testing		differences
	Left	Right	Left	Right	
Road	61%	73%	45%	52%	p<.05
Mirrors	10%	3%	26	23	p<.05
Interfaces	6%	2%			
Dashboard	13%	9%	13%	12	ns

We did a repeated measures ANOVA to check if differences were significant (if p >5%) or not (NS). There is a significant difference for the percentages of time looking at the road between the ADVISE interface and the standard interface. Drivers look more at the road with the ADVISE interface (p<.05) than for the standard interface. This is observed for both the left lane change situations (p<.05) and for the right lane changes situations (p<.05).

As it was not possible, for the standard interface, to distinguish between looking at the interface and looking at the mirrors we grouped those two measures for the ADVISE interface. In this case, the percentage on the interface is reduced for the ADVISE interface compared to the standard interface (p<.05) and this result is also observed for both the left lane change situations (p<.05) and for the right left change situations (p<.05).

Finally, we do not observe any difference for the time spent looking at the dashboard between the session with the ADVISE Interface and with the standard interface.

6.2. Collisions

Of the 14 subjects, 8 encountered at least 1 collision during the test phase. The overall number of accidents represented 16 collisions out of 280 trials in total (5% of Observations). Furthermore, we do not observe significant differences between the two conditions with the ADVISE interface or with the Standard Interface.

6.3. Lateral position on the lane.

We measured the maximum deviation (in meters) from the center of the lane when using the ADVISE and standard interfaces. The maximum deviations seem relatively close from one interface to another. The following figure 3 reports the mean and standard deviation for the maximum deviation on the lane using the ADVISE and the standard interfaces. The results of an ANOVA revealed no significant difference in the maximum deviations between the two driving conditions (F <1).

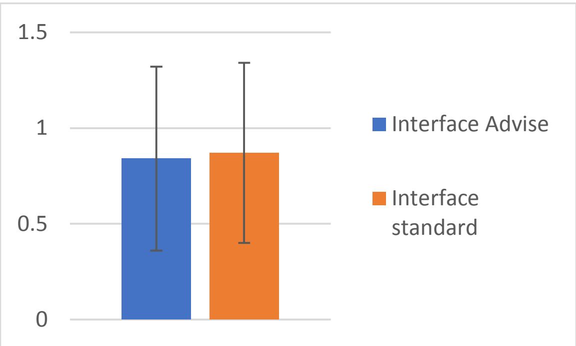

Figure 3. Mean and standard deviation for the maximum deviation on the lane using the two interfaces.

6.4. Ergonomics questionnaire

Cognitive load Wilcoxon signed-rank tests for matched samples were performed to compare scores of mental demand, visual demand, Interference and performance between the two interfaces (see figure 4 below). The analysis shows that the interference score is at higher level for the ADVISE interface than for the standard interface (p <0.05). We also observe that mental demand and performance approached significance with a lower score for mental demand and a higher score for performance for the ADVISE interface (p=.083 and p=.072 respectively). Finally, the static analysis do not show any interface effect for visual demand scores (W = 18, p = 0.352).

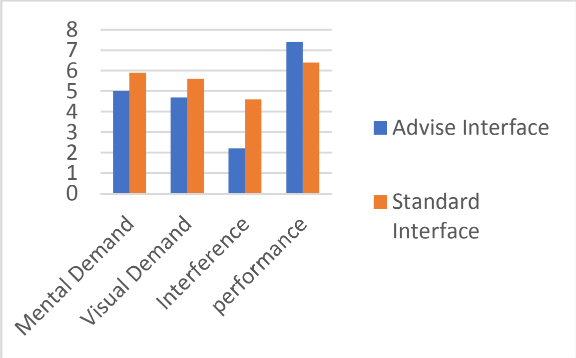

Figure 4. Mean cognitive load scores for both interfaces.

Acceptability Acceptability was measured through the two-dimensions of utility and Satisfaction. Wilcoxon signed-rank tests for matched samples were performed to compare the utility and satisfaction scores of the two interfaces. The results show a significantly higher utility score and satisfaction score for the ADVISE interface than for the standard interface (for both tests: p <0.05).

User preferences Finally, we proposed some questions about the preference for the two interfaces. Participants prefer the ADVISE interface (79%) to the standard interface (29%). All the participants found “adequately visible” the ADVISE interface while 35% of participants found “not visible enough” the standard interface. 86% of participants think that the ADVISE interface can help them to be more alert while only 50% thought this for the standard interface. Finally, 72 % of participants would use the ADVISE interface while only 36% the standard interface.

7. DISCUSSION

The results of the present study validate that older drivers can keep their foveal vision on the road better with the ADVISE interface. Eye Tracker data analysis show that with the ADVISE interface the driver does not need to look directly at the interface as often as the mirror blind spot warning. This result may be explained by the fact that the driver takes in the information through their peripheral vision. Visual distraction is thus minimized since the drivers can keep their eyes on the road to control the gap with the car he wants to overtake. This improvement leads to safer situations, especially for older drivers, since it becomes more and more difficult with aging to deal with dual task situations due to an age related executive

function deficit. Thus, the ADVISE interface should preserve against distraction and interference and thus support inhibition which enables quick and efficient reaction to sudden hazardous situations.
The ADVISE interface has not shown any detrimental effects and has shown itself to be as good as a conventional interface for avoiding accidents and maintaining the lateral position on the road. Further to this, our analysis of the ergonomic questionnaire indicates that the participants seem to be more disturbed in their driving by the standard interface than by the ADVISE interface. Older drivers tend to report better performance and less mental demand with the ADVISE interface than with the standard interface. Furthermore, older drivers also find the ADVISE interface more useful and report more satisfaction while using it. Thus, older drivers appreciated the ADVISE interface and found it useful to the blind spot ADAS and overtaking situations.

8. CONCLUSION

To summarize, we have developed and investigated the effects of an augmented reality HUD interface for older drivers and visually impaired drivers. The results of this study confirm that augmented reality dedicated to peripheral vision appears to be a good solution to efficiently integrate ADAS. We can conclude that the ADVISE interface leads to changes in driving behavior. With such an interface, older drivers can keep their eyes straight ahead for a longer time during their preparation for the lane change manoeuver. Older drivers also claim more comfort with such an interface.

This interface has been design to deal with central and peripheral visual problems. All of our participants were able to use this interface, including the participants with early central and peripheral deficits. Moreover, the population investigated in this study were fairly young older drivers without prominent impairments. In a next step, we propose to test this interface with patients presenting a more pronounced visual deficit.

Our test has been designed without auditory warning. Thus, our results indicate that the interface presented alone is efficient. However, it would be interesting to couple the ADVISE interface with an auditory warning and test it again.

Although this interface has been developed for older drivers with a visual deficit, it may nevertheless be of use to younger drivers. The findings of this research may help interface designers to create ADAS interfaces adapted for the older driver population.

Furthermore, with such an interface we could envisage the development of a calibration system which would optimize the visual HUD inputs according to the visual characteristics and, more particularly, to the pathology of each driver.

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