Immersive Virtual Reality Simulation as a Tool for Aging and Driving Research

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Abstract. The aging process is associated with changes to many tasks of daily life for older adults, e.g. driving. This is particularly challenging in rural areas where public transportation is often non-existent. The current study explored how age affects driving ability through use of an immersive virtual reality driving simulator. Participants were required to respond to typical driving events: stopping at an intersection, controlling vehicle speed, and avoiding objects in the road. Results showed that older adult performance was consistently lower than the younger adult group for each driving event, and matched those of real-world accident data. Post-study survey data suggested that all participants were able to easily interact with the driving simulator. Results also demonstrate the efficacy of immersive virtual reality as an effective research tool. Findings from this research will influence the development of compensatory augmentations, or navigational aids, and enrich our understanding of driving and age-related concerns.

Keywords: Spatial cognition · Aging · Gerontechnology · Human computer interaction · Virtual reality

1 Introduction

Driving is an important means of navigation for older adults who want to maintain their health and independence [1, 2]. However, the aging process often leads to cognitive and physical changes that can have profound effects on driving behavior, such as magnified safety concerns, increased risk of getting lost, and greater self-doubt for older drivers. It is estimated that there will be more than 71 million adults over the age of 65 by the year 2030 [3]. Addressing the dearth of research on spatial aging and driving, as is the goal of the current study, is vital to the safety and well-being of older adults, who represent the fastest growing demographic in the country.

There are several driving concerns specifically known to be issues for older drivers. This research addresses four key areas of concern, including: breaking at intersections, drifting out of lanes, avoiding obstacles, and maintaining proper speed [4]. The Insurance Institute for Highway Safety has found that older drivers (65+ years) are over-represented in collisions involving these problem areas [4]. The current work was motivated by two major goals. The first was to better understand challenges for older drivers that ultimately effect their safety and independence. This was assessed by evaluating error performance and reaction times for the four areas of concern for older

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drivers. The second was to extend current VR research to evaluate the efficacy of using immersive virtual reality simulations as a tool supporting this program of research.

The virtual reality simulation used here differs from previous investigations by utilizing a head mounted display (HMD). Most previous work studying spatial aging and driving research has employed static displays incorporating desktop monitors and CAVE systems (see [5] for review on different VR approaches). These approaches do well at providing the experimental control and safety that VR affords, but often require high computational demands and are less realistic than HMD-based immersive simulations. Unless these traditional systems include a 360 degree field of view (requiring many monitors/projectors, significant space and cost, and computationally intensive hardware/software) they lack the immersion that an HMD provides. The advantage of HMDs is that they couple visual updating with head movement, similar to the experience of real world driving, thus providing a more realistic interface for use in driving research. Modern HMDs are compact and are becoming more and more cost effective as the virtual reality industry moves into the commercial gaming/entertainment sector. Within the past few years, the enthusiasm surrounding VR technology has skyrocketed and has significantly benefitted from strong corporate interests (e.g., the 2 billion dollar purchase of Oculus by Facebook). Competition between new and existing VR companies is leading to sharp increases in the advancements of VR hardware while continuing to reduce the cost of the constituent technology. Increased testing of its efficacy as a research tool with various demographics (such as older adults) and reduced cost will improve availability and favorability with researchers. This is important given the lack of research that currently exists using immersive VR to study aging and driving.

The results from this work will also provide important foundational knowledge to guide future development of what we have termed compensatory augmentations. These augmentations will incorporate simulated information to enhance normal decreases in sensory and cognitive abilities that occur across the lifespan, thereby supporting safer and more efficient navigation. For example, enlarging or highlighting a sign as a driver approaches can compensate for reduced age-related processing speed by allowing the driver to notice important information more quickly, thus providing them with more time to react. We postulate that drawing a driver's attention to important signage and information cues will help with improving driving events, such as breaking at intersections and avoiding obstacles, as is tested in this research.

2 Virtual Reality Simulation Experiment

2.1 Equipment

This study investigates a novel use of VR as a research tool by evaluating the driving safety of older adult populations. VR motion sickness is a concern for younger adults and is further exacerbated with age [6]; thus, we designed our system to help alleviate simulation sickness through careful matching of real and virtual visual expectations, choice of textures/models, and superior clarity/refresh rate of the display. We used a Sensics, Inc., Z-Sight 60° FOV HMD that provides dual OLED 1280×1024 resolution displays to render the virtual environments [7]. This unit provides clear graphics and a wide field of view. The selection of textures/models for the environment was established through pilot testing that evaluated and compared various parameters known to potentially cause nausea and negative VR side effects. We used these pilot results as a guide in our design decisions to use lower polygon models with simplified textures during rendering. These models/textures both improved the frame rate of the simulation as well as reduced the visual strain that is often associated with the rendering of complex textures, especially those that move in peripheral vision. The virtual environment designed and implemented in this experiment was developed with Unity 3D, employing the Easy Roads 3D package to create the course. The Unity Car platform was used for the physics engine. The driving simulator was constructed in-house using the driver's seat from a Ford Crown Victoria and the steering wheel and pedals from a disassembled Playseat racing seat. The low platform and roll-cage style stabilization bars were designed for safety given the intended use of the driving simulator with an older adult population. Figure 1 shows the driving simulator used for this research.

Fig. 1. Photo of participant using the VEMI driving simulator

2.2 Participants

Thirty-two participants completed the study, evenly split between two age groups. The older adult age group consisted of sixteen people (7 female), ages 60–82 (M = 69.4, SD = 6.2). The minimum age was set at 60 years, as research suggests that this is when the largest age-related effects on spatial abilities begin to manifest (see [8, 9] for reviews). The younger adult age group included sixteen people (8 female), ages 18–34 (M = 21.9, SD = 3.6). Prior to starting the experiment, the older adult group completed the Montreal Cognitive Assessment, a common instrument in aging research for assessing cognitive impairment (all participants scored equal to or greater than 26, indicating no abnormal cognitive impairment) [10]. The research was approved by the University of Maine's local ethics committee and written informed consent was obtained from all participants.

2.3 Procedure

Participants began the experiment with a 5 min practice phase. During this period, they practiced on a simplified course where they could adjust to both the driving simulator and the virtual reality experience. Upon completion of practice, a criterion test was given to assure that participants were comfortable with the entire system. For this test, they had to maintain a speed between 10 and 15 mph while weaving back and forth between 6 cones, which were placed a set distance apart in the middle of the virtual road. They then observed a stop sign after passing all traffic cones. The criterion test was designed to assess the participant's ability to use the driving simulator while managing acceleration, speed, vehicle control, and breaking behavior, as these were all factors of interest subsequently evaluated in the experimental trials. No participants failed this criterion (no cones were hit and all participants stopped before the sign). After completing the practice session and criterion test, participants moved on to the final experimental course.

The driving events participants experienced during the final course are known hazards for drivers over 65 [4]. The events tested included: intersection surveillance, speed maintenance, lane drifting, and obstacle avoidance. The course contained multiple speed limit zones ranging from 25 to 65 mph. Speed maintenance was defined as the participants ability to properly accelerate/decelerate in order to adjust their speed as they encountered the various speed limit signs. Two different types of intersections were incorporated within the final course: those with stop signs and those with traffic signalization, which are both common intersection types. Figure 2 shows a simulator screenshot of an intersection event.

The course required participants to drive through a town, as well as operate on the highway. There were two situations requiring obstacle avoidance within the final course: the first was to pass a vehicle controlled by pre-programmed artificial intelligence while on the highway, and the second was to go around a small construction area in the road. Participants were informed prior to beginning the final course that during this phase, their primary goal was to abide by all regular driving rules and regulations as well as adhering to any posted information.

Data was continuously collected throughout the trial, logging parameters about the participant's behavior and vehicle status (at 100 ms intervals). To assure consistency, all participants completed the same course and experienced the same events. Results were then evaluated based on direct comparisons of event performance and reaction times between the older and younger groups.

3 Results

Data collected during the experimental driving course included status parameters of the vehicle, such as current lane, speed, direction, and driving event completion. Lane drifting

Fig. 2. A simulator screen shot of an intersection event (4-way stop)

(LD) was defined as approximately 25 % of the vehicle width leaving the intended lane and entering the oncoming lane. Drifting out of the correct lane was a particular problem for the older adults who averaged 3.25 LD per person. By contrast, younger adults averaged only 0.81 LD per person. Comparison of these means yields a significant difference between the two age groups, $t(30) = 2.74$, $p = 0.01$, with older adults LD performance being 4 times worse than that of younger adults. Indeed, this decreased performance is indicative of a general lack of attentional focus maintained by the older adults as they drove in the simulation. A higher number of lane drifts increases the chance for an out of lane collision with an oncoming vehicle, as has been shown from real world data [4].

Analysis was conducted for each driving event with success rates determined by: properly stopping at an intersection, passing obstacles without collision, and correctly observing posted speed limits. When we separated success rates out by the individual events, we found that the older adult group achieved only a 56 % success rate for correct intersection behavior, compared to the 82 % success rate found with the younger adult group, $t(30) = 2.83$, $p < 0.01$. This result indicates that only 44 % of older adults properly stopped before the white line at the intersections. Reaction times for older adults were also 15 % slower than the younger adults for breaking at intersections. The slower reaction time for older drivers represents the difference between stopping in time at an intersection versus crossing the line or even hitting a car in front of them.

Accurate speed limit maintenance, defined as making a change in acceleration or deceleration towards the correct posted speed, for the older adult group was also surprisingly low at 48 %, while performance was at 80 % for the younger adult group, $t(30) = 3.94$, $p < 0.01$. When evaluating reaction times for initiating this change in speed towards the correct limit, older driver's reaction times were 85 % slower than their younger counterparts. Given the already reduced reaction times shown in the intersection data, in-proper speed maintenance can further reduce time to react for other driving events, such as obstacle avoidance.

Analysis of obstacle avoidance performance also showed the older adult group to be at a disadvantage compared to their younger peers, with an 81 % success rate compared to the 100 % success rate for the younger adult group, $t(30) = 2.42$, $p = 0.02$. This means that the older adult participants hit 19 % of the obstacles whereas the younger adults hit none. Reaction time data for obstacle avoidance also showed older adults to be at a disadvantage with 75 % slower times to react to the obstacles than younger adults. An important factor required for safe driving is the ability to perceive and react to the surrounding environment. Anything less than achieving 100 % for successful obstacle avoidance represents a red flag and indicates that this is a real problem that needs to be addressed.

The lower overall performance observed for the older adult drivers as compared to the younger driving group is consistent between each measure and can explain problems in real-world driving behavior. When we aggregate the data across the driving events, the older adult group averaged only a 62 % overall rate of success, while the younger adult group performed reliably better, with an 87 % overall rate of success, $t(30) = 5.40$, $p < 0.01$. These low success rates by the older adult group are concerning given the lack of any distractions during the experimental course that are often experienced during real-world driving (e.g., traffic, pedestrians, severe weather, etc.).

4 Conclusions and Future Work

This research set out to investigate known driving concerns, e.g., lane drifting and obstacle avoidance, for older adults through the use of immersive virtual reality simulation. The use of VR simulation for aging research affords benefits of experimental control and human safety that are difficult to obtain via real-world testing. These factors are particularly important for driving research where participants and experimenters may be exposed to greater risks in real-world settings. Customization of virtual worlds allows researchers to create and test limitless scenarios as well as eliminating the dangers associated with testing driving events.

Previous studies have shown the benefits of virtual reality technology using CAVEs and desktop systems [5] and the current work extends this effort to using immersive HMD-based simulations. The current results support the efficacy of this technology as a research tool, given that less than 15 % of participants in this study experienced any negative affects compared to upwards of 60 % in previous research [11]. We attribute this reduction of negative affects to the use of a high quality immersive display and careful a priori selection of the 3D environment content (models/textures). Post-study survey data indicated that the participants reported having a positive experience with the driving simulator and all expressed a desire to continue participation in future projects using our system.

Reaction time results from the current study compared well with other research addressing older adult driving performance using virtual reality. One such study, using three large televisions as monitors, found older adult's reaction time for breaking events to be about 16 % slower compared to performance by younger adults [12]. This is congruent with our finding of a 15 % slower reaction time for older drivers with our immersive HMD-based simulator. The same study also found that the reaction time for younger drivers was significantly faster than older drivers, but this difference between groups disappeared when the younger drivers were using cellphones [12]. The effects of slower reaction times have been shown to increase the frequency and severity of collisions in real world driving [13, 14]. Likewise, in the current work, slower reaction times led to lower success rates for driving events (e.g., failure to stop at an intersection or avoid an obstacle in the road). The lower performance here may explain the over-representation of older adults in real world collision data for the same problem areas.

The driving events tested in this research pose real world risks for older drivers who tend to be over-represented as a group for collisions related to lane drifting and intersection behavior [4]. Of note, this research lacked any distraction that could have captured or divided the driver's attention during the final course. In other words, even given an ideal driving scenario with no potential distractions, there were still significant age-related differences across multiple performance categories. In the real world, such ideal circumstances are rarely the case, suggesting that our data are likely a conservative estimate of the problem. When taking this into consideration, the low success rates of the older drivers are a serious issue and serve as a stark reminder of the real-world risks faced by this demographic that need to be further studied.

Future work will explore augmented reality solutions to improve the driving performance of older adults and specifically address the problem areas evaluated in the present study. Compensatory augmentations are aimed at enhancing pre-existing abilities that older adults still possess in order to compensate for the sensory and cognitive decline experienced through the aging process. These augmentations will help draw the driver's attention to navigation-critical information. For example, speed limit signs are important to identify, yet are usually spatially separated by a significant distance. Should a driver miss a sign, they would be unaware of that road's speed limit until they came across another sign. One solution, based on development of compensatory augmentations for driving, would use augmented reality to enhance the size and brightness of signs, as seen below in Fig. 3. This type of aid would help direct the user's attention to important driving-critical information and could be implemented in a number of ways (e.g., increased size, brightness, or via multisensory cuing such as vibration, visual, or audio cues) for various types of signage (speed, stop, yield, etc.). Other possible compensatory augmentations will deal with improving mental representations (cognitive maps) and spatial awareness through landmark identification. This sort of augmentation will keep the navigator informed of their position in relation to important landmarks around them, helping to provide a better grounding between their immediate perception and their cognitive map of the environment.

Fig. 3. An example of a possible compensatory augmentation. Left image has a normal size sign while the right image shows a sign that has been enlarged as the driver approaches.

During the development of these compensatory augmentations, consideration will also be given to common age-related diseases that may affect navigation. For example, Age Related Macular Degeneration (AMD) is known to reduce visual acuity and contrast as well as other eye conditions, such as glaucoma that can affect the peripheral visual field [15, 16]. These visual deficits could be compensated for via the presentation of additional visual information or with better identification of key environmental cues. Future work from our research group will focus on developing and evaluating these compensatory augmentations in a virtual setting before moving to real world testing. We postulate that successful virtual testing and subsequent implementation of compensatory augmentations will lead to an increase in safety and independence for older navigators during real-world driving.

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