Driving Simulation: How Low Can You Go?

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Abstract

Older and cognitively impaired drivers perform worse in driving simulators as cognitive function declines (e.g. Rizzo et al, 2001). How realistic must driving simulations be to discriminate different categories of impaired drivers? High-end, high-fidelity, immersive simulators are expensive and unsuited for general use, whereas standardized neuropsychological (i.e. paper and pencil) tests have had mixed success in predicting driver fitness. Consequently, we designed a low-cost, PC-based, abstract virtual environment (VE) for assessing cognitively impaired drivers. Instead of striving for visual realism, the VE provides abstract representations of necessary visual cues in a single screen. The VE captures key elements of real-time driving in driving-like scenarios generated with flexible, usable, and cost effective PC software. This software comprises a suite of tools for testing cognitive functions engaged by driving tasks, such Go No-Go decision making and the ability to ignore irrelevant driving distracters ("mudsplashes"). Pilot studies in several dozen subjects show that the VE tools discriminate between drivers with neurocognitive disorders (e.g, Alzheimer's disease, executive dysfunction from frontal lobe lesions) and older comparison drivers without cognitive impairment. Moreover, no drivers showed simulator adaptation syndrome or dropped out of pilot studies due to discomfort. We are comparing VE task performances with real world driving outcomes.

Introduction

The current trend in virtual environments (VE) is the pursuit of realism. Unfortunately, the price or realism has expanded beyond the point where many research and clinical organizations have the technical staff and financial resources to utilize virtual environments for research or assessment. Our previous and current research aims to explore the creative design and development of abstract virtual environments as cost effective widely deployable tools for research and assessment of human behaviour and cognitive function.

Our approach to design has been guided by understanding the needs, abilities and resources available to the clinical research community. Cost of equipment, software, system maintenance, and staff training can be significant barriers to whether virtual environments can become accessible and usable beyond the current user community. Development of a cost-effective and easy-to-maintain system requires visual representations that communicate spatial orientation and optical flow in the limited field of view of a standard PC desktop monitor. This approach draws from perceptual psychology, computer graphics, art, and human factors studies of visual cognition. We deviated from traditional simulation approaches, focusing on our assessment needs without assuming visual realism was necessary. The VEs were designed to provide sufficient pictorial and motion cues relevant for perceiving spatial relationships of objects and user orientation (Wanger, Ferwerda et al. 1992; Ellis 1993; Cutting 1997; Palmer 1999). Similar to high-fidelity driving simulators and in-vehicle navigational systems, we utilize motion parallax, optical flow caused by moving objects and the observer, shading, texture gradients, relative size, perspective, occlusion, convergence of parallel lines, and position of objects relative to the horizon. By deviating from a realistic VE design we have an open design space for creative exploration of scenario design and development. Scenario design is guided by cognitive neuroscience; to localize performance errors in specific cognitive domains that are crucial to the real-world tasks being simulated. (Rizzo and Severson 2003)

We first provide a brief overview of two studies that have utilized the Go/No-Go abstract virtual environment for assessing cognitive abilities and the role of personality and risk taking behaviour in drivers. We next provide a detailed description of a Mudsplash abstract virtual environment study. The findings from these studies raise the question of whether abstract virtual environments may perform as well or better than high fidelity virtual environments for assessment of human behaviour and cognitive function.

Go/No-Go Abstract Virtual Environment

Our initial study, conducted at the University of Iowa's Department of Neurology, utilized the Go/No-Go abstract virtual environment for evaluating decision-making in neurologically impaired subjects. The study was conducted with 50 subjects: 28 had neurological impairments causing impaired decision-making (26 with focalbrain lesions, 2 with Alzheimer's disease) and 22 were neurologically normal. Preliminary results are promising, suggesting that abstract VEs can distinguish decision-making impaired people where traditional neurological test batteries may not. The results of the pilot tests using sophisticated, yet surrealistic ('low fidelity") scenarios are promising and highly relevant to the simulator fidelity question: "how low can you go?" Significant differences in errors (i.e., crashes into closed gates and failure to go at open gates) and reaction time measures ($p<0.05$, all cases) were found between brain-damaged and control subjects. Between group differences identified using the Go/No-Go task were not consistently demonstrated on standard neuropsychological tests. Moreover, the finding of a shallower learning curve across Go/No-Go trials in brain-damaged subjects suggested a failure of response selection criteria based on prior experience, as previously reported in brain-damaged individuals with decision making impairments on a gambling-related task (Bechara et al. 1997)

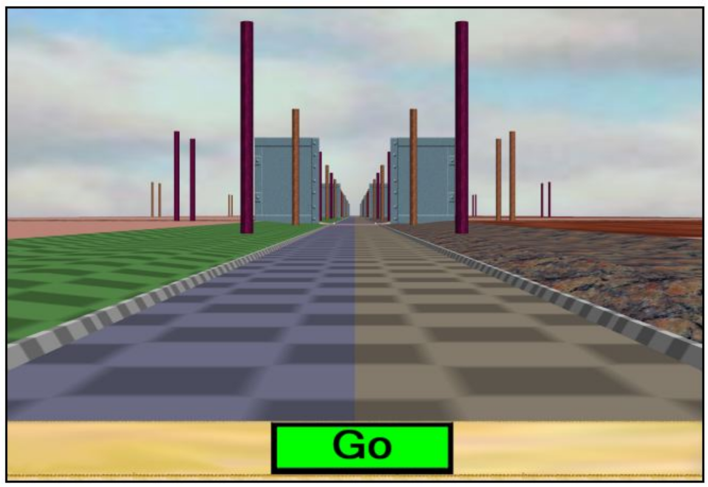

Figure 1: Go/No-Go Abstract Virtual Environment

In the Go/No-Go scenario, each subject drove through a series of intersections spaced 200 meters apart. Each intersection had gates that opened and closed. When the subject reached 100 meters before an intersection, a green "Go" or red "Stop" signal appeared at the bottom of the display and a gate-closing trigger point was computed based on a deceleration constant, gate closure animation parameters, subject speed, and amount of time allotted to the subject to make a decision. Gates began closing the moment the subject reached the gate closing trigger point. The allowed decision times (braking distances) were "easy", "medium", or "difficult" (shortest possible braking distance). Approximately 1/3 of the gates were represented at each difficulty level and difficulty levels were randomized so as to be unpredictable to the subject (Rizzo and Severson, 2003).

A second study, conducted by Dr. David Schwebel of the University of Alabama Birmingham's Department of Psychology, used the same Go/No-Go task to assess the role of three personality traits; sensation-seeking, conscientiousness, and anger/hostility in predicting risky driving behaviour. One factor long recognized as relevant to predicting dangerous driver behaviour is the driver's personality. Seventy-three participants completed personality and driving history questionnaires, and engaged the Go/No-Go abstract virtual environment scenario. In multivariate analysis, sensation-seeking was identified as the best predictor of self-reported driving violations. To test the construct validity of the VE measures, the speed and distance composites were correlated to self-reported risky driving on the DBQ and the DHQ, with sex and years of driving experience partialed. Higher rates of self-reported real-world driving violations on the DBQ were related to four of the VE measures—higher rates of hitting closed gates ($r(63) = .32$, $p < .01$), lower rates of excessive slowing at open gates ($r(63) = -.29$, $p < .05$), less time in the course ($r(63) = -.33$, $p < .01$), and quicker speed departing gates ($r(63) = .33$, $p < .01$). These trends suggested that people with more driving violations in their history drove through the virtual environment more quickly. Correlational analyses also suggested self-reported use of speed on the DHQ correlated negatively with time spent to complete the virtual environment course ($r(63) = -.22$, $p < .10$) and with instances of excessive slowing at open gates ($r(63) = -.29$, $p < .05$).

Behaviour in the VE correlated moderately with self-reported risky driving behaviours. This finding matches results studying real and simulated driving performance among older adults (Freund et al., 2002 and Lee et al., 2003) and suggests use of VE as a means to test risky driving is a valid and potentially useful alternative to self-report measures. (Schwebel, et al. 2006)

Mudspash Abstract Virtual Environment Scenario

A third study, conducted at the University of Iowa's Department of Neurology, utilized the Mudsplash virtual environment for evaluating cognitively impaired drivers' ability to ignore irrelevant distracters.

Methods

Participants

Fifty-four legally licensed drivers participated in this study. This included 9 participants with early stage of Alzheimer's disease (AD) (mean age = 78 years, SD = 8.5, range 57-88), 26 neurologically normal, older participants (mean age = 68 years, SD = 8.3 years, range 50-78), and 19 neurologically normal, younger participants (mean age = 36, SD = 8.4, range 24-49).

Participants with AD were recruited from a registry in the Department of Neurology. Their diagnosis of probable AD relied on the NINCDS-ADRDA criteria (McKhann, Drachman et al. 1984). All reported cognitive impairments that affected activities of daily living, but were still living at home and able to attend personal needs (e.g., eating and dressing). Early stages of cognitive decline were diagnosed based upon performance on neuropsychological tests including the Mini Mental State Exam (MMSE) (Salmon, Thomas et al. 2002). Participants were excluded if computed tomographic and magnetic resonance imaging scans indicated destructive brain lesions due to cerebrovascular and neoplastic disease. Exclusion criteria included acute medical illness, alcoholism and other forms of drug abuse, stroke and depression. Informed consent was obtained in accord with institutional and federal guidelines for human subjects safety and confidentiality.

Procedure

To test cognitively impaired drivers' ability to ignore irrelevant distracters we used a non-photorealistic representation of a 3D virtual space, with dynamic pictorial motion cues. Because our target display was a single computer monitor, the scenario and virtual environment had to be designed to present sufficient visual and pictorial cues to provide situational awareness in a 60 degree field of view.

Figure 2: Research assistant demonstrating simulation hardware

As in the previously described studies, the virtual environment comprised a straight, flat, two-lane road intersected by a number of gates. Driver inputs were recorded from a Logitech Momo Force-Feedback steering wheel and accelerator/brake hardware peripherals. All software for the experimental task was written in C++. Graphics software relied on OpenGL and Multigen- Paradigm's Vega. The visual database was developed in Multigen-Paradigm's Creator. The experiment was run on a Dell Optiplex GX240 computer with Nvidia GeForce3 graphics card and 21-inch LCD monitor. (see Figure 2).

In the mudsplash scenario, each subject drove through a series of 80 gates spaced 200 meters apart. The first five gates were designated for warm-up and training. After becoming familiar with the experimental setup (including the task and the steering wheel, accelerator pedal and brake controls), the subject was instructed to travel through the next 75 gates as quickly as possible without hitting the gates.

Each gate encounter by the driver originally sat in the open position. However, as the subject approached, one half of all gates closed entirely before the participant could travel through ("closing gates"). One fourth of the gates closed partially, but without blocking the subject's route, ("half-closing gates"). The remaining fourth of the gates did not make any movement ("open gates") (see Figure 3). Closing and half-closing gates began to close as soon as drivers passed an invisible trigger. The position of the trigger was calculated for each gate from a deceleration constant, gate closure animation parameters, the subject's speed 140m from the gate, and a standard amount of time allotted to the subject to make a decision.

On 42 of the 75 gates, a "mudsplash" (See Figure 3) flashed on the driver's computer screen 50ms before the gate began to close. (For open gates, mudsplashes occurred 50ms before the time when the gate would have begun to close.) The mudsplash remained on the screen for 500ms before disappearing. Similar mudsplashes have been shown in previous research to occlude visual attention, and prevent them from noticing even highly salient visual change (O'Regan, Rensink et al. 1999).

Throughout the drive the computer recorded the normalized position of accelerator and brake pedals (0-100%) as well as subject's velocity. Dependent measures included: errors in stopping or going through gates, average time to complete a gate, and average change in accelerator position in one second following the mudsplash. Additionally, subjects' longitudinal performance across all 75 gates was examined to investigate learning issues.

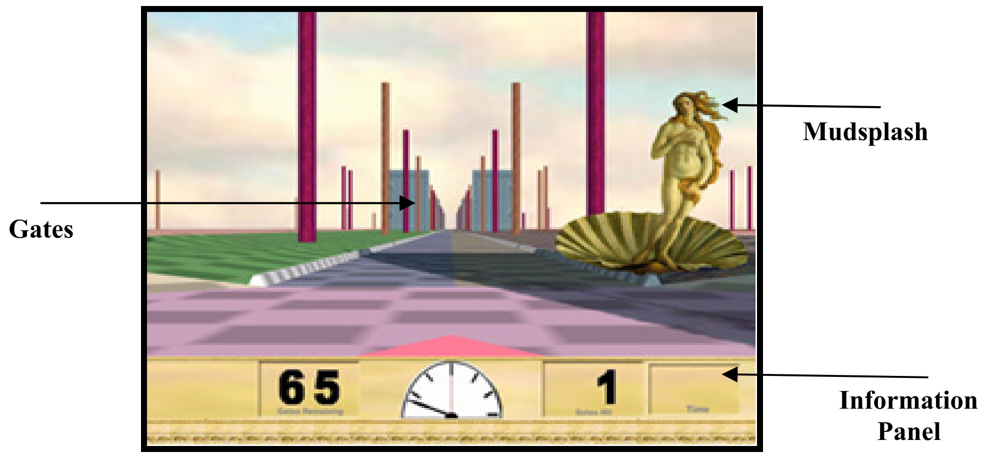

Figure 3: Mudsplash scenario screenshot

We hypothesized that older drives and those with Alzheimer's Disease would commit a greater number of stopping and going errors and require a longer average time to complete the scenario's gates. We also expected impaired participants to demonstrate more change in accelerator position in response to the irrelevant distracter, and to show less improvement overall across the 75 gates.

Results

The average time participants required to finish a gate is summarized in Figure 4.

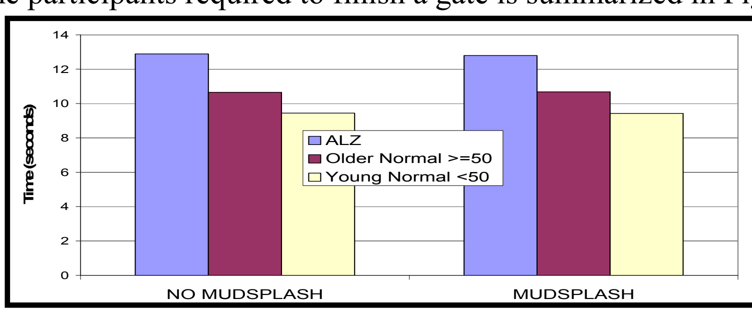

Figure 4: Average Time to Complete an Individual Gate

Following a significant overall ANOVA p = .0012, we conducted pair wise comparisons based on Bonferronis' adjustment. We found that the AD participants took significantly longer to clear a gate than younger normal participants (p = 0.0002) and older normals (p = 0.0124). No significant difference was observed between older and younger normals (p = 0.1527).

To investigate the effect of the irrelevant distracter on time, we used paired t-test to compare average gate time on trials where the mudsplash was present versus absent. No significant differences in overall gate completion time were found in either AD (p = 0.8191), older normal (p = 0.6848), or younger normal participants (p = 0.6856).

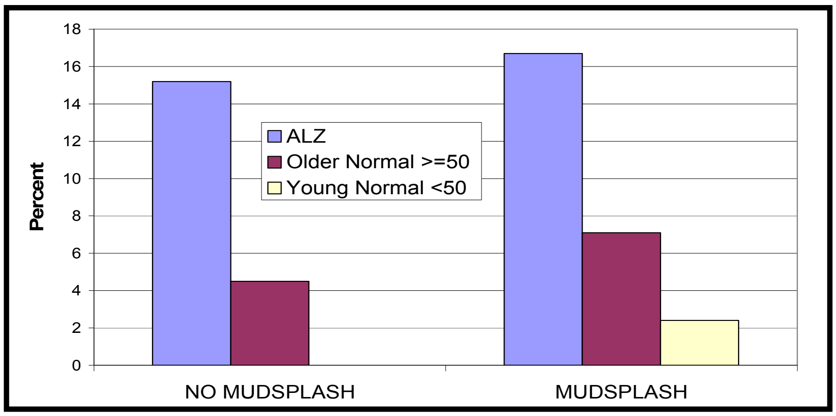

Figure 5: Median Percentage of Gates Where an Error Occurred. Two types of errors were included in this analysis. A subject could have made a stopping-error (they stopped at an open or half-closing gate) or going-error (hit the gate on a closing gate).

The frequency of errors is summarized in Figure 5. The significant Kruskal-Wallis test (p = 0.0012) showed evidence of significant differences between the groups, thus, pairwise comparisons were conducted using Wilcoxon Rank Sum Tests. AD participants were significantly more likely than the older normal (p = 0.0222) and the younger normal participants (p = 0.0015) to make an error. Older normal participants were also significantly more likely than the younger participants (p = .0225) to make an error.

To investigate the effect of the irrelevant distracter on errors, we compared gates where the mudsplash was present and absent using Wilcoxon Signed Rank Tests. No significant differences in overall errors were found in either AD (p = .3594), older normal (p = 0.881), or younger normal participants (p = 0.1619). Across all subjects, however, there was a significant difference in performance between mudsplash present and absent trials (p = .0129).

To further investigate the effect of the irrelevant distracter, we analyzed the position of the accelerator pedal in the one second following a mudsplash. On trials where no mudsplash occurred, we calculated when the mudsplash would have occurred and analyzed the position of the accelerator in the following second. We calculated the maximum absolute value of accelerator displacement from the moment the mud splash [would have] occurred. These values are summarized in Figure 6. AD participants showed no significant differences in accelerator displacement on mudsplash present or absent trials ($p = 0.0742$). Significant differences were present for older normal ($p = 0.0005$) and normal younger participants ($p = 0.0002$).

To address whether subjects were able to adapt to the task, we analyzed each participant's average time to complete a gate and their number of overall failures. To analyze gate completion time, we used linear regression to obtain an estimate of the slope for each subject and each gate type while modelling the time to complete a gate type by the actual gate number. We then took the mean of these slopes to create a mean estimate of group's effect on time. To find a p-value, we compared these mean estimates to zero using a one-sample t-test. We found no significant mean estimates for AD ($p = 0.6200$) older normal ($p = 0.8242$), or younger normal participant ($p = .0783$)

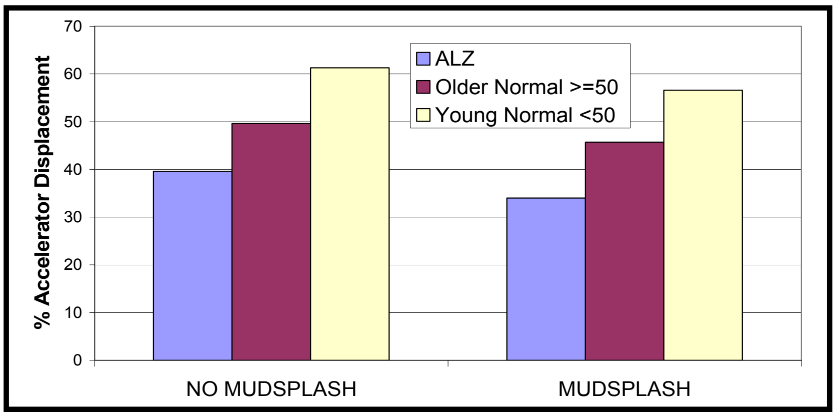

Figure 6: Average Absolute Value of Displacement of Accelerator Position Following Mudsplash. Values are given in percentage of maximum displacement of accelerator (e.g., removing foot from a complete pressed accelerator would create and absolute-value of Displacement of 100%).

To address learning issues in regard to errors, A Spearman's correlation coefficient was computed within each subject and the mean of the correlation coefficients was used to obtain the mean estimate. A one-sample t-test was then used to test whether the mean estimate is equal to zero. A significant correlation was not observed for AD participants ($p = .7023$) but was observed in older ($p = .0060$) and younger ($p < .0001$).

Discussion

AD participants took longer than both older and younger normal participants to complete the gates of the go/no-go task. The AD participants committed more errors than older and younger normal participants. Additionally, older normal participants were more likely than younger participants to make errors. The presence of an irrelevant distracter, in the form of a mudsplash, generally affects participant number of errors and accelerator positioning. However, groups differed significantly only with respect to accelerator positioning. Experimental evidence suggests general improvement along the course of the task for older and younger normal participants, but not for those with AD. This test's ability to differentiate the performance of individuals with cognitive decline due to aging and further decline due to AD provides preliminary evidence to support the promise of abstract virtual environments as a clinical assessment tool.

The study found little evidence to show that mudsplash had an effect on any of the three groups in particular. The mudsplash only showed an effect only in the analysis of drivers' absolute displacement of the accelerator pedal. However, both the older and younger subjects showed significant difference in displacement and mudsplash and non-mudsplash trials. While the AD participants failed to show a significant difference in performance, this may be an artifact of the small number of AD participants reducing the power of statistical test for that group.

Simulator Sickness

No subjects exhibited any simulator adaptation syndrome (SAS) symptoms or dropped out of Phase 1 testing due to discomfort. To provide additional insights on whether SAS symptoms are present in system users we plan to administer the Simulator Adaptation System Questionnaire (Rizzo, Sheffield et al. 2003) in Phase II of our research.

Conclusion

Together, these three studies illustrate that abstract virtual environments demonstrate promise as effective tools for behaviour and cognitive research. Future plans include additional analysis of potential correlations between instrumented vehicle data and the abstract virtual environments.

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