Cognitive Rehabilitation Potential of a Driving Simulation Game for Brain Injury: A Pilot Study

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Abstract
The aim of this exploratory work was to examine how a driving simulation game might provide Speech Language Pathologists (SLPs) with an additional evidence-based commercial game option when working with their patients who have had a brain injury (BI). Research has indicated that cognitive skills required for safe driving are aligned with top SLP goals. Seven participants who had a BI played Xbox One 'Forza Motorsport 6' driving simulation game for three 2-week periods with six weeks off between driving periods (18 weeks total). Participants enjoyed the driving sessions and did not find the game difficult. We found a marked (but not statistically significant) improvement in two of the top SLP goals, (1) attention/concentration and (2) processing speed, during the periods that the participants were driving. However, participants did not demonstrate overall improvement in any of the top SLP goals we examined over the 18-week study. In future work, we plan to perform a similar study with a larger sample size and improved experimental design to strengthen the reliability and validity of our findings.

Author Keywords
Games; brain injury; rehabilitation; cognitive goals, speech-language pathologist.

Table 1 Top game goals by therapist type

Physical Therapists
1. Dynamic balance 2. Standing 3. Weight shifting 4. Endurance 5. Static balance
Occupational Therapists
1. Standing 2. Hand-eye coordination. 3. Dynamic balance 4. Attention/Concentration 5. Endurance
Speech-Language Pathologists
1. Attention/Concentration 2. Memory (general) 3. Visual-spatial memory 4. Processing speed 5. Problem solving

ACM Classification Keywords
K.4.2. Computers and Society: Social Issues (Handicapped persons/special needs); K.8.0. Personal Computing: Games.

Introduction

Brain injuries (BI) are recognized as a major public health concern by the Centers for Disease Control [4]. There are multiple and varied repercussions of experiencing a BI, including lifelong physical and/or cognitive disabilities, shorter lifespan, and lower quality of life [5]. It is estimated that 6.4 million children and adults in the US live with a lifelong disability as a result of a traumatic BI (e.g. falls, car accidents – 5.3 million) or a stroke (1.1 million) [4].

Many clinicians include games, both commercial (e.g., Nintendo® Wii™, Microsoft Xbox® with Kinect®) and specialized platforms (e.g. Jintronix [8]), to help motivate people who have had a BI perform exercises similar to those prescribed for rehabilitation [10]. Because of their affordability and availability, commercial games are a popular choice [10] even though they are often considered too difficult for this audience [6,12].

In previous work, we partnered with 34 therapists who work with people who have had a BI at three rehabilitation hospitals in the Chicago area (Schwab, Marianjoy and the Lovell Federal Health Care Center) [11]. We explored how therapists used commercially available video games with the objective of maximizing commercial game use in therapy; top therapy goals varied among therapist types, see Table 1. Not surprisingly, Physical and Occupational therapists were focused largely on physical goals, while the Speech-Language Pathologists (SLP) were primarily concerned with cognitive-related goals. (SLPs provide multiple other types of therapies as well, e.g., help with swallowing post-stroke; these goals were the most common identified by our SLP participants). And while there were multiple commercial games that therapists rated as effective for physical goals, there were very few that addressed cognitive-related goals. Top SLP goals we specially considered in this study were: (1) attention/ concentration, (2) short-term visual memory and (3) processing speed.

Research has indicated that cognitive skills required for safe driving are aligned with top SLP goals including abilities to: (a) select and attend to relevant information (attention/ concentration), (b) focus while performing a visual task (visual working memory), and (c) quickly process dynamic information (processing speed) [2]. As a result, we hypothesized that the game mechanics required of driving simulation games could potentially provide SLPs with additional commercial game options for therapies.

Researchers have investigated cognitive abilities required for safe driving; most often to assess an individual's driving fitness, e.g., people with dementia [3]. Targeting the population of people with a BI, researchers have also investigated driving simulations to evaluate an individuals' driving ability post-stroke [1], and for assessment of veterans who had blast-induced traumatic brain injuries [9].

In this study, we worked with adults attending the New Focus program at the Anixter Center in Chicago to assess the cognitive rehabilitation potential of the Xbox One 'Forza Motorsport 6' driving simulation game for

Table 2 Participants

Pseudonym	Age	Gender	Cog Score**
Keri	28	F	86.6%
Harriet	23	F	83.2%
Sidney	25	M	75.6%
Francis	29	M	72.3%
Quintin	38	M	71.4%
Michone	37	F	64.7%
Andy	30	M	55.4%

**Cognitive assessment scores were collected by New Focus therapists in May 2016 (about halfway through the study)

people who have had a BI. The New Focus program aimed to help their clients relearn abilities that included cognitive retraining. To our knowledge, our study is the first to evaluate the cognitive rehabilitation potential of a driving simulation game for people with a BI.

Methods

In the next sections, we present our participants, data collection and analysis methods and our hypotheses.

Participants and the New Focus Program

Inclusion criteria was determined by the New Focus director; participants considered for inclusion were identified as: (1) capable of understanding informed consent; (2) having the ability to play the game and complete our assessments; (3) expressing interest in the study; and (4) not having permission to drive a 'real' car during the study. Therapists evaluated clients as they were admitted to the program and on a bi-yearly basis; evaluation included cognitive abilities, e.g., orientation to time, attention span, and memory recall. See Table 2 for the demographics of our seven participants including their cognitive scores.

Clients typically attended New Focus from 9:00 AM to 2:15 PM weekdays; their day was broken up into 45-minute sessions with 15-minute breaks. Sessions included dance/movement therapies, cognitive training, computer lessons and physical exercise. Sessions were customized based on individual needs.

Data Collection Procedures

Data collection occurred between February and September in 2016. We were on site Mondays and Wednesdays during the afternoon sessions. To create an engaging driving experience, we set up two game carts with 50” televisions, racing seats that were designed for the Forza Xbox One game, and racing wheels for Xbox One (by HORI) with a gas pedal; the Forza game is known for its realistic physics [7]. Because the participants had a range of physical disabilities, we attached an extended shelf for the foot pedal so we could clamp the gas pedal to either side of the chair (see middle image in Figure 1). Clients drove in 'Free-play' mode with rental cars, which afforded multiple different racetracks of varying degrees of difficulty. We took some additional steps to simplify gameplay: (a) we limited the number of competitors to five; (b) we set the competition to the easiest setting; and (c) we chose to have all assists selected, for example, braking around curves so clients did not have to use the brake pedal (i.e. only gas) while driving.

We used three interactive programs (in the same sequence) in the Brain Baseline app on iPad minis to assess our three dependent variables (attention/ concentration, visual working memory, and processing speed). We chose the Brain Baseline app to assess clients' cognitive functioning because it was used by SLPs in our previous work for therapy sessions.

- To assess processing speed, we used the 'Speed' program. The interactive program displayed a red dot on screen for about 5-seconds at random intervals. Users could press either the left or right button with the goal of pressing the buttons as soon as they saw the red dot. See Figure 2 for a screenshot from the Brain Baseline website.
- To assess short-term visual memory, we used the 'Visual Short Term Memory' (VSTM) program. The program first flashed four square color blocks for about 2-seconds on screen and then displayed one

Figure 1 Driving Set-up

color block indefinitely. The program required users to determine if the later block matched any one of the four previously displayed blocks, Figure 3.

- To assess concentration/attention, we used the 'Flanker' program. Flanker flashed five arrows for about 2-seconds on screen and required users to identify the direction of the middle arrow, Figure 4.

Participants drove for three sessions that consisted of 2-week periods with six weeks off between driving periods. We assessed the dependent variables 12 times: (a) one week before each driving period (3 baseline assessments), (b) on Wednesdays after a shortened driving session (6 driving assessments), and (c) in the third week after a driving session (3 post-study assessments), see Table 3. Beginning with the second driving session, we also noted two observations from our perspectives: (1) level of engagement (from 1-5), and (2) level of help needed for gameplay (1-5).

Table 3 Assessment Schedule

Session	1	2	3
Baseline assessments weeks:	0	8	16
Driving (assement on Wed) weeks:	1	9	17
Driving (assement on Wed) weeks:	2	10	18
Off weeks:	3	11	19
Off weeks:	4	12	20
Midterm assessment weeks:	5	13	21
Off weeks:	6	14	22
Off weeks:	7	15	23

Hypotheses
We focused on three hypotheses. First, we hypothesized an overall improvement in Brain Baseline scores from the original baseline (week 0) to the last post-study in the three goals (week 21); improvement was expected in part, because of increased familiarity of the cognitive assessment tasks regardless of driving. Second, we expected higher Brain Baseline scores during the driving treatment periods compared to before or after the treatment periods. And third, we hypothesized that the use of driving simulations would benefit people who were less cognitively impacted by their BI more than those who were highly impacted.

Data Analysis Procedure
While we scheduled 12 assessments, two participants missed one Wednesday driving/data collection. To compensate, we averaged the driving session assessments resulting in a total of nine assessments for each client for our calculations: (1) 3-driving scores; (2) 3-baseline scores; and (3) 3-post-study assessments taken three weeks after a driving session.

To test the first hypothesis (overall improvement), we conducted a Wilcoxon signed-ranked test for a non-parametric two group comparison with related samples between the original baseline and the last post-study assessment for each assessment type (speed, VTSM and attention). To test the second hypothesis (peak performance during driving sessions), we created three scores for each assessment type: (1) average driving assessments combined; (2) average baseline assessments combined; and (3) average post-study assessments combined. We conducted individual Wilcoxon Signed Ranked tests to compare (a) driving to baseline assessments and (b) driving to post-study assessments. To test the third hypothesis (driving will benefit people who were less cognitively impacted), we conducted a non-parametric correlation using Spearman's rho that assessed the correlations among clients' cognitive scores (as assessed by Anixter) to their overall average assessments.

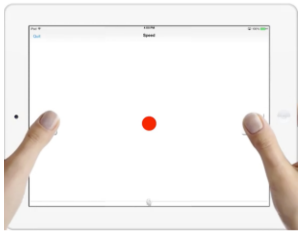

Figure 2 Speed Screenshot

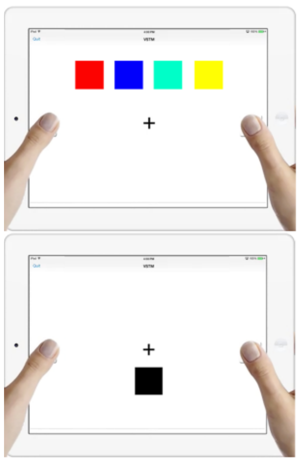

Figure 3 VSTM Screenshot

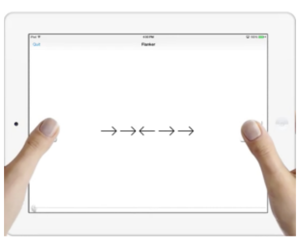

Figure 4 Flanker Screenshot

Findings

For our subjective observation scores, we rated the level of engagement as high for most of the sessions; we assessed overall engagement at 4.3 of 5. Clients needed very little help by the second driving session; we rated the level of help needed at 1 of 5.

Hypothesis 1: Overall Improvement

A Wilcoxon signed-ranked test showed that the difference between the baseline scores and the final post-study scores did not elicit a statistically significant change for any of the assessments: (a) Speed processing (Z = -1.483, p = 0.138), (b) VSTM (Z = -.405, p = 0.686) and (c) Flanker/attention (Z = -.447, p = 0.655). The median scores surprisingly decreased for VSTM and for Flanker/attention. Conversely, the Speed scores did increase; the median Speed rating was 5 at the baseline and 18 in the final post study assessment. See Figure 5.

Hypothesis two: peak assessments at driving times

A Wilcoxon signed-ranked test showed that the difference between the average assessments taken while driving were consistently higher or about the same (but not significantly different) from the average baseline assessments taken the week before the driving sessions: (a) Speed processing (Z = -.314, p = 0.753); (b) VSTM (Z = -.676, p = 0.499; and (c) Flanker/attention (Z = -.314, p = 0.752). See Figure 6.

A Wilcoxon signed-ranked test also showed that the difference between the average assessments taken while driving were also consistently higher or about the same from post-study assessments taken three weeks after driving sessions: (a) Speed (Z = -.085, p = 0.933); (2) VSTM (Z = -.169, p = 0.866); and (c) Flanker/attention (Z = -.524, p = 0.600). See Figure 6.

Hypothesis three: relationship of the cognitive scores

Recall, we hypothesized that the clients' cognitive scores (as assessed by the Anixter Center) would be associated with higher average assessments over the entire study; however, there was no consistent association when analyzing scores using a non-parametric correlation with Spearman's rho:

- Cognitive scores and combined Speed processing scores: ($r_s(7)$ = -.286, p = .535);
- Cognitive scores and combined VSTM scores: ($r_s(7)$ = -.393, p = .383);
- Cognitive scores and combined Flanker/attention scores: ($r_s(7)$ = -.071, p = .879).

Discussion

While we found that the participants enjoyed the driving sessions and did not find the game overly difficult (subjective measures), the results from our objective measures were somewhat mixed.

First, from the first baseline assessments to the final post-study assessments, we only saw improvement in the speed processing scores, and those were not significant. We expected that just learning effects of the assessment programs alone would result in overall improvement for all the clients. However, as Figure 5 indicates, the total baseline scores (taken one week before the three driving sessions) demonstrated higher scores than the post-study scores (taken three weeks after the three driving sessions). We speculated that this incongruous and surprising finding was in part due to the clients becoming bored with the Brain Baseline

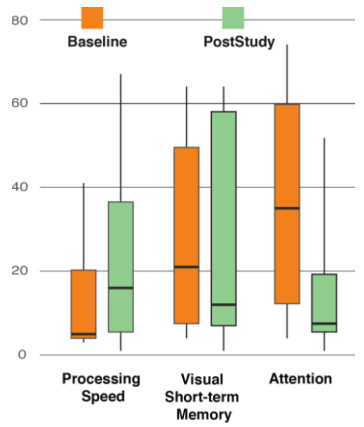

Figure 5 Overall Changes from Baseline 1 to Final Post Study

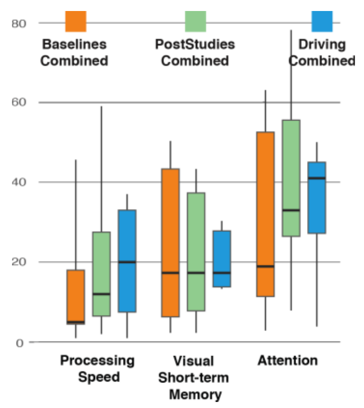

Figure 6 Baseline Scores (taken week before driving) - Post Study Scores (three weeks after driving) and Scores Assessed During Driving

Assessments; i.e., by the time we had them take the final post-study assessments they had completed the assessments at least 11 times already. We noted that as the study continued, there was little excitement about doing the assessments; additionally, because the participants were no longer driving in the study in the final post-study assessments, there may have been little motivation to perform well.

Our second hypothesis, that the assessment scores would peak during driving sessions when compared to baselines and post-study, was somewhat supported for speed processing and attention. The highest assessment scores were during driving sessions, followed by post-study for both measures. However, the scores were essentially flat for visual short-term memory, see Figure 6. Additionally, with only seven participants, even with repeated measures, we did not have enough power to see statistical differences assuming that our findings would generalize. This finding indicated that driving simulations might help improve speed processing and attention for people who have had a brain injury, but that a larger study is needed to investigate the full potential.

Finally, our last hypothesis that the clients' cognitive scores (as assessed by Anixter) would correlate with their assessment scores was also not supported. This finding indicated that any potential benefits of the driving simulation on speed processing and attention do not appear to be related to overall cognitive functioning and that a wide range of BI patients might potentially benefit from driving simulation games.

Limitations and Future work

Overall, our findings were promising but somewhat disappointing; however, we feel that our promising null findings worth discussion. Our small sample size limited the strength of our findings; i.e., our initial power analysis found that for a medium effect size of .28, and collecting assessments at 12 intervals that we would need a sample size of 15 to use repeated measures ANOVA for each assessment ($p<.05$ assumed). Unfortunately, we could not recruit enough people from the clientele at the Anixter Center. Other workarounds further reduced our power, e.g. scheduling difficulties (participants missing attendance) forced us to combine the assessments we collected during the driving sessions. Moving forward, we suggest several modifications to reproduce this study:

- Use alternative instruments for assessing the dependent measurements. The Brain Baseline app had limitations that included: (1) some participants had difficulty holding the iPad and using their thumbs due to partial hand paralysis – we worked around this by using alternative methods, e.g. placing the iPad on a table and holding the iPads for the clients; and (2) participants became bored with the Brain Baseline apps over the 12 assessments.
- Use a control group that is not driving. While we did not see any significant learning effects as reflected by the original baseline and final post-study scores, a closely matched control group who took the assessments without driving would have been a good addition to the study. However, a matched control group is always a challenge in such a diverse audience.

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