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USING A DRIVING SIMULATOR TO IMPROVE DRIVING AWARENESS IN STROKE SURVIVORS: A PILOT STUDY

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ABSTRACT

Many stroke survivors wish to resume driving post-stroke to regain their independence. However, stroke often affects driving awareness, including awareness of one's own driving abilities. The aim of this study was to determine whether there is any evidence that a driving simulator can improve driving awareness in stroke survivors, as no known causal studies have determined this. A case study methodology was used for this research, and we performed a set of experiments in which participants were provided with three hours of exposure to a driving simulator. We then used objective measures to compare their driving awareness prior to and following the exposure in order to determine whether any improvements had occurred. The results of this pilot study suggest that there may be a causal link between driving simulator exposure and increase in driving awareness in stroke survivors.

Keywords: DriveAware, DriveSafe, Driving Ability, Rehabilitation, Stroke.

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1. INTRODUCTION

Stroke is considered to be the most debilitating health issue. The World Health Organisation (WHO) defines a stroke as "the clinical syndrome of rapid onset of focal (or global, as in subarachnoid haemorrhage) cerebral deficit, lasting more than 24 hours or leading to death,

with no apparent cause other than a vascular one [1].” Strokes are the second leading cause of death and severe disability in the world, accounting for 9% of deaths, second only to ischaemic heart disease [2]. Stroke also has a significant impact on the lives of those that manage to survive. For instance, the impairments sustained by survivors following a stroke often mean that they are no longer able to drive. Stroke even affects their driving awareness, including awareness of one’s own driving abilities [3][4]. Knowing that one’s ability to drive is often a sizeable component in their independence and overall quality of life [5], this can greatly affect a survivor’s happiness, mood, social life and individuality [6]. Returning to driving post-stroke positively affects a stroke survivor’s life quality in a substantial way [6].
Often, stroke survivors who wish to resume driving post-stroke necessitate a safe environment in which to practice or re-learn their driving skill. Driving simulators can recreate the on-road driving conditions in a completely safe environment. By giving stroke survivors the opportunity to practice or re-learn driving in a driving simulator, they may improve and rehabilitate their driving awareness, all with minimum risk. The aim of this study was to investigate whether there is any evidence that a driving simulator can improve driving awareness in stroke survivors.

2. RELATED WORK

In health, simulators have been used to assist with the rehabilitation of health issues including diminished motor capabilities [7], upper [8] and lower [9] limb weakness and rehabilitation of driving ability [10], all of which are likely to be useful to stroke survivors. Similarly, the use of simulators in the rehabilitation of stroke survivors, with particular reference to driving awareness has been investigated. For example, using driving simulators, Scott [11] found that a stroke survivor’s level of awareness of their deficits relating to cognitive ability and motor and sensory benefits positively affected their driving ability. McKay et al. [4] found stroke survivor participants had overestimated their driving ability. This demonstrated that they had impaired self-driving awareness. Patomella et al. [3] found that most stroke survivors who fail on-road driving assessments demonstrate limited driving awareness. These studies suggest that a stroke survivor’s view of their own driving abilities may not reflect their actual on-road abilities and if this is so, they have impaired driving awareness.

Devos et al. [12] found that stroke survivors who trained in a driving simulator achieved higher results in on-road assessments than those who were simply given cognitive training. This is supported by the conclusion of Hitosugi et al. [13] who found that stroke survivors who are given the opportunity to use a driving simulator are more likely to resume driving. What is not clear from these studies is whether there is a causal link between simulator exposure and driving awareness.

3. METHODOLOGY

This pilot study used a case study methodology because a case study aims to look at the fine detail of specific cases [14][15][22], which is ideal for stroke rehabilitation research since each stroke survivor's case (including the specifics of their stroke and their resulting disability) is highly individualised. The main advantage of a case study approach is that it allows for an in-depth understanding of each case [16]. This study would then be used to refine the data collection methodology before a full case study is performed [17]. The aim of this study was to investigate whether there is any evidence that a driving simulator can improve driving awareness in stroke survivors.

The driving simulator (Figure 1) consists of custom-developed software and, off-the-shelf games and Virtual Reality (VR) hardware and software. The design and development of the system are ongoing and being used as part of the Project Neuromender [23]. In this study, the driving simulator was run on a Dell Precision T5500 personal computer connected to a Logitech G25 electronic steering wheel. The display used was a 42-inch TCL Plasma Multimedia Display running at a resolution of 1024 ×768 with an aspect ratio of 16:9. The Dell Precision T5500 ran Windows 7 Professional 64-bit with Service Pack 1. It had a 1.83GHz Intel Xeon processor with 2GB of RAM and a nVidia Quadro FX 3800 graphics card. While the simulator supports the Oculus Rift DK2 VR headset, we opted to use the TV screen instead. According to the advice of the clinical neuroscientist who supervised the entire procedure, when the VR headset is used with the simulator on stroke survivors, the feeling of confinement due to the not so wide field of view of 100 degrees and the low refresh rate of 60 Hz would likely have caused motion sickness in them.

The simulator provided a visual 3D road environment and participants interacted with the simulation using a Logitech G25 controller with a steering wheel with paddles mounted on a driving rig. The simulation ran in real time providing at least 30 frames per second.

In carrying out this study, participants were invited to perform a series of exposures on a driving simulator (Figure 1). As the aim of the study was to establish a causal link between simulator exposure and driving awareness, there was no need to have a high-fidelity simulation of any particular vehicle or environment and to control for variance of driving ability in the test subjects.

We used a standard assessment suite used in clinical practice for assessing driving awareness to evaluate the change in driving awareness. The participants were also interviewed at the end of the study to determine if there were any perceived benefits.

Fig.1. The driving simulator

3.1 Participants

Five stroke survivors participated in this experiment. These were obtained through convenience sampling, being previous patients of the supervising clinical neuroscientist. Two participants withdrew for personal reasons. Thus, only three participants completed the study. The participants were controlled for age (being within a relatively close age range), gender, years since their stroke and time driving post-stroke (having all been driving for a reasonable amount of time post-stroke). Given their enrollment in the study through convenience sampling, controlling the level of disability that had been caused by their strokes was not possible.

Participant 1 was a 72-year-old male who had an ischaemic stroke on the right side of his brain five years prior to this study. Currently, he still has limited movement in his left arm and hand, and therefore walks with a cane, while he also has some issues with balance. He cannot perform small movements and has issues with control. He has driven for two and a half years post-stroke.

Participant 2 was a 66-year-old male who had two ischaemic strokes, one in the right side and the other in the front of his brain seven years prior to this study. He still has a minor cognitive disability affecting memory and weakness on the left side of his body including his hips. He also suffers from some depression, which he manages with medication and tires easily. He has been driven for 7 years post-stroke.

Participant 3 was a 71-year-old male who had a haemorrhagic stroke in seven years prior to this study. He still has issues with memory, particularly short-term memory, and balance in situations where he has limited space. He returned to the road, one-year post-stroke and only occasionally having issues with directions because of cognitive disability.

3.2 Exposure to simulator

The participants were given three hours of exposure to the simulator as two, 30-minute sessions each week for a total of six sessions over three weeks. Sagi et al. [18] indicated that two hours is the amount of time it takes in healthy individuals for neuroplasticity to occur. The sessions were limited to 30 minutes on the advice of the clinical neuroscientist who supplied the participants, due to the participants likely becoming too tired to receive any benefit after that time span. Two sessions were held every week for three weeks, as two sessions best fitted in with the participants' schedules and still allowed their required participation to be completed in a timely manner.

For experimental purposes, the sessions of exposure needed to be controlled. The instructions stroke survivors were asked to perform on the driving simulator attempted to replicate a driving assessment so that each participant performed the same set of activities during each session. A driving assessment is used by licensing authorities to determine whether a driver should be allowed on the road. Using a set of instructions based on an actual driving assessment was done purely for control purposes and was not used with the intention of assessing the driving ability of the participants during the exposure, as this was not the aim of this study. A driving assessment involves separate parts where a participant is asked to drive, and then perform a manoeuvre repeatedly [19]. The fact that participants were not being assessed also meant it was not necessary for the driving simulator to be a high-fidelity simulation of the real world.

During each of the six exposures, participants were first asked to accustom or re-accustom themselves with the driving simulator controls. This ensured that they understood and remembered the controls before initiating each exposure.

In the first stage, the participants were asked to drive around a winding track (Figure 2) that featured 44 turns (31 × 90-degree turns and 13 × 180-degree turns). By using this track, participants would be forced to use the steering wheel, accelerator and brakes frequently, in fast succession and therefore become accustomed to the handling of the simulator's controls and to the simulated environment.

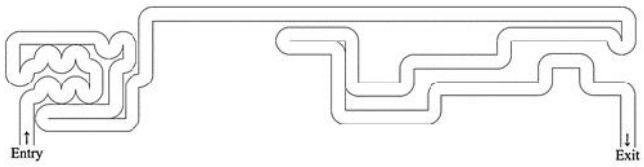

Fig.2. A schematic of the winding track

In the second stage, the participants were instructed to follow directions to perform three manoeuvres, similar to a driving assessment [19]. The first manoeuvre was a reverse driveway park; the second manoeuvre performed was a parallel parking, and the final manoeuvre was to perform a three-point turn at a specified location. After completion of the manoeuvres, the participants were asked to free drive, until the 30-minute exposure time had been completed.

4. DATA COLLECTION AND DATA ANALYSIS

An objective assessment of the survivors was carried out before and after exposure to the simulator. The goal was to assess whether there was any actual benefit from the exposures for the stroke survivors to develop a case study for each survivor. A subjective interview was carried out at the end of the study to determine perceived benefits.

4.1 Assessment Data Collection

For the assessment, we used a computerised standard suite with three components normally used in clinical practice called DriveSafe/DriveAware (DSDA) [20]. DriveSafe assesses a driver's awareness of their environment while driving. The DriveSafe tool outputs a score that has a range of 0 to 84. DriveAware, on the other hand, assesses a driver's awareness of their own driving abilities on a range of 0 to 17 [20]. The third component, an intersection rules assessment, with output scores ranging from 0 to 8, shows participants eight

intersections and asks them to determine the order in which the cars in each of the intersections would be allowed to proceed [20]. The primary goal of using the three assessments is to determine whether an on-road driving assessment is required for a driver or whether they would definitely pass or fail [20]. Pre- and post-tests using these assessments were used to determine whether a participant's driving awareness had increased after the three hours' worth of exposure. The three component assessments were performed by a clinical psychologist who had the clinical expertise and experience required to conduct such assessments. Since DSDA has been validated [20] to predict actual on-road driving awareness, any driving awareness level increase measured by these as a result of driving simulator exposure can be believed to translate to the real world.

As established, stroke survivors are likely to have impaired awareness of their own driving abilities [3][4][11]. However, since all the three participants had been cleared for driving and have all driven for a reasonable amount of time post-stroke, their self-reported driving awareness is more likely to be accurate. The interview questions asked and possible answers on a Likert scale [21] are outlined below.

Question 1.1: How would you rate your driving awareness after using the driving simulator for three hours in comparison to before your participation? The participants were asked to choose an answer from the following: Much Better / Somewhat Better / Stayed the Same / Somewhat Worse / Much Worse.

Question 1.2: Why did you give this rating?

Question 2.1: How beneficial do you feel the driving simulator and method used could be to other stroke survivors in improving their driving awareness? The participants were asked to choose an answer from the following: To a Great Extent / Somewhat / Very Little / Not at All.

Question 2.2: Why did you give this rating?

Driving awareness was explained to the participants as being the level of awareness they have while on the road and of what is happening on it, along with their awareness of their own driving abilities.

4.2. Data Analysis

Each participant's results were analysed separately as individual cases; they were then compared and contrasted to create the necessary conclusions needed to address the aims of

this pilot study [14][15][22]. For each participant's assessment results, data analysis was performed by comparing the post-test result scores with the pre-test ones (with the score improvements being analysed in both absolute and percentage amounts) in order to see whether any improvement had occurred in driving awareness and its sub-areas for that particular participant. The interview questions at the end of the objective part of the study were used to evaluate each survivor's perceived benefits of simulator exposure and formed part of each individual's case.

5. RESULTS

This section summarises the DriveSafe/DriveAware assessment results. Section 6 incorporates the results of the interviews into the discussion. Table 1 shows the participants' pre- and post-test results, for driving awareness (from DriveSafe/DriveAware). Each column shows the different raw scores provided by each of the different assessments, plus the absolute and percentage changes between the pre- and post-tests.

Table 1. Participant Assessment Results

		DriveSafe / DriveAware Scores		
		DriveSafe Score (range 0 – 84)	DriveAware Score (range 0 – 7)	Intersection Rules Score (range 0 – 8)
Participant 1	Pre-Test	82	16	8
	Post-Test	84	17	8
	Absolute Change	2	1	0
	Percentage Change	2%	6%	0%
Participant 2	Pre-Test	78	14	7
	Post-Test	81	16	8
	Absolute Change	3	2	1
	Percentage Change	3.6%	11.8%	12.5%
Participant 3	Pre-Test	67	10	7
	Post-Test	77	15	8
	Absolute Change	10	5	1
	Percentage Change	11.9%	29.4%	12.5%

6. DISCUSSION

This section first discusses the analysis of each participant's results as cases. For each participant, their assessment results from DriveSafe/DriveAware were analysed to determine the actual benefit they received from the simulator. Outcomes from their interview at the end of the study period are also indicated. After the results from each of the three participants had been collected and analysed, they were compared, contrasted and summarised below to create the necessary conclusions needed to address the aims of this study.

Participant 1 demonstrated mild improvements in driving awareness, with his DriveSafe and DriveAware scores increasing by 2% and 6% respectively. The intersection rules score, on the other hand, did not improve (being the maximum possible score before and after the exposures).

Participant 1 also noted that he found that after being in hospital rehabilitation for five months, he found it scary even being a passenger on the road. The use of a driving simulator at this early stage, he said, would help build a stroke survivor's confidence and awareness on the road post-stroke.

Participant 2 demonstrated moderate improvements in driving awareness, with his DriveSafe, DriveAware and Intersection rules scores increasing by 3.6%, 11.8% and 12.5% respectively (with his Intersection rules score increasing to the maximum 8).

Participant 2 noted that the simulator exposure would have been more helpful for him in the first-year post-stroke. Like participant 1 and also speaking from his own experiences, he felt that the simulator and method used could be beneficial for other stroke survivors in improving their driving awareness 'to a great extent'.

Participant 3 demonstrated the largest improvement in driving awareness, with his DriveSafe, DriveAware and Intersection rules scores increasing by 11.9%, 29.4% and 12.5% respectively (with his Intersection rules score increasing to the maximum 8).

Participant 3 indicated that he was inadvertently exposed to additional driving awareness training. It was not possible to isolate the effects of the uncontrolled training from the effects of the control exposure on the simulator on his driving awareness. Participant 3 thought that his driving awareness was "somewhat improved" after the controlled exposure.

Both participants 1 and 2 demonstrated mild to moderate improvements in driving awareness after 3 hours of exposure to the simulator, always improving if there was room in the testing

to do so, meaning that there is evidence that driving simulator exposure may improve driving awareness in stroke survivors.

Participants 1 and 2 agreed that the driving simulator exposures given as part of the study could help stroke survivors in the early stages of rehabilitation, whereas Participant 3 felt the simulator would be 'somewhat' beneficial.

These results suggest that there is evidence that a causal link may exist between simulator exposure and improving driving awareness in stroke survivors. Given the results, this area warrants further investigation through a full experimental study.

7. CONCLUSION

There was objective evidence in the case study to indicate that driving simulator exposure may increase driving awareness in stroke survivors in this pilot study. The results also suggest that stroke survivors who have driven post-stroke for a reasonable amount of time may only perceive limited benefit from the limited driving simulator exposure used here. Even if an exposure benefits a stroke survivor if they do not perceive any benefit they are less likely to continue with the exposure. The participants felt that stroke survivors who are in the earlier stages of rehabilitation and have not already returned to the road may perceive greater benefit from the exposure method used.

7.1 Constraints

In ideal conditions, more than three hours would have been allocated to each set of exposures. It is not known whether participants would have made more significant gains and perceived more benefit if the exposure period was longer. Secondly, the study originally intended to include stroke survivors who had not already returned to the road. However, it was not possible for all of the intended participants to participate in this study, due to them having other commitments, holidays, financial issues related to travel and health problems. The financial issues related to travel do, however, highlight one important issue that impedes stroke rehabilitation - if a stroke survivor cannot afford to travel to where the rehabilitation will be performed, they will not be able to receive any benefit from it.

The use of a case study approach also means that generalisation of the results to other stroke survivors is difficult [15]. Since this is a pilot study and only three participants were used, more participants of more varied types would make the generalisation better.

7.2 Future Research

The study establishes that are further areas of research are worth pursuing. Firstly, there was evidence that the driving simulator exposure method that was used here would be mild to moderately beneficial for stroke survivors who have been driving for a reasonable amount of time post-stroke. However, they may not perceive much benefit due to the basic exposures, which means that they may not be motivated to continue with further exposures, despite any actual benefit. A full experimental study is warranted to determine both objective and perceived benefit with stroke survivors who have been driving for a reasonable amount of time post-stroke with more complex simulator scenarios and exposure methodology.

Secondly, interviews at the end of the study indicate that the basic exposures used in this study may be more beneficial for stroke survivors early in rehabilitation after stroke. A full experimental study is warranted using stroke survivors who were driving pre-stroke but had not had post-stroke driving experience.

The third area of study is to examine if exposure to simulators can improve driving awareness in survivors with different cognitive and physical deficits resulting from their stroke.

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