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Immersion factors affecting perception and behaviour in a virtual reality power wheelchair simulator

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Virtual Reality based driving simulators are increasingly used to train and assess users' abilities to operate vehicles in a controlled and safe way. For the development of those simulators it is important to identify and evaluate design factors affecting perception, behaviour, and driving performance. In an exemplary power wheelchair simulator setting we identified the three immersion factors display type (head-mounted display v monitor), ability to freely change the field of view (FOV), and the visualisation of the user's avatar as potentially affecting perception and behaviour. In a study with 72 participants we found all three factors affected the participants' sense of presence in the virtual environment. In particular the display type significantly affected both perceptual and behavioural measures whereas FOV only affected behavioural measures. Our findings could guide future Virtual Reality simulator designers to evoke targeted user behaviours and perceptions.

1. Introduction

Previous research has shown that virtual-reality-based applications are in increasingly wide-spread use for such tasks as driving. Driving simulators are used for, but not limited to, assessment, learning, rehabilitation, and entertainment (Wilson, 1999). One representative and exemplary class of such driving simulators are power (electrical) wheelchair (PWC) simulators (Cooper et al., 2005). They provide a risk-free environment that would allow users to drive efficiently in order to evaluate their ability at PWC driving. Despite their potential, existing PWC simulators have been found to be less usable than demanded and expected (Alshaer et al., 2013). While previous research could show positive transfer effects from the virtual simulator to the real world, the users experienced difficulties in operating the simulator attributed to immersion factors like display characteristics (Harrison et al., 2002; Archambault et al., 2012). In addition, the use of Virtual Reality personal computer (PC) technology, i.e. interactive 3D desktop computer systems, for PWC simulation seems to be underdeveloped and under-researched. Only one software product is commercially available on the market: WheelSim (Abellard et al., 2010), unfortunately unsuitable for training and assessment (Alshaer et al., 2013).

To close this gap in the availability of a suitable research platform for the investigation of design factors for this class of Virtual Reality (VR) simulators we developed a simple, but usable power wheelchair simulator which can be operated with different peripheral devices and can be configured to meet the needs of our research. We conducted initial interviews with professional experts (four occupational therapists) and consulted the appropriate literature, e.g. (Alshaer et al., 2013; Kjeldskov, 2001; Harrison et al., 2000; Pithon et al., 2009) leading to the identification of system requirements. For instance, the ability of the users to drive accurately depends on how they perceive the scale of the space of the virtual environment (VE), which is a prerequisite for the validity as a training and/or assessment tool.

Another example is that the presentation of a self-avatar (a visual representation of the user's own body or body parts) in VEs in general has been shown to not only increase the sense of presence but also to improve size and distance judgments (Schultze, 2010). There is evidence (Ries et al., 2008; Lim and Reeves, 2009; Dodds et al., 2011) that a self-avatar could serve as a familiar size cue that provides scaling information and act as a frame of reference in the VE. Sun et al. (Sun et al., 2015) add that the presence aspect of the user's body can lead to significant effects on performance. In a PWC simulator, the visualisation of the virtual PWC itself would also provide scaling information about the dimensions of the

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virtual space and act as a usable frame of reference for spatial judgments. In this study we add an additional question: Would the self-avatar provide additional cues and serve as a dual reference.

It is well researched that misperceptions of a simulation space can result in erroneous judgments that could alter the user's behaviour (H et al., 2010; Henry and Furness, 1993). Therefore, it is important not only to measure users' perception but also to differentiate behaviour. However, how to best measure the accuracy of space perception in VEs remains a difficult question (Geuss et al., 2010). Research in the past used verbal estimation, perceptually direct actions, and imagined action to estimate perceived distance in a VE (Rébillat et al., 2012). In verbal estimation, perceived distance assessed through familiar units, such as meters. In perceptually direct actions, subjects would preform an action, such as blind walking or imagined action (Rébillat et al., 2012) (Geuss et al., 2010), which only provide rather indirect measures.

In 1979, Gibson (Gibson, 2014) introduced the concept of "affordance" which emphasizes the relationship between objects and their observers. For instance, a gap can afford passage if it is wide enough for the user. Many studies, since then, have demonstrated the practicality and usefulness of using affordance theory to measure user perceptions in VE (Mark, 1987) (Warren and Whang, 1987). According to Geuss et al. (Geuss et al., 2010), "affordance judgments may be especially useful as a perceptual measure of size in graphic displays because they require the user to see the space in terms of their own ability to act and therefore may be considered more task-relevant". In our research presented here we use the affordance of "pass-ability" though wall-openings to measure perceived spatial size and distance.

Our research addressed the following questions: How accurately can PWC users make the right decisions when navigating a virtual environment? How do they perceive a particular gap as passable? How do different immersion factors (display type, field of view, and self-avatar presence) influence their behaviour, perception and sense of presence? Behaviour was measured through embedded actions (implicit performance); perception through self-report of the perceived size/distance in the VE (explicit judgment); and sense of presence through a standard questionnaire. The manipulated factors were self-avatar presence versus no self-avatar presence); a static field of view (FOV) versus a changeable FOV; and monitor display versus head-mounted display (HMD). This yielded a 2 (avatar presence) X 2 (FOV) X 2 (display type) mixed-design experiment. It is important to emphasise that the methodology involved both participants' self-report indication (whether a particular action can or cannot be performed) and behavioural decision-making (participant actually passed through or went around a particular gap).

We hypothesised that: 1) users' implicit performance, explicit judgments, and sense of presence, would be better with the more immersive HMD regardless of field of view change or avatar presence; 2) users' implicit performance, explicit judgments, and sense of presence would be better with the changeable field of view regardless of display type or avatar presence; 3) users' implicit performance, explicit judgments, and sense of presence would be better with the presence of a self-avatar regardless of the display type, and 4) users' implicit performance, explicit judgments, and sense of presence would be better with the changeable field of view, HMD display, and self-avatar.

2. Method

2.1. Participants

A pilot study with five participants was conducted to provide a formative evaluation of the procedures and instruments. This was followed by the actual experiment where 72 subjects participated. There were 46 males and 26 females with a mean age of 21.9 years ($SD = 4.68$, age range = 18–47), including students from the departments of Psychology and Information Science, of the University of Otago. Participants from the Psychology department were recruited via an online system and students were rewarded with class credits whereas participants from Information Science were recruited via personal connections and classroom announcements, and were rewarded with chocolate bars. All participants had normal or corrected-to-normal vision. Institutional ethical approvals were obtained from both departments.

2.2. Apparatus

2.2.1. Virtual environment

All 3D models were built by using Google *SketchUp*. The virtual PWC, including the virtual joystick, was modelled on real PWC dimensions with an average width of 68 cm. The VE used in this experiment was a high-fidelity 3D model of an abstracted (low distraction) hallway. The hallway consisted of walls, doorframes, and sets of two poles designed to represent gaps of varying widths throughout the hallway. To avoid participants' distractions and to remove cues to size and distance provided by familiar objects no furnishings or decorations were added. The hallway was wide enough throughout so that subjects could freely and easily navigate the environment (Fig. 1). The virtual self-avatar was produced by "*MakeHuman*", a 3D character-building application.

The hallway consisted of four doorframes of different widths distributed over the hallway. Similarly, there were four gaps of different widths between two poles, (see Fig. 1) spread along the hallway. The doorframe and gap widths were differentiated based on the minimum clear gap width that the PWC could pass through, which is 76 cm (Access, 2000, 2001). Two doorframes/gaps were passable (easy to pass = 76 cm, hard to pass = 72 cm) and two were not passable (hard to judge = 64 cm, easy to judge = 60 cm). Fig. 2 shows the widths of all four gaps/doorframes and how they were associated with the PWC width.

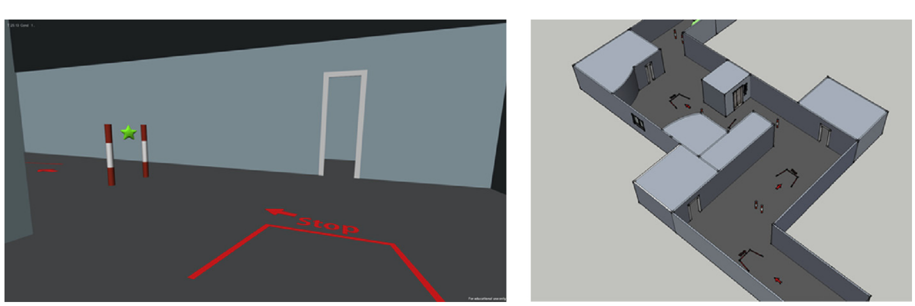

Fig. 1. PWC simulator (hallway).