Wheelchair Skills Training Using Virtual Reality

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It is estimated that 1% of the global population are wheelchair users (WUs). To promote the integration of WUs in society and enhance their independence, it is important that they know how to manoeuvre a wheelchair safely. Several training programmes for wheelchair driving skills have been developed; some programmes entail navigating in everyday settings (i.e., homes, schools, etc.), while others focus on controlled environments where a set of tasks are performed.

Keywords: virtual reality ; wheelchair ; training ; sensors

1. Introduction

In efforts to overcome these barriers to wheelchair training, many researchers have investigated the use of technology to provide wheelchair training that can be low-cost and more accessible [1][2][3]. For instance, research shows that WU training using virtual reality (VR) can increase engagement with tasks [4], can be motivating, and can mitigate the risks faced in real-world training (i.e., risk of falling) [5]. However, these training methods vary widely in nature, including the following three key aspects: the hardware adopted to present the VR environment to the user, the controller for navigation, and the design characteristics of the VR environment itself. This sparks the question of what are the characteristics of an effective VR training system that enables trainees to transfer their learnt skills to real life. To answer this question, each of the mentioned aspects needs to be examined.

Firstly, the presentation hardware can vary in the level of immersion depending on how much the screen can surround the user to provide a non-immersive (using monitor screens), a semi-immersive (using CAVE systems; a system that projects the virtual environments on walls), or a fully immersive (using head-mounted displays (HMDs)) experience. For instance, John et al. [6] carried out a VR training study for powered wheelchair users with participants split into a control group (no training received), an HMD training group, and a monitor screen training group. The study found an overall higher improvement in skills for the HMD training group, which reduced distractions from the trainees' surroundings and increased focus on the training. From a user's experience perspective, Débora et al. [7] found that when participants used HMDs, it elicited higher levels of presence and pleasant and exciting emotions. Increased presence was also found by Alshaer et al. [8], whose results demonstrated that HMDs led to better involvement and ability to navigate through obstacles. These findings suggest that HMDs may offer advantages in wheelchair skills training over other hardware options.

Secondly, the chosen controller for navigation may depend on the mobility needs of the WUs which can range from joysticks to brain–computer interfaces (BCIs) [9]. As such, VR can be controlled using gaming joysticks [10], powered wheelchair joysticks [4][6][11][12], sensors on the wheels [13], or eye-tracking devices [11], just to name a few. Most of the work in the field of VR for wheelchair skills training focused on powered WUs who use a joystick for navigation in real life [1]. However, joysticks vary from one another, and many VR training programmes use joysticks different from the ones WUs use in their day-to-day life. Undergoing VR training using a different joystick may result in the user having to get adjusted to multiple controllers which vary in mechanical aspects and thus affect the retention of skills. To provide a solution to this issue, Zorzi et al. [14] designed a method of navigation using an inertial measurement unit (IMU) sensor that can be retrofitted to various joysticks. This method has the potential to allow users to train independently and in the comfort of their own chair, making it an efficient alternative to other controllers.

Thirdly, the design characteristics of the VR environment also varied among the body of literature. Some environments were realistic, recreating a virtual replica of laboratory rooms [11] or rehabilitation centres [4], while others were less realistic and contained elements of gamification, such as having the user collect balls of a specific colour while avoiding collision with other coloured balls [6]. Zorzi et al. [14] proposed a VR environment replicating the (real-life) Wheelchair Skills Training Program (WSTP) [15][16]; they found that VR training for harder tasks enhanced the acquisition of skills in real life. However, their study reported a limitation in their work, mentioning that participants found the environment to be very realistic and disengaging. Adding elements of gamification could be a solution to increase engagement.

No study has compared the effects of a non-gamified environment to a gamified environment when it comes to rehabilitation, specifically wheelchair driving skills training. When examining the aesthetics and gamification of the virtual experience and its effects on user performance and retention of skills for the real world, the literature in the context of wheelchair training is lacking. However, there exists strong support in the literature in other contexts of training, which highlights the strength and efficacy of gamification in VR training to further enhance users' outcomes. For instance, Palmas et al. [17] compared gamified and non-gamified VR musical instrument assembly training and found that the use of gamification can enhance the efficacy of a VR training programme.

2. Environment Design of Wheelchair Skills Training in VR

Wheelchair skills training using VR has been a topic of research since the 1990s [1]. VR offers a potential solution to the challenges posed by traditional training methods, which require time and resources that may not be accessible to everyone [1]. As such, VR can be a useful supplement to traditional training methods. One of the shortcomings of current VR training approaches is the heterogeneity in their design [1]. Designs vary from realistic replicas of real-life environments such as laboratory rooms [11] or rehabilitation centres [18], while others are less realistic [19].

The body of research highlighted the benefits of using realistic virtual environments and found that they meet the participants' expectations of real-life powered wheelchair driving [18]. Moreover, participants may easily transfer the skills learnt in VR to real life, given that the tasks in the two contexts are similar [20]. In a study conducted by Torkia et al. [18], participants (clinicians and children who are wheelchair users) were asked for feedback about their VR training experience (driving through a replica of a rehabilitation centre); they suggested increasing the interaction with the VR environment and adding sounds to improve the sense of presence and training efficacy [18]. To achieve these two goals, aspects of gamification could be added to the VR training to enhance the motivation and engagement of the participants [21]. In fact, when participants were asked about the most enjoyable part of their training, they described actions and interactions they had with the virtual world [18]. Furthermore, less realistic environments can resemble gamified worlds, which may be necessary if participants have, for example, multiple disabilities and therefore require specific designs [19]. John et al. [6] used a less realistic environment design that contained gamified tasks and showed that driving skills acquired in VR are retained in real life. Yet, using gamified environments is a less common approach to wheelchair skills training, and so its benefits are not yet fully explored.

3. Gamification in Training

The term gamification refers to the use of game aspects in non-gaming contexts [22]. Aparicio et al. [23] defined a framework for gamification, which can help improve the participation and motivation of carrying out certain tasks. The authors suggested ways to motivate people using game mechanics (e.g., points, levels, leaderboards, etc.) that favour autonomy, competence, and relatedness.

When examining if game mechanics are effective in VR rehabilitation systems, Kern et al. [24] developed an application to increase motivation by promoting relatedness, autonomy, and competence during gait rehabilitation. In their system, they used elements of gamification, including an engaging storyline, a gamified reward system, and a social companion. Compared to traditional rehabilitation, their system allowed for increased decision freedom, increased perceived task meaningfulness, lower anxiety, lower frustration, and lower physical demand.

Gamification was also found useful by Putze et al. [25], who developed gamified training for motor imagery brain–computer interfaces (MI-BCIs). The elements of gamification included were a themed environment, score points, progressive increase in speed across several training runs, and levels. The results showed that gamification improves MI-BCI skills for beginner users and stimulates low levels of fatigue.

The use of game mechanics in VR training has also been found effective in the improvement of skills in real life by Ulmer et al. [26] in training for assembly tasks. The authors [26] suggested that even though gamified VR could provide support for the completion of the tasks at the beginning of training, this positive effect can decrease gradually. Furthermore, both positive and negative feedback should be provided throughout the training to balance the participant's feeling of competence without adding pressure. The authors suggested that effective gamified VR training should motivate the participants to build, retain, and recall their knowledge of the performed tasks.

As for how the users feel about gamified VR training, Yan et al. [27] investigated the acceptance of gamification by older adults. They used a total of six games designed for life-skills training, leisure (e.g., hobbies), and motor exercise development. The findings revealed that after exposure to the VR games, participants felt they were useful and easy to use.

However, the studies directly comparing the effects of gamified VR training to non-gamified ones are very limited. Palmas et al. [17] investigated gamification's benefits over non-gamification in the context of training assembly tasks and found that it enhanced the efficacy of the VR training application. Despite the existing body of research exploring the benefits of gamification in various contexts, there remains a gap in understanding the specific advantages of using a gamified approach versus a non-gamified one in the domain of rehabilitation, specifically wheelchair driving skills training. The unique challenges and goals of wheelchair skills training necessitate a tailored investigation into the potential benefits of incorporating gamification in VR training systems.

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