Application of virtual reality technology to the assessment and training of powered wheelchair users

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ABSTRACT

The current study presents quantitative and qualitative data concerning the development and application of two non-immersive virtual environments (VEs) to the assessment and training of adult powered wheelchair users with complex neurological impairments. Aspects of manoeuvrability skills and route-finding were addressed. Results indicated that whilst the participants considered the VEs to be realistic and well represented, and the tasks reflected the skills needed to manoeuvre a powered wheelchair, completing the manoeuvrability tasks was more challenging in the VE than in real-life. Implications of these findings are discussed. Additional data are provided from two patients who commenced a series of training sessions using the manoeuvrability skills VE.

1. INTRODUCTION

Several authors have examined both the positive and negative implications of powered mobility on peoples' lives. Most reported feeling empowered, being more productive, enjoying more leisure and achieving more self-care (Miles-Tapping, 1997). However, Field (1999) notes that the same technology has also lead to concerns about safety, particularly accidents and injuries involving powered wheelchairs. Due to the high cost of powered wheelchairs, an evaluation usually takes place of the physical and cognitive-perceptual abilities necessary for use of such a chair before one is purchased for an individual. Individual factors include level of intellectual functioning, physical limitations, visual problems and seizure risk (Breed and Ibler, 1982). Despite the increased opportunities that come with powered chairs, Swan et al (1994) suggest that often "the evaluation of user proficiency and the suitability of a given wheelchair is largely guesswork". A detailed assessment of an individual's seating needs is required before provision of an optimal seating system. Subsequently, training is required in order to improve the users independent mobility. Evaluation tools have been developed for clinical use (Field, 1999). However, training in a powered wheelchair can be expensive in terms of staff input and can be potentially unsafe (Hasdai et al, 1998). Training is often carried out using a wheelchair loaned to the patient which may not fully meet their needs (Swan et al, 1994). Children learning to use powered chairs are often frustrated initially as they have not yet developed adequate control over the chair, leading to collisions (Desbonnet et al., 1998).

Hasdai et al (1998) suggest that a joystick controlled computer simulation may be a useful solution for training physically disabled children with skills analogous to those needed to use powered wheelchairs. A simulated training environment may prove motivating and would reduce the danger of collisions during the training phase as the patient would not actually be moving. Several studies have addressed the efficacy of computer simulations as a means of training powered wheelchair users. Hasdai et al. (1998) compared physically disabled children with and without prior experience of driving a powered chair. Both groups were assessed using a functional test devised for the research and a computer simulation consisting of navigation through two-dimensional mazes similar in layout to a school environment. The inexperienced group then received training for 30-45 minutes twice a week for up to 12 weeks before being assessed again. Training consisted of exposure to increasingly difficult mazes with verbal instructions and feedback. On functional evaluation, the inexperienced group showed significant improvement in performance after training but did not reach the standard of the experienced drivers. Prior to training, the simulator scores (based on number of collisions and time taken to complete the maze) of the inexperienced group were significantly lower than those of the experienced group. However, following simulator training, the group's standard rose to that of the experienced drivers. The authors concede that the two-dimensional simulator was unsophisticated in comparison to technologies allowing virtual reality based simulators. However, they conclude that the wheelchair simulator developed would be useful “in the absence of an opportunity to engage in, and as preparation for, actual driving experience”.

Inman, Loge and Leavens (1997) used three virtual environments of increasing difficulty to train children in skills for driving wheelchairs. The first two worlds were safe, entertaining situations, designed to encourage skills necessary for independent mobility (e.g. independent exploration, cause and effect relationships). The third world aimed to build on the skills developed in the first scenarios, through exploration of a community environment, with increasingly complex situations to deal with. The authors place an emphasis on the students’ motivation, ensuring that the scenarios are made fun where possible. The children’s driving skills (particularly turning, stopping before hitting a wall and travelling in a straight line) improved with time spent on training in the virtual world. The authors also note that many of the children chose to look at a large monitor in front of them rather than using the head-mounted display. Although this decreased their degree of immersion in the virtual worlds, it did not decrease the children’s interest in using the system.

Desbonnet et al (1998) describe the non-immersive Virtual Reality Training System (VRTS) for disabled children. To maximise the usefulness of the simulator as a training tool, users were able to navigate the virtual environment using the controller fitted to their chair. The authors concluded from these preliminary investigations that the VR wheelchair bore a reasonable resemblance in look and feel to a real chair but that the system was of limited value as a training tool due to the limited visual realism and the relatively crude modelling of the behaviour of the wheelchair. This study highlighted the need to address both these factors when developing virtual environments intended to assist in training powered wheelchair users.

In order to function independently in a powered wheelchair, an individual must attain a high level of manoeuvrability and dexterity but they must also demonstrate an ability to find their way around the locations they will visit in their chair (e.g. locations within an in-patient rehabilitation unit). Research has shown the value of exploration of virtual environments in learning about their real life equivalents with able-bodied samples (e.g. Brooks et al, 1999; Ruddle et al, 1997) and learning disabled samples (e.g. Wilson, Foreman & Tlauka, 1996). Work has also begun to address VR training of route-finding problems in neurologically impaired individuals. For example, Brooks et al (1999) found evidence of the efficacy of non-immersive VR in route learning for a patient, MT, with amnesia within a hospital rehabilitation unit. Following daily VR training sessions over three weeks duration, MT was able to perform a series of trained routes in the real unit. This continued to be true for another six weeks after training had ended, suggesting that knowledge gained in a virtual environment can transfer to real life. This study adopted an errorless learning approach to route finding training. Evidence has shown that learning is facilitated by preventing errors during training and such an approach is of benefit for those undergoing rehabilitation and learning new skills (e.g. Graf and Schacter, 1985; Rizzo et al, 1997; Wilson et al, 1994).

The current study seeks to address the efficacy of virtual reality in training adults with severe neurological impairment to improve their ability to use their powered wheelchairs independently. The study is concerned with two aspects of training. Manoeuvrability and dexterity skills are addressed through using a series of virtual tasks repeated over trials with feedback and performance review. Route-finding training is assessed using a separate virtual environment that represents a section of the hospital in which the patients are resident. Route-learning is facilitated by using an errorless learning paradigm adopting a series of computer-generated visual and auditory cues. Carry-over of skills is addressed in real-life settings following training. Qualitative and quantitative data is provided from an able-bodied sample (rehabilitation therapists), a sample of experienced powered wheelchair users and from initial training sessions with novice chair users or those requiring ‘top-up’ training. The study is a multi-stage project. There are three main stages involving able-bodied users, experienced powered wheelchair users and novice powered wheelchair users. Within each stage there are also different sections of the procedure. The stages and sections of the project are as follows:

Stage One: Able-bodied users exploring training and hospital environments

Stage Two (A): Experienced users performing manoeuvrability tasks in real life

Stage Two (B): Experienced users performing manoeuvrability tasks in VR

Stage Two (C): Experienced users exploring the hospital environment

Stage Three (A): Novice users performing manoeuvrability tasks in real life

Stage Three (B): Novice users being trained on manoeuvrability tasks in VR

Stage Three (C): Novice users performing manoeuvrability tasks in real life

Stage Three (D): Novice users being trained in route finding tasks in VR

Stage Three (E): Novice users being assessed in route finding in real life

2. STAGE ONE - ABLE BODIED USERS

2.1 Stage One Participants.

Ten able-bodied members of staff at the Royal Hospital for Neuro-disability volunteered to take part in this part of the study. Of these, four were qualified Occupational Therapists, four were qualified Physiotherapists, and two were Physiotherapy Assistants. Participants had between nine months and ten years experience of working in neurological rehabilitation (mean = 3 years 10 months) and varying amounts of experience of assessing and working with powered wheelchair users, from "none yet" to ten years.

2.2 Stage One Equipment.

Two non-immersive virtual environments were constructed using Superscape VRT software (Version 5.6) and ran on a Pentium III 550Mhz desktop computer with a 17 inch monitor. During this stage participants controlled their movement in the environments using a standard PC games joystick. Two virtual environments were developed, the first represented a single large room (known as the Assembly Room) in the Hospital. A series of chairs and tables were set up in the virtual environment to provide manoeuvrability tasks. The manoeuvrability tasks were as follows:

a) Driving the wheelchair forward in a straight line for 10 metres.
b) Reversing the wheelchair in a straight line for 2 metres.
c) Driving the wheelchair into an enclosed space.
d) Reversing the wheelchair back out of the enclosed space.
e) Completing a 180° turn around a stationary object.
f) Completing a 'slalom' around a series of stationary objects.
g) Stopping the wheelchair suddenly, to command.

A second virtual environment represented one floor of one wing of the hospital, comprising a large rehabilitation ward with a day area, four large four bed bays, four single bedrooms and a sitting room. Four treatment areas were also represented, comprising an individual therapy room, a computer therapy room, an art therapy room and an occupational therapy kitchen. The environment also included substantial lengths of corridors and a concourse area used by the patients and their families for relaxing and socialising. Signage and wall decorations were represented by incorporating digital photos. The environment included several walking people dressed to look like hospital staff and many stationary people seated in wheelchairs. At this stage of the project the moving people walked in a random manner.

2.3 Stage One Procedure

Sessions lasted approximately 30 minutes. Initially the joystick control of the virtual wheelchair was described and each participant completed a set of tasks in the 'virtual training environment' in order to gain an impression of the movement and responsiveness of the virtual wheelchair system. Participants were encouraged to make comments as they used the environment and were asked to give verbal feedback when the set of tasks had been completed. Participants were then introduced to the second virtual environment, to be used for route-finding training with experimental participants. They completed a set route which involved visiting each location in the environment in turn (e.g. sitting room, therapy room, computer room, art room). Having reached the final location, participants were asked to follow the route in reverse order. All participants were then asked to complete a short feedback questionnaire concerning a number of aspects regarding the virtual environment, including objects, colours, scale and movement.

2.4 Stage One Results

Feedback was collected using anonymous written questionnaires and recording verbal comments. The two virtual environments received a favourable response from the sample of therapists with regards to aspects of colour, perspective and level of detail with a mean rating of between 3.8 and 3.9 for each (1 = not at all well represented, 5 = very well represented). However, the computer-generated people in the main hospital environment, and the movement of the wheelchair were noted as particular limitations of the system receiving a mean rating of 2.6 and 3.1 respectively. These issues became the focus of development prior to the second stage of the study. Qualitatively, two participants suggested that the virtual environments could be beneficial if used as an adjunct to the training normally provided by Occupational Therapists. It was suggested that the system could be used to identify potential problems whilst waiting for a powered wheelchair.

3. STAGE TWO - EXPERIENCED USERS

3.1 Stage Two Participants.

Ten powered wheelchair users from the Royal Hospital for Neuro-disability volunteered to take part in this part of the study. Participants were selected on the basis of their high level of experience and skill in using their powered wheelchair. This selection was made by the research team, in conjunction with an Occupational Therapist. Six participants had had their powered wheelchairs for over ten years, three had had them for between five and ten years and one for less than five. All participants provided informed consent to take part in the project. Medical approval was obtained from the responsible senior physician in the hospital. Each participant completed one session in real life lasting approximately 30 minutes and one session using the virtual environments lasting approximately 45 minutes. The two sessions took place within 2-7 weeks of one another.

3.2 Stage Two Equipment.

The two virtual environments were as described in section 2.2 with further development on walking people (people now followed pre-programmed paths) and more accurately modelled wheelchair movement. The real-life 'training environment' was set out in the real Assembly Room using chairs and tables. The room and layout were the same for all participants. The doors to the room were closed so that there was no noise or distraction from outside. The only people in the room were the participant and two investigators. Participants used their own powered wheelchairs to complete the manoeuvrability tasks in real life. For the virtual environments they sat in their own chairs and used a wheelchair joystick connected to the computer via a PC wheelchair converter unit which was designed and made specifically for this study. If possible, their own joystick was connected to the computer. Otherwise, a similar wheelchair joystick was connected and was fixed to the participant's chair in the same position as their usual one. At this stage of the project it was not possible to develop converter interfaces to allow all possible makes of wheelchair controller to be used with the virtual environments.

3.3 Stage Two (A) Procedure: Completion of manoeuvrability tasks in real life.

Participants used their own powered wheelchairs to complete a series of driving tasks around a real-life environment. These were the same tasks as those to completed by the same participants later (in virtual reality) and by the able-bodied participants (virtual reality). The following performance measures were taken: time taken to complete each task; number of separate manoeuvres needed to complete a task; number of collisions during each task; distance travelled during each task.

A sensor and four magnets were attached to one back wheel of the wheelchair and a digital counter displayed the number of quarter revolutions of the wheel, allowing measurement of the distance travelled for each task. As wheel size varied between individual chairs, the circumference of the wheel was checked for each participant to allow precise measurement of distance. Time to complete each task was measured using a stopwatch. At the end of the real-life manoeuvring tasks, participants completed a short feedback questionnaire, conducted as an interview.

3.4 Stage Two (B) Procedure: Completion of manoeuvrability tasks in Virtual Reality.

In the first part of the session the VR training environment was presented. Before starting on the manoeuvrability tasks, participants were given a short time to practice using the wheelchair joystick to control their movement in the virtual world. Following this, the tasks described earlier were completed. On completion of the six tasks, participants completed a short feedback questionnaire (conducted as an interview) based on the questions asked about the real life tasks.

3.5 Stage Two (C) Procedure: Exploration of Larger Hospital Virtual Environment.

Participants were then introduced to the virtual hospital and asked to complete a predetermined route around the hospital. As for the able-bodied volunteers, the route began in the main room of the ward and involved visiting each main location in turn. Having reached the final point, participants were asked to follow the route in reverse order and were given the opportunity to explore the environment further if they wished. At the end of the session, participants completed another short feedback questionnaire with questions based on those on the able-bodied questionnaire.

3.6 Stage Two Results

3.6.1 Time taken to complete tasks. Comparisons between virtual reality and real life proved problematic because it was not possible to set the virtual wheelchair to the same speed as each individual's real wheelchair. However, for all ten participants, the total time taken for the six tasks was greater in virtual reality than in real life. For all tasks, the mean time taken in VR was greater than in real life. There were some exceptions, where individual participants were quicker in VR. Two participants were quicker on Task 1 (Forward), three were quicker on Task 2 (Reverse) and two were quicker on Task 4 (Reverse out of gap). The tasks that appear to have the largest difference between real life and VR are driving into the gap, the 180º turn around the table and the slalom. These are the three tasks where it could be argued that the considerable fine control is required to avoid collisions and therefore also where any differences between the real life and VR joystick will be most evident.

3.6.2 Distance travelled to complete a task. Distance travelled was measured in real life and VR for tasks 1, 2 and 6 to look at deviation from a straight line (Forward and Reverse) and at how close to the chairs participants stayed on the slalom. Difficulties were encountered in measuring distance travelled in real-life. The system of magnets to record revolutions of the wheel proved logistically unreliable and therefore data is not presented from these participants.

3.6.3 Collisions. There were a total of 4 collisions for all participants for all tasks in real life and a total of 140 collisions in the virtual environment. The largest numbers of collisions occurred for the tasks involving turning and obstacles, i.e. turning into the gap (26), the 180º turn around the table (57) and the slalom (46) in VR. These are much increased from the real life figures and could be explained by a number of factors including that the speed of the virtual wheelchair may have been set higher and thus made tighter manoeuvres more difficult to perform accurately. Unfamiliarity with the controls may also have had the same effect. The discrepancy between number of collisions between real-life and virtual reality may be explained by differences in the set-up of the joystick and movement (sensitivity, acceleration etc) from participants' real wheelchairs and the unfamiliar medium of virtual reality.

3.6.4 Number of separate manoeuvres. Participants generally used only one manoeuvre for each task in real life. In the virtual environment, the mean number of manoeuvres used was higher for all tasks. This was most noticeable on the three tasks involving turning and obstacles, i.e. turning into the gap, the 180º turn around the table and the slalom.

3.6.5 Tasks found easiest and most difficult. Reversing and the slalom were the most frequently selected as most difficult in both real-life and virtual settings. In real life, reversing is difficult since a real powered wheelchair will not immediately reverse in a straight line because of the front castors coming round into line whilst in VR reversing is hard because of the lack of peripheral vision. The slalom requires a considerable amount of fine control and dexterity. Driving forward in a straight line was the task chosen by the most people as being the easiest task in both settings.

3.6.6 Feedback comparing real life and VR training environments. After using the virtual training environment, participants were asked to compare how they found the tasks in the two environments (1=much easier, 5= much harder). A mean rating of 4.1 was given (range 3-5), showing that all participants found the tasks the same or more difficult in the virtual environment.

Participants were asked if they thought that the driving tasks were representative of the skills needed to drive a powered wheelchair and whether there were any relevant tasks missing. Six participants replied that the tasks were representative. Suggestions for additional tasks included: a three-point turn; uphill and downhill; unexpected obstacles (e.g. people walking out in front of the wheelchair); more straight line driving; some tighter obstacles; reversing into a gap as well as driving in; and having an open space to use prior to doing the course.

Most participants made additional comments when asked about driving the virtual wheelchair. Several participants commented on the lack of peripheral vision in VR and the implications this had for positioning themselves in the world. The joystick was generally thought to be quite difficult to control and quite different from what participants were used to, although most commented that the controls would get easier with practice.

3.6.7 Results from questionnaires about main virtual hospital environment. Aspects of the virtual environment such as colour, perspective, level of detail and scale of objects received acceptable mean ratings of between 3.8 and 4.4 (1 = not at all well represented, 5 = very well represented). Computer-simulated people and movement of the virtual wheelchair received lower ratings, of 3.0 and 2.9 respectively. This follows the same pattern as the able-bodied study. Further refinements of these aspects of the environments became a development priority following this stage of the study.

4. STAGE THREE - INEXPERIENCED USERS

4.1 Stage Three Equipment

The two virtual environments were used with further developments to wheelchair behaviour and walking people. People could now be stopped by the experimenter, so that the wheelchair driver could manoeuvre around them while they were stationary. A series of fading cues and prompts was added to the hospital environment to allow an errorless learning procedure to be followed for route learning. Participants used powered wheelchairs from the hospitals loan assessment stock.

4.2 Stage Three Procedure

Procedures varied slightly between participants depending on their circumstances, see individual sections for details. In general participants were asked to complete the manoeuvrability tasks in real life and then in virtual reality. They will then receive further training in virtual reality until they reach predetermined criteria on the training tasks. Following this, they will use the virtual hospital environment to learn a series of routes between the different locations using the errorless learning techniques. When they can complete routes within the virtual environment they will then be tested on those routes in real life.

4.3 Participant One - "CD" - Preliminary Results

CD is a 20yr old male who suffered a traumatic brain injury following an assault and has mild cognitive impairments. He had not used a powered wheelchair before taking part in the study. He practised for a few minutes prior to performing the six real life tasks in order to gain familiarity with the controls. He then performed the six real life manoeuvrability tasks according to the study protocol. Feedback was gained using a structured questionnaire. Two days later CD was introduced to the virtual training environment. A wheelchair joystick was attached to his manual chair and connected to the computer as in the previous stage of the project. As before, the participant had a few minutes prior to performing the tasks to get used to the controls. The same six tasks were then performed in the virtual environment. Following this, questionnaire feedback was obtained.

CD reported that the real life experience was "fun" whilst the VR experience was "a lot harder". Having completed both sessions, he said that real life was "better" and "easier". He found the 180° turn the most difficult task in both environments. In real life, he reported that the slalom was the easiest task, whilst in VR he reported that reversing in a straight line was easiest. This anecdotal feedback is reflected in performance measures. CD took longer to complete the virtual tasks, he travelled further, made more collisions and a greater number of separate manoeuvres. This confirms the impression provided by the experienced powered wheelchair users. The participant is currently taking part in conventional powered wheelchair training with an Occupational Therapist, after which he will be re-assessed on both the virtual and real-life manoeuvrability tasks.

4.4 Participant Two - "RS" - Preliminary Results

RS is an older male patient who had started conventional powered wheelchair training some time ago but was found to be easily distracted whilst driving. The training had therefore been discontinued. As described above, the participant performed the six manoeuvrability tasks in real life and then four days later performed the same tasks in the virtual environment. As with participant CD, on his first virtual reality training session, RS took longer to complete the tasks, travelled further and made more collisions when compared to real-life. VR training sessions were then commenced on a daily basis. During the training session the participant was asked to complete each task in sequence whilst receiving coaching and constructive feedback regarding aspects of their performance from the experimenter. Due to the participant's distractibility, the six tasks are generally only run through once per session. At the time of writing, the participant had performed the tasks in the virtual environment a total of ten times. His performance varied day-to-day and appeared to be related to tiredness and distractibility. Over the sessions, it was found that the participant benefited from regular reminders to remain focused on the task and to take each task slowly and progress in small movements.

4.5 Participant Three - "PB" - Preliminary Results

PB is a young female patient who had begun conventional powered wheelchair training with an Occupational Therapist. The participant has almost no expressive language and has moderate receptive language impairment. As for the other participants, she performed the six tasks in real life and then in VR a few days later. PB's performance on the virtual tasks generally conformed to that seen in the previous participants with regards to time taken, distance travelled, collisions made and separate manoeuvres. There was more variability in PB's performance however, such that when reversing out of the gap, she was quicker and made no collisions in the virtual environment and when reversing in a straight line she needed considerably less manoeuvres to complete the task.

VR training sessions then commenced on a daily basis. Generally, the six tasks are run through twice in a half-hour session. At the time of writing, the participant had performed the tasks in the virtual environment a total of ten times. Her performance has varied slightly between sessions, possibly related to tiredness. She performs the tasks relatively quickly and has perfected three of the tasks, although this is not consistent across sessions. Due to PB's receptive language impairment, she benefits from having the route required for each task pointed out on the monitor and, for the longer and more complex tasks, having this broken down into small steps.

5. DISCUSSION

The current study aims to provide both qualitative and quantitative data regarding the development of two non-immersive virtual environments for the training of powered wheelchair users. Results to date indicate that for able-bodied participants, experienced powered wheelchair users and one novice user, the simulated wheelchair and training system received favourable responses regarding colour, depth/perspective, scale, look of objects and level of detail. The representation of simulated people in the environment received a less favourable rating, as did the movement of the virtual wheelchair, both aspects were subsequently developed during the study.

Qualitative and quantitative data from participants indicated that whilst the virtual environments were considered realistic and well represented, and the tasks represented the skills needed to manoeuvre a powered wheelchair, completing manoeuvrability tasks was generally more challenging than in real-life. For the experienced powered wheelchair users this increased difficulty may represent the novelty of using a virtual system compared to the real powered wheelchair, however initial data from a complete novice produced a similar differential. In addition, differences in the responsiveness of the virtual wheelchair and issues regarding the validity, reliability and sensitivity of the performance measures used in the study require further consideration. These issues have implications for the sensitivity of virtual environments as a training tool in this context. Whilst it may be expected that the virtual system proves initially more challenging due to its novelty, the size of the difference must not be so great as to de-motivate the user or to prove overly challenging and thereby limit carry-over of skills into real-life. On-going training sessions will shed further light on whether the high level of difficulty experienced in the virtual environments represents an initial 'teething' stage or persists throughout the training period.

A number of difficulties were encountered in measuring performance in both virtual and real-life. The number of collisions made during individual tasks and the number of separate manoeuvres made during a task appeared to be sensitive measures of performance. Other performance measures, such as time taken and distance travelled, proved logistically difficult to measure with sufficient accuracy and may represent a range of confounding factors (e.g. reaction time and speed of the virtual wheelchair relative of the real powered wheelchair, behaviour of the virtual wheelchair compared to the real powered wheelchair when reversing) which would not be considered as representing an individual's skill in using the wheelchair. Developing a system of measurement and recording which accurately reflects skilled performance remains crucial in order to critically evaluate training outcome and improve training methods.

Several experienced chair users noted that the lack of peripheral vision was a problem when using the simulated chair. This particularly affected the participants' ability to check to the side and behind when reversing but may also have affected their ability to adjust their position relative to the stationary objects in the slalom task. This remains a limitation of non-immersive virtual simulations at present and requires particular consideration and development for applications in the field of wheelchair training.

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