# Investigating the impact of method of immersion on the naturalness of balance and reach activities

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## ABSTRACT

Immersive virtual reality is gaining acceptance as a tool for rehabilitation intervention as it places a person within a safe and easily configurable synthetic environment, allowing them to explore and interact within it through natural movement. The purpose of the study was to explore the usefulness of different types of virtual environments in the rehabilitation of upper limb function and balance in stroke patients. Although the above characteristics are ideal for rehabilitation of motor disorders, acceptance is hampered by insufficient knowledge of the effect of method of immersion on the naturalness of human movement. This study begins to address this by comparing the impact of two typical methods, Head Mounted Display (HMD) and immersive projection technology (IPT), on the naturalness of reach and balance activities. The former places the simulated image in front of the eyes, whereas the latter projects it around the user so that they perceive a holographic effect when wearing stereo glasses. Using the novel approach of placing the HMD in the IPT allowed subjects perceiving the environment through either, to be observed moving within the IPT holograph. Combined with sharing the same tracking and camera systems, this provided a direct comparison of tracking measurements, interaction behaviour, video and other observational data. The experiment studied subjects moving objects around a simulated living room setting initially on a level surface and then whilst varying the height and shape of the walking surface through raised planks. Performance in the synthetic environment, using both display types, was compared to that in a physical mock up of the living room. The experimental results demonstrate similar balance and reach movements in the physical mock up and the IPT, whereas a striking reduction in naturalness in both activities was observed for HMD users. This suggests that an inappropriate choice of method has the potential to teach unnatural motor skills if used in rehabilitation. Reasons for the difference are discussed along with possible remedies and considerations for practical applications within a clinical setting.

## 1. INTRODUCTION

Although immersive virtual reality technology has demonstrated substantial benefits in many sectors (Hughes, 2004), its potential has not been fully realised in many. The technology has been demonstrated particular attention in a range of both sensorimotor and cognitive training scenarios. Immersive virtual reality offers considerable potential for practice and assessment within rehabilitation, as it places a person within a safe and easily configurable synthetic environment allowing them to explore and interact within it through natural movement. To be effective in these domains, the technology must not alter the way in which people use their bodies. Many experts seem to hold strong yet differing opinions on the relative strengths and weaknesses of various methods of immersion but little if any research has directly compared the impact on naturalness of user movement. However, another concern in rehabilitation is the practicality of placement and maintenance of equipment within a clinical setting. Replacing a real environment with a virtual counterpart requires much larger and generally less robust technology, if the body is to be visible within it. For virtual reality to be widely adopted for rehabilitation we need a better understanding of the display factors that affect naturalness of body movement and to apply this in the design of systems for clinical settings. This paper starts to address the former and discuss the latter.

By placing a person within synthetic space in which body movement can be accurately monitored with respect to the simulated environment, immersive technologies offer particular potential in rehabilitation of patients with balance and reach disorders. Rehabilitation often requires individuals to relearn movement skills. Optimal ingredients for relearning have been described to be: "1) optimal sensory information 2) variability of practice 3) similarity between the context of training and the context of application" (Mulder & Hochstenbach, 2003). It is in the areas encompassed under 2) & 3) that virtual environments have the greatest contribution.

This study undertook a preliminary investigation of the impact of method of immersion on the naturalness of balance and reach activities. The approach was novel in that we observed subjects within a CAVE-like cubic Immersive Projection Technology (IPT) display, who either saw their body within the projected environment, or only the environment and some virtual representation of their hands and feet through a Head Mounted Display (HMD). This allowed straight forward analysis of body movement with respect to the environment and task. The experiments were carried out exclusively on subjects not suffering from motor disorders in order to assess risk and to understand the simple case of impact on able bodied people before adding the complex variables of disability and treatment.

The qualities of a VR system are typically measured in terms of Immersion and the user subjective illusion of Presence (Slater et al., 2001). The former relates to objective qualities such as the number of senses immersed in the simulation, the extent to which they are immersed, for example field of view, and the fidelity of representation, for example resolution. In contrast the latter describes a sense of being in the virtual, as opposed to the real environment (Meehan et al., 2002). Presence has many attributes and methods of measurement and the reader is pointed to the compendium of Presence Research (2005). This paper concentrates on the effect of immersion on the practice of the skill that is being learned. Therefore we focus on the faithfulness of body movement in response to given stimuli. Postural responses have previously been used in presence research as a behavioural objective corroborative measure of presence (Freeman et al., 2000). Here we observed the posture and reaching gestures of the subjects both at the time of the experiment and subsequently from video footage and tracked data.

The purpose of the study in this paper was to investigate the relationships between method of immersion, reach and balance. As this study concentrates on core issues that are relevant to a wider set of applications, we do not describe the rehabilitation system further in this paper. Related work of virtual reality in rehabilitation is surveyed with a focus on balance disorder and loss of motor control. A technical specification concisely describes the equipment used in the experiment. The experiment itself is then described, followed by results, discussion and conclusion.

### *1.1 Related Work*

The comparison of IPT and HMD has not been widely studied. A lack of user studies is reported by Manek 2004 and a complete absence of direct comparisons reported by Steed 2005. The studies that we have found are restricted to selection, manipulation and locomotion. Reach and grasp is one method of selection. Once grasped, the object can be naturally manipulated. Locomotion refers to exploratory movement within the space, for example walking or turning. Manek found no previous literature on user studies comparing selection and manipulation techniques between the two methods of immersion (Manek, 2004) and showed that: selection and manipulation tasks can be affected by display type; that task performance can suffer when selection and manipulation techniques are migrated from one display type to the other; and that migrated techniques can be modified to compensate. A more recent study (Steed & Parker, 2005) reported that interaction techniques have been designed almost exclusively for HMDs, however, demonstrated that selection tasks were performed better in IPTs than in HMDs while little difference was noticed in that of manipulation tasks. The above comparisons were primarily focussed on the efficiency of object interaction; however, they did consider naturalness as an impacting factor. A correspondence between visual and proprioceptive senses is commonly seen as a major impacting factor on naturalness. Mine et al. (1997) presents a unified framework for VE interaction based on proprioception. Natural walking and turning is supported within a confined space by both display types, and the limits of the space can be overcome through manipulation of viewpoint through a hand held device. The typical configuration for an IPT is to have projection surfaces on three walls and a floor. Adding the fourth wall and roof significantly increase the complexity of the display and the space required to house it. One study showed that users of a typical IPT were less likely to use their body as opposed to the hand controller to turn (Bowman et al., 2002) and suggests that this is due to the missing wall. However, the configuration of the IPT was found to impact on orientation, moving and acting when comparing a six sided cubic display to a panorama (Kjeldskov, 2001). Balance disorders are disturbances that cause an individual to feel unsteady, giddy, woozy, or have a sensation of movement, spinning, or floating (NIDCD, 2005). Virtual Reality has been widely used for the treatment and rehabilitation for patients with the vestibular type of balance disorders. In such applications the aim is to produce a postural adjustment response in the viewer (Owen et al., 1998). Subjects can be observed to sway to compensate for moving images. This was demonstrated for stationary subjects in an HMD (Kuno et al., 1999) and both stationary and linearly walking subjects within an IPT (Keshner & Kenyon, 2000).

## 2. SPECIFICATION OF THE TEST ENVIRONMENT

A VR system uses real-time interactive graphics with three-dimensional models, combined with display technologies that give the user immersion in the model world and allow direct manipulation (Bishop & Fuchs, 1992). VR interfaces can include different displays systems, haptic interfaces, and real time motion tracking devices which are used to create environments allowing a user to interact with virtual objects in real-time through multiple sensory modalities. With an immersive environment, the software ensures that the visual scene's projection is always appropriate to the user's head positions to create the correct perspective view of three-dimensional objects and environment.

Immersion measures the extent to which sensual stimuli from the real world is replaced by synthetic stimuli. It is a multidimensional measure and considers the number of senses involved, the extent to which the real world is replaced and the fidelity of the synthetic stimuli (Slater et al., 2001). In order to maximise the accuracy of analyses or the transferability of skills learned in a VR rehabilitation tool, movement response to stimuli must be faithful to that in the real world. The previous section described other studies that found alignment between visual and proprioceptive senses to be an important factor in the naturalness of reach operations and it is reasonable to assume that it may also impact on balance. We therefore restrict our study to methods of immersion that attempt to align these two senses by surrounding the user in the displayed image. The two most common display types with this characteristic are the HMD and cubic IPT (e.g. CAVE). HMDs place displays in front of the eyes that move with the head. In contrast the IPT projects images onto large screens that surround the subject and are viewed through stereo glasses synchronised to a flicking offset in the image. Our approach to the comparison is novel in that we always observed the subjects within the IPT, even when they viewed the world through the HMD, allowing us a direct comparison of all recorded and observational data.

The two display types differ in a number of factors, most noticeably the subject only see his own body in the IPT. There are several additional attributes of HMDs that may have an effect on a user's performance. They come in a wide range of resolutions and different field of view (FOV). A lower FOV results in "tunnel vision" and might decrease immersion, but higher FOVs require spreading out the available pixels, which can decrease resolution and introduce distortion. In addition, there are ergonomic issues related to HMDs such as display size, weight and the ability to adjust various visual parameters (Bowman et al., 2002). Both of the displays used are better described as typical rather than state of the art. The IPT had four active surfaces, three walls and a floor and the HMD had a field of view of 60 degrees. In this case the IPT was more considerably more expensive the HMD. A study using state of the art rather than typical equipment would have used at least a five sided IPT and a HMD with at least a 110 degree field of view. Such luxuries were not available to us. A V8 HMD was used which has a resolution of 640x480. In contrast the IPT has a much wider field of view provided the subject does not turn towards an open wall. The previous section described how this characteristic can result in unnatural control of turning. Both systems use a tracking device to calculate the correct viewpoint and from this the stereo perspective. The primary hand is also typically tracked. Within our experiment we tracked the head, both hands and both feet. In order to draw direct comparison we used the same tracking system with both displays. The tracking system used was a magnetic Ascension Technologies Flock of Birds. We found that the registration (working volume) of the tracking system was insufficient to accurately monitor the feet from the default mounting within the IPT. We therefore placed tracking points below the knees and calculated foot position from these. Grasp-like selection of objects was achieved through a Pinch Glove on each hand capable of detecting a pinch between finger and thumb.

Within the IPT the user can see his own body, however representing a virtual hand that depicts grasp status can help to see what the system thinks is happening and thus cope with small tracking inaccuracies and temporary pinch glove failures. The HMD user can not see his own body and thus we are left with the choice of either giving no visual feedback of body position or of tying a virtual body to his movements. The latter is known to induce difficulties in accomplishing some tasks (Burns et al., 2005), however, the former can cause worse problems unless a close alignment between visual and proprioceptive feedback can be guaranteed. Given the complexities of ensuring this, including the accurate modelling and tracking of every limb, we decided to limit embodiment to hands and feet.

The simulation for the IPT ran on an SGI Onyx under the IRIX 6.5 operating system while that for the HMD ran on a Xenon PC with a dual-headed Nvida Quadro graphics card with Suse Linux 9.2. Apart from platform and display dependent components, the simulation and model were identical. The program was written in C/C++ and interfaces with the OpenGL Performer™ library version 3.0 scene graph library. The OpenGL Performer™ library supports multiple CPUs and provides a high-level graphics application programming interface (API). Tracking data and video were recoded with respect to the virtual environment throughout the experiment. The former recorded head, hand and feet movement. The video camera was placed just above head height at the entrance to the display.

## 3. EXPERIMENTATION

The purpose of the experiment was to investigate the impact of method of immersion on the naturalness of reach and balance. The scope was partly set by ethics and management of risk. We did not want to experiment on subjects with balance and reach disorders before we had assessed the impact of the technology on healthy subjects. This paper describes this initial experiment only. Furthermore, removing the variables of method and stage of treatment clarified the results.

### *3.1 Test Environment*

A major challenge for rehabilitation is identifying effective and motivating intervention tools that enable transfer of the skills and abilities achieved within a VE to function in the real world. The importance of this in transferring sensorimotor skills has been demonstrated (Rose et al., 1996). For this reason we chose to simulate an everyday setting to which patients could relate and for which the transfer of skills would improve quality of life. The chosen simulated setting was a living room in which familiar objects could be picked up and moved around and various shaped planks placed above the floor for balancing. A basic physical mockup was built for comparison.

Four Scenarios were examined in the synthetic environment while varying the method of immersion. : repositioning of objects through reach, grasp, carry and placement; walking along a plank 2m over the floor; walking along a brittle plank 4m over the floor; and repositioning of objects while balancing on a 0.5m high curved plank. One and two handed object interaction were compared by simulating gravity in a way that required larger objects to be grasped by two hands before they could be moved. The first two scenarios were repeated with the physical mockup but for safety reasons the plank was only raised to 50cm above the floor.

The next subsections describe the particular experiments in more detail underlined with respective photographs taking during the trials.

### *3.2 Subjects*

Twelve adults without any sensorimotor disorder age between 22 and 32, with different professional background and VR-knowledge have taken part in these experiments. Subjects were given time to familiarise themselves with the interface and basic activities and practiced each scenario before it was measured. This was necessary as people experiencing the VE for the first time had problems with judging the distance and functionalities of grasping. However, after a few training sessions the performance was considerable increased to close to that observed in the real world.

### *3.3 Tasks in Detail*

*3.3.1 Repositioning of objects through reach, grasp, carry and placement.* In the first task subjects were asked to move various objects between predefined places in the room. With their right hand, subjects moved a potted plant, key board and small book, then moved the small book again with the left hand and finally moved a large book and then a chair with both hands. Before this first experiment, participants practised the handling of grasping virtual objects with the gloves, by recognising different states of the virtual hands and to interact with virtual objects. Afterwards, they were asked to perform a series of test-runs in a defined order.

*3.3.2 Walking along a plank 2m over the floor.* The second experiment measured balance but not reach and carry activities. The plank was rendered such that it appeared on the physical floor, whereas the floor of the room was rendered so that it appeared two metres below this. If the subject walked of the side of the plank, both plank and floor would raise so that the physical and virtual floor coincided. The task set was to walk up and down the plank several times without falling off.

The subjects were asked to start the balance experiments in there own time, thereby allowing them to familiarise and position themselves within the environment. This gave the participants the opportunity to feel more confident with the surrounding environment, and also avoided falling down before the experiment started.

**Figure 1.** *Balancing on a brittle plank 4m above the floor while observing the environment through the IPT.*

**Figure 2.** *Balancing on a shaped plank while observing the environment through the HMD.*

*3.3.3 Walking along a brittle plank 4m over the floor.* To measure the impact of increased anxiety, the above experiment was repeated for a much higher plank that would break if the subjects moved too quickly (Figure 1).

*3.3.4 Repositioning of objects while balancing on a 0.5m high curved plank.* Balance and carrying were measured together in the final test which was also made harder by using a curved plank (Figure 2). This time, only right hand manipulation was asked for.

## 4. RESULTS

Results presented here compare the naturalness of movement of subjects viewing the environment through HMD and IPT. The measurements presented in this paper are taken from tracking and video data. Tracking data describes the movement of feet and hands but not all experiments have logged both. Snapshots of the video data are presented in the paper and samples of the videos will be given in the presentation and have been submitted along with this paper. In terms of both tracked and video captured movements typical characteristics emerged across all test subjects that clearly differentiated the impact of method of immersion. In all experiments the typical visually observed and videoed movements of the IPT subjects indistinguishable from those in the physical mockup, while HMD subjects consistently demonstrated changed movement behaviour. The following subsections each describe typical samples.

### *4.1 Repositioning of objects through reach, grasp, carry and placement*

Comparing tracked movements while repositioning objects, the curve of hand trajectories appears to be slightly smoother and considerably less erratic for the IPT users. This is most noticeable when looking from above at objects is being carried across the room, Figure 3. The videos are more telling as they clearly demonstrate exaggerated bends in the legs and back of subjects wearing the HMD, Figure 6.

### *4.2 Walking along a plank 2m over the floor*

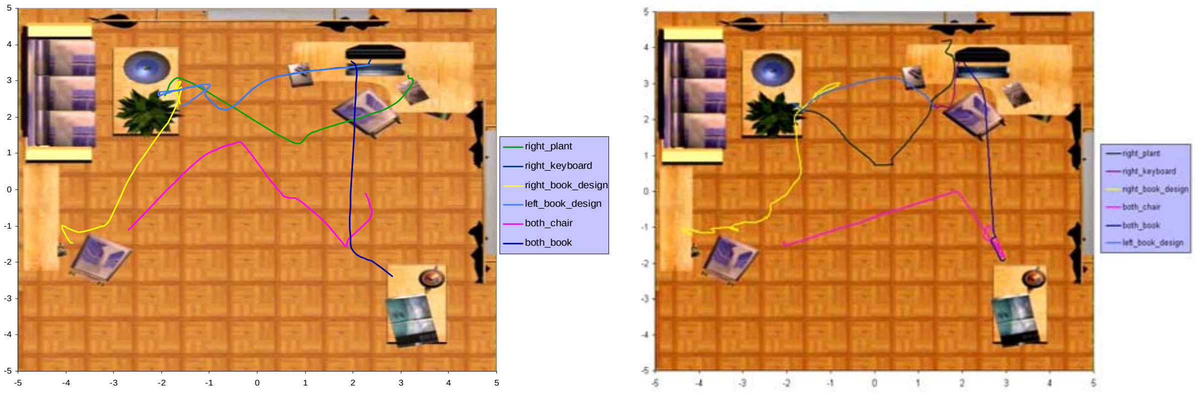
The impact on balance can be clearly seen by comparing the trajectories of the feet for subjects in both displays, Figure 3. The IPT subjects were able to smoothly walk up and down the plank turning efficiently at each end. In contrast HMD subjects stumble along the plank and seldom reach the other end without falling off. Video footage also shows stark differences. The HMD subjects continually gaze at their feet while holding their arms close to the body and often reaching for the HMD. They move reluctantly along the plank and on occasion appear close to physically falling. In contrast IPT subjects seem to gaze about one metre in front of their feet. They appeared to perceive the height and appeared to act accordingly by stretching out their arms to balance. It was interesting to observe that users of both technologies often exhibited surprise when they “fell off” the plank.

### *4.3 Walking along a brittle plank 4m over the floor*

The results were consistent with above, however, some HMD subjects were noticeable more reluctant in their movement. One subject actually refused to do this experiment in using the HMD after experiencing a minor fall in the physical mockup.

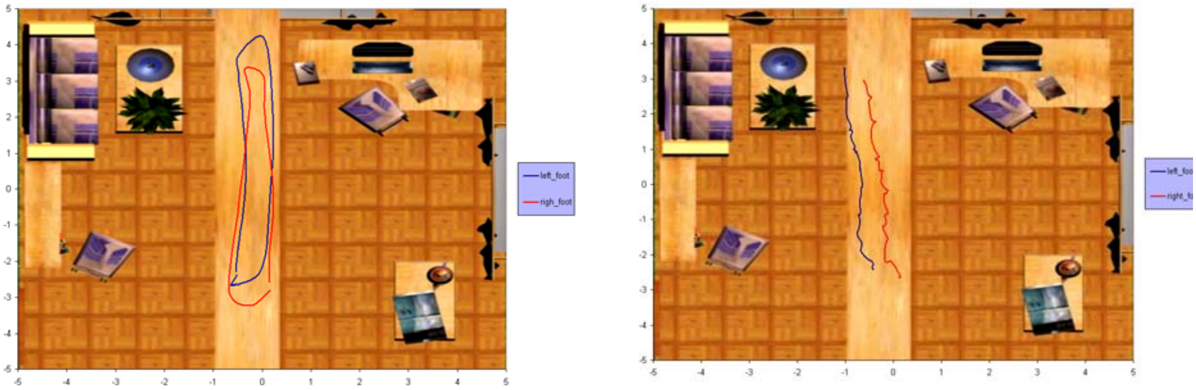
### 4.4 *Repositioning of objects while balancing on a 0.5m high curved plank*

The last task we asked participants to perform was to reposition objects while walking along a raised plank curved plank, Figure 2.



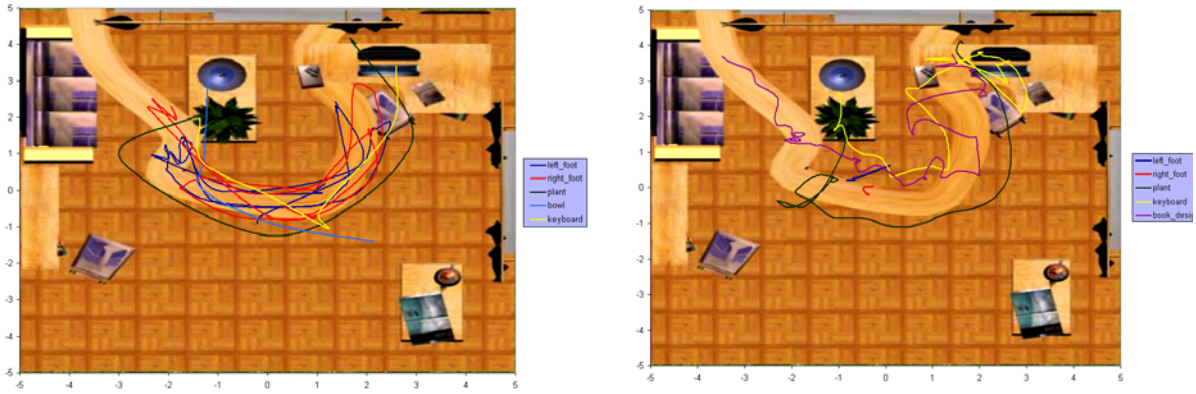
*(a)* *(b)*

**Figure 3.** *Path traces while repositioning of objects (a) in the IPT versus (b) HMD.*



*(a)* *(b)*

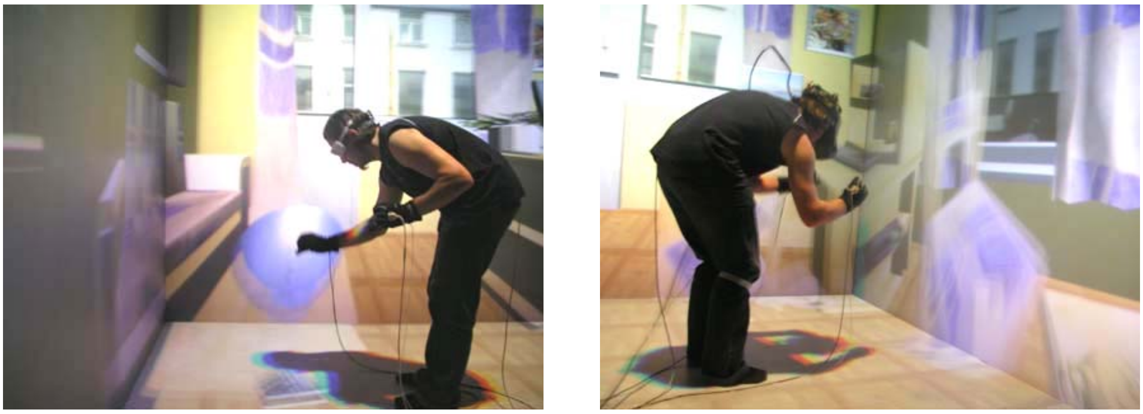
**Figure 4.** *Path traces while balancing on a wood plank over the room (a) in the IPT versus (b) HMD. In (a) the user did a full circle while in (b) the user fell of at the end of the plank.*



*(a)* *(b)*

**Figure 5:** *Path traces while repositioning of objects during balancing on a shaped plank (a) in the IPT versus (b) HMD while in (a) the user had no real problems to balance along the plank, this was much harder using a HMD.*

Both the postural and trajectory behaviours were consistent with the first two tests. IPT subjects moved efficiently and naturally, whereas HMD subjects exaggerated back and leg bends while reaching and could not balance effectively on the plank. Figure 5 contrasts typical trajectories to show that IPT subject can smoothly move around the curved plank and complete all object movement tasks whereas HMD subjects typically achieve neither.



(a) (b)

**Figure 6.** *Behaviour (body posture) during repositioning of objects (a) in the CAVE verses (b) HMD.*

## 5. REHABILITATION CONSIDERATIONS

The focus of this paper is on the impact of method of immersion on the naturalness of human movement. In this section we outline some wider concerns that relate to practice and placement within a clinical setting. Rehabilitation often requires teamwork between the patient and therapist. This teamwork may be hindered if the therapist is hidden from the patients view. One example of hindrance is that it hard for the therapist to demonstrate while the patient is immersed. A second is that patients may feel uncomfortable and even vulnerable if they are being watched without seeing the watcher and can be easily startled by unexpected intervention. A third hindrance is that the practitioner may not be able to relate the patient's movements to objects that are displayed on another device, for example a monitor. IPTs allow co-located users to see each other within the space, whereas HMDs require avatar representation of people. The former is more realistic but with commonly available technology, the perspective of the image is focussed on only one user and so a therapist might observe a patient reaching to one side of an object while the patient sees her hand touching it. HMDs overcome the perspective problem but introduce problems of fidelity in terms of accuracy and realism in the representation of participants.

A major consideration is practical deployment within a clinical setting. Much rehabilitation is done in cluttered spaces such as hospital, office or home. Placing the large screens of an IPT within such environment may often be impractical. Conversely, moving around a cluttered space wearing an HMD brings the danger of injury. Although IPTs have been built for less than $30K and entertainment HMDs can be purchased for much less, systems with over 110 degrees field of view regardless of orientation within the device still cost orders of magnitude more.

## 6. CONCLUSION

Immersive virtual reality offers considerable potential to rehabilitation as it places people in safe, easily configurable environments in which their movements can be accurately recorded. To be effective in rehabilitation it is important that the technology should not negatively impact on the naturalness of the patient's movement. We have demonstrated although IPT subjects do appear to move naturally when moving objects and balancing, HMDs can negatively affect this naturalness. In our tests, HMD subjects performed badly in balance and object placement tasks and their posture and trajectory were consistently unnatural. In contrast this IPT the movement of IPT subjects could not be distinguished from those using a physical mockup. We suspect the problems with the HMD might arise from a mismatch in proprioceptive and visual senses, brought about by not being able to see one's own body; low field of view; and stability of head set. It is possible that the mismatch in the senses can be reduced by tracking and faithfully representing all limb movement. The field of view issue and perhaps that of stability could be addressed with a state of the art HMD. Further work is needed to establish if these effects are fundamental to HMD technology or can be effectively eliminated. Specific to rehabilitation, further work is required to analyse placement and practice with regard to the characteristics of immersive displays.

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