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6 Virtual Exercise Environment for Participation and Adherence of People With Disabilities

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Abstract

This project develops and evaluates the use of virtual reality (VR) technology, together with appropriately adapted exercise equipment through an augmented reality interface, to create virtual exercise environments (VEEs). These environments allow persons with disabilities to exercise, train, and even compete with others. This chapter presents our current research on VEEs to facilitate participation and adherence using a rowing VEE as a prototype with open-source software and common off-the-shelf hardware components. The three specific aims of this project are to make exercise more enjoyable and less repetitious, to provide the means to easily set and track exercise participation and training goals, and to provide opportunities for individuals to engage in "virtual" competition with others. The responses of 33 participants comparing a three dimensional (3-D) immersive VEE with a regular monitor-based equivalent system are presented and analyzed.

Keywords: 3-D immersion, augmented reality, exercise environment, virtual reality

1 Introduction

Individuals who exercise regularly are healthier and tend to enjoy a better quality of life than those who are sedentary. This is especially true for persons with disabilities. For individuals not currently exercising, there are physical, attitudinal, and societal barriers to beginning and continuing a program of regular exercise. Recent empirical studies have demonstrated the importance of environment in influencing physical activity. A meta-analytic review of 19 studies by Humpel, Owen, and Leslie (2002) found that (a) accessibility of facilities, (b) opportunities for physical activity, (c) safety, (d) weather, and (e) aesthetics were leading determinants of participation in physical activity. While the Humpel et al. study reviewed research on the exercise habits of the general population, there is ample evidence that these factors are of even greater importance in determining participation in physical activity by people with disabilities. People with disabilities face a variety of personal and environmental barriers to participation in physical activity. Weather conditions such as excessive heat in summer or excessive cold and dangerous surfaces in the winter make outdoor exercise extremely hazardous for people with disabilities.

This chapter presents our current research on virtual exercise environments (VEEs) to facilitate participation and adherence. Exercising at home or in a fitness center presents numerous challenges for people with disabilities. Few fitness centers offer fully accessible opportunities for people with disabilities, and exercising at home can become boring for even the most dedicated exercise participant. Research has shown that individuals are more likely to engage in a program of regular exercise if the exercise is fun (i.e., their enjoyment outweighs their discomfort) and if they have a "partner" with whom they regularly exercise (Johnson, Rushton, & Shaw, 1996). For persons with disabilities, there are far fewer opportunities to exercise with a partner, and exercise may be more likely to be perceived as a chore than as an eagerly anticipated part of the day's activities (Heath & Fentem, 1997; Ravesloot, Seekins, & Young, 1998; Rimmer, 1999).

One approach to overcoming these barriers is to use technology to bring engaging, entertaining, and motivating exercise opportunities *to* people with disabilities. Specifically, this project develops and evaluates the use of virtual reality (VR) technology, together with appropriately adapted exercise equipment through an augmented reality interface, to create VEEs. These environments allow persons with disabilities to exercise, train, and even compete with others. The following are the three specific aims of this project:

1. Make exercise more enjoyable and less repetitious.
2. Provide the means to easily set and track exercise participation and training goals.
3. Provide opportunities for individuals to engage in "virtual" competition with others.

A prototype VEE with a wheelchair-accessible, augmented, VR-based cardiovascular rowing system has been developed not only to facilitate participation and adherence for people with disabilities but also with the intent of tapping into the potential for commercial or private manufacture, marketing, and distribution. FitCentric's NetAthlon, a commercial software application, has been adapted for the VEE along with WaterRower, a standard commercial rowing exercise machine. NetAthlon supports a variety of off-the-shelf and adapted exercise equipment. The prototype VEE uses Industrial Virtual Reality's ic3D augmented VR system.

The VEE was showcased at the 2006 National Institute on Disability and Rehabilitation Research (NIDRR) Rehabilitation Engineering Research Center Rectech State of the Science Conference on Exercise and Recreational Technologies for People with Disabilities in Denver. A number of people with disabilities used the VEE and were amazed at the potential of this technology. More follow-up studies are currently in progress.

2 Methods

Our approach makes extensive use of readily available technology used in gaming and entertainment products, making the development highly cost effective. Commercial trends continue to reduce the cost of the computing equipment required to create VEEs, making the acquisition of such equipment possible in the future even for people with modest means.

Each of the three specific aims of the project is described in more detail.

2.1 Make Exercise More Enjoyable and Less Repetitious

VR has been used in many different settings for persons with disabilities (Boian et al., 2002; Browning, Cruz-Neira, Sandin, & DeFanti, 1993; Jack et al., 2000; Johnson et al., 1996). Most of these uses have been associated with either rehabilitation or specific training. In addition, manufacturers of exercise equipment have in recent years added a sense of variety to their equipment using multimedia. Currently, the most common class of exercise equipment provides video monitors with different images meant to represent a variety of exercise locales, although synthetic-image VR experiences are beginning to be available.

VR may employ varying degrees of "immersion," ranging from a nonimmersive experience closely akin to watching television, to a synthetic interactive experience similar to a video game, and finally to an environment that attempts to create an experience as close to the "real" experience in three dimensions as possible (Browning et al., 1993). These "fully immersive" environments are rapidly moving from the computer graphics laboratory to the consumer. For this project, we provide VEEs for persons with disabilities for rowing waterways, lakes, or canals (Figure 1).

Using common off-the-shelf VR components to provide a more immersive and therefore a more realistic environment poses several significant questions for our testing. For example, what fraction of our population will be able to successfully use the system? What is the effect of the width of the field of view—does it only allow users to look straight ahead, or does the field extend to the peripheral vision of the user? This question is important, as there are instances in which individuals report adverse effects including nausea or dizziness (Lin, Duh, Abi-Rached, Parker, & Furness, 2002). These effects are sometimes referred to as "cybersickness" or "simulator sickness." The effect of simulator sickness is ameliorated with high-resolution graphics, and we are working to validate these claims for persons with disabilities.

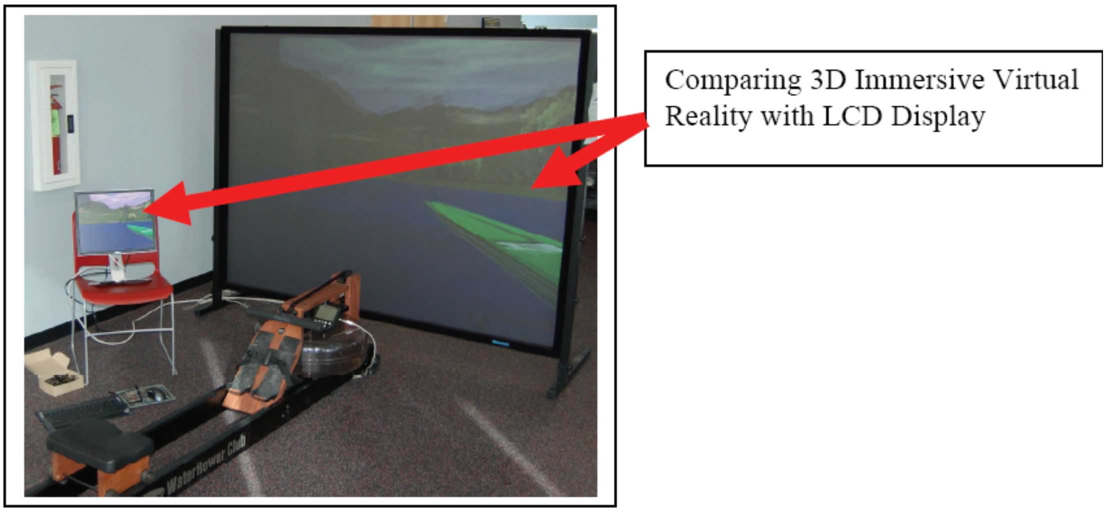

Figure 1. Prototype #D Immersive and 2-D LCD-based Virtual Rowing Exercise Environment for Comparison Studies.

2.2 Easily Set and Track Exercise Participation and Training Goals

Other technology needed to create the VEE builds on engineering and technology efforts designed to provide feedback to support development of motor skills (Figure 2) and to provide an outlet for creative/aesthetic expression for persons with severe disabilities. The work generally involves a set of sensors that can detect even very small motions and the translation of these detected motions to control the auditory and visual environment. An early prototype project known as CARE HERE (Creating Aesthetically Resonant Environments for the Handicapped, the Elderly and Rehabilitation) has been developed by people in Europe and Australia.

This project adds sensors to synchronize the rowing environment. The visual field changes in proportion to the user's rowing machine belt pulling rate. We hypothesize that this capability will increase the user's engagement and enjoyment of exercise.

For exercise equipment that has been appropriately adapted, we are able to significantly improve the quality of the VEE by making it appear that the chosen route is being traveled at a rate consistent with the user's rowing speed. This level of interaction only requires that the exercise equipment be capable of reporting the rate at

Figure 2. Motor skills enhancement used for persons with disabilities using a rowing VEE.

which the user is rowing. The second step in making the exercise environment more realistic is to provide force feedback to the exercise machine. For example, rowing can be made harder for an upstream course than a downstream course by changing the water resistance in the augmented reality simulation. Adding more water in the WaterRower container increases the water resistance and vice versa.

Those sharing VEEs may have a widely varying range of motor abilities and fitness. In order to allow individuals to easily share VEEs, each participant's motor ability and fitness has to be normalized to create a "level playing field." This normalization is based on the user's prior performance on the same or similar courses. When desired by the user, normalization can be disabled in order to provide a more direct measure of exercise progress.

2.3 Provide Opportunities for Individuals to Engage in "Virtual" Competition

We have begun to experiment with collaborative VEEs. Most of us are more likely to keep an exercise date if we make that date with a friend. However, individuals with disabilities may find it inconvenient, or difficult, to meet someone for this purpose. Transportation is one of the most frequently reported barriers to community participation for people with disabilities, making shared exercise programs problematic. Moreover, individuals may live a considerable distance from the person or persons with whom they wish to exercise.

We are developing a means for individuals to share VEEs. For example, two people who live in different cities could arrange to "ride" a particular rowing path.

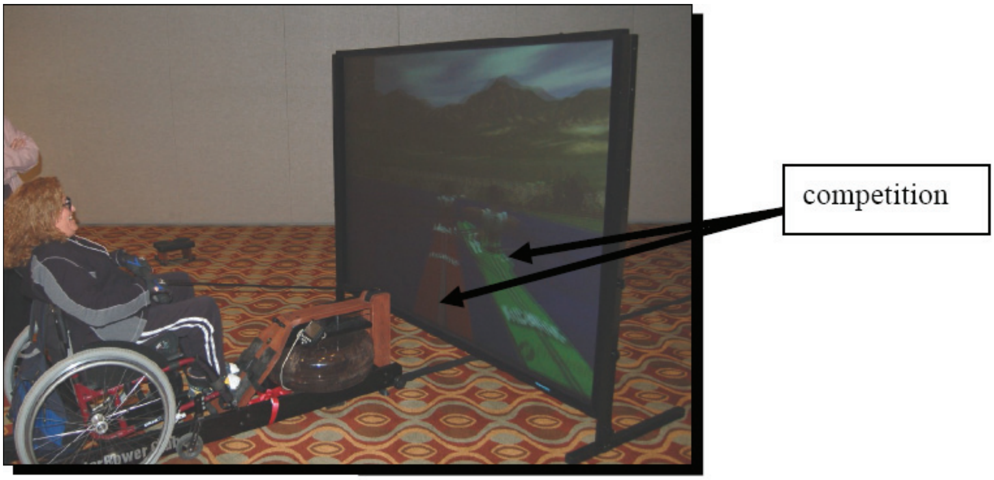

Figure 3. Competition in virtual rowing.

Although each person is actually using an appropriately equipped device in his or her home, they can share the same VEE experience. In addition to the chosen path being represented to each person, an “avatar” of the other person also appears in the VEE, just as if they were rowing along the path together. An “avatar” is an on-screen image that represents the user in a VEE. Other users see the avatar as the representation of the user in the environment. The avatar represents a different colored rowing machine as selected by the user. For example, in our prototype example shown here, the user is represented as a red rowing machine while the competitor is shown by a green rowing machine. The relative position of the avatars—whether one rower is ahead of the other or the rowers are side by side—will reflect the relative rowing speed of the two riders, just as if they were rowing together on an actual lake or river.

3 Overall Architecture

This project represents a step toward developing an open-source Remote Exercise and Game Architecture Language (REGAL) system for Rectech. The main application of REGAL will be in the domain of remote recreation and rehabilitation, thereby alleviating the need for therapists to travel for routine monitoring of their patients. Additionally, the open source will facilitate collaboration among researchers and will lead to an alternative platform to compare and contrast the ingredients in some of the proprietary technologies being promoted by some private companies.

REGAL consists of (a) a baseline architecture and (b) a virtual augmented reality architecture on top of the baseline architecture. The design philosophy of the baseline architecture is based on Electro architecture.

Electro is an application development environment designed for use on cluster-driven tiled displays, VR systems, and desktop workstations. Electro is based on the MPI (message-passing interface) process model and is bound to the Lua programming language. With support for 3-D graphics, 2-D graphics, audio, networking, and input handling, Electro provides an easy-to-use scripting system for interactive applications spanning multiple hosts and a variety of displays. Using a set of scripts, Electro applications are iteratively created. It begins with a basic scene, adds a scene hierarchy, makes the scene interactive, and adds an intelligent camera. Electro is based on OpenGL (Open Graphics Language) and requires an NVIDIA GeForce FX (or better) or ATI Radeon 9600 (or better) graphics card.

The virtual augmented reality architecture on top of the baseline architecture is described by means of the prototype rowing VEE. The technical details of the prototype rowing VEE are provided next.

The Rowing VEE can be operated in three modes:

1. *Seat on wheels*, for participants who do not need wheelchairs
2. *Wheelchair on floor*, for participants whose wheelchair can climb on top of the rowing machine
3. *Wheelchair on ramp*, for participants whose wheelchairs cannot directly climb on the rowing machine

The software and hardware details are provided next.

3.1 Software

FitCentric Technologies Inc.'s (Montclair, California) NetAthlon (http://www.fitcentric.com/html/netathlon.htm), a commercial software application, has been adapted for the VEE. NetAthlon supports a variety of off-the-shelf and adapted exercise equipment. Rate of travel through the synthetic environment is proportional to the rate at which the rowing exercise equipment is operated. The current design of NetAthlon is geared more to support competition than to support shared exercise. Using a local area network or the Internet, NetAthlon permits rowers using fitness machines to compete against other rowers on fitness machines located elsewhere. Another FitCentric software product, UltraCoach, provides a customizable fitness data management system. NetAthlon uses rule-based training plans from workout data. The rules are intended to guide the user based on specific situations to keep the content interesting. It provides graphics in (a) a "first-person mode," in which the user's head bobs up and down, (b) a "third-person mode," in which a camera follows the user, and (c) a TV mode, in which the system changes camera shots like a TV show.

Proprietary solutions such as NetAthlon are not suitable for research and development because the architecture is not open. Lack of open standards hampers content development. Open standards for immersive VEEs are needed. Using lessons from CSAFE (Communications Specification for Fitness Equipment; http://www.fitlinxx.com/CSAFE/), we are investigating open standards to provide an opportunity for multiple entities to build standardized VR content. The research on open standards is based on analyzing current technological components from (a) VR exercise software (e.g., FitCentric's NetAthlon); (b) 3-D courses (e.g., FitCentric courses); (c) exercise equipment such as the rowing machine from WaterRower (Warren, Rhode Island, http://www.waterrower.com/), which provides good initial compatibility with CSAFE and NetAthlon; (d) advanced graphics using Open Inventor Application Programmer Interface (API); (e) serial and/or wireless communication between the exercise equipment and the VEE; and (f) interface standards to projectors, big screens, and polarized glasses.

3.2 Augmented Reality Hardware

WaterRower, a standard commercial rowing exercise machine, has been adapted for the augmented reality user interface. Our prototype VEE uses Industrial Virtual Reality (Westmont, IL) ic3D system consisting of a 3.60-GHz, 2-GB RAM Intel Xeon Processor; NVIDIA ForceWare 3-D Stereo Driver; circular polarized glasses; two DLP projectors stacked on top of each other so that the images overlap (Figure 4); circular polarizers; and a 60-in. × 80-in. rear-projection screen from Stewart Filmscreen Corporation (Torrance, California). The rear projection screen is coated with a special polarization preserving material. These are custom made and coated with "Disney black diffusion film." The performance of such a material is superior because of its minimal stereo cross talk and because of its contrast qualities.

The prototype ic3D system is based on GeoWall technology (Vaidyasubramanian, Nayak, & Lopez, 2003). Two stacked InFocus LP530 DLP projectors have been used so that the images overlap (Figure 4). Circular polarization is used so that stereo is maintained even when viewers tilt their heads. Inexpensive passive stereo glasses have been used. A ForceWare NVIDIA 3-D Stereo driver facilitating full-screen stereo

Figure 4. Dual-stacked projectors in ic3D system based on GeoWall technology.

viewing of many Direct3D- or OpenGL-based applications has been used. NVIDIA ForceWare is a cheaper alternative to Christie's Active to Passive 3-D Converter (AP Converter). The update speed of the 3-D environment is synchronized and is proportional to the rate of the rowing paddle movement. Table 1 summarizes the hardware and software used.

4 Results and Discussion

The Rowing VEE was showcased at the 2006 NIDRR Rehabilitation Engineering Research Center Rectech State of the Science Conference on Exercise and Recreational Technologies for People with Disabilities in Denver. A number of people with disabilities used the VEE and were amazed at the potential of this technology. Figures 1 through 3 represent one such user at the State of the Science event.

A more formal study lasting for one session of about 30 minutes is currently being designed and is outlined here. The study participants exercise by pulling on a handle as in a standard rowing exercise machine. While performing the exercise, participants compete against computer-generated rowers. The primary purpose of this research is to assess the level of motivation and engagement by participants if a good VR environment is provided to them. The goal is to find ways to motivate people to participate in exercise. We aim to develop exercise technologies that are accessible to people with disabilities. As such, both able-bodied individuals and those with disabilities are participating in this research. The collected information will be used to assist in design changes on the resistance, aesthetics, and interface of the exercise device and virtual environment.

Consequently, two study groups are currently being designed: one consisting of able-bodied participants and the other consisting of people with disabilities. A questionnaire incorporating measures of satisfaction and other descriptive data for this initial cohort is used to gather information needed for the design and development

Table 1. Summary of Hardware and Software Used

Hardware	ic3D passive stereo system with a 3.60-GHz, 2-GB RAM, Intel Xeon Processor; NVIDIA ForceWare 3-D Stereo driver; circular polarized glasses; two DLP stacked projectors; WaterRower rowing machine
Software	FitCentric NetAthlon rowing software; Open Inventor API for VR modeling

process. Participants are asked to evaluate the perceived quality and value of the exercise environment. The major steps of the study are outlined next.

Step 1: First, an inclusion-exclusion criteria test is applied through a questionnaire. Eligible participants must

- not have had a traumatic injury to their shoulders, arms, or hands in the past;
- not have low or high blood pressure. The participant's blood pressure prior to participation is measured to ensure it is within normal levels (140–100/90–50 mmHg);
- not be receiving medical treatment for pressure sores or respiratory problems (asthma, etc.);
- not have any heart, lung, or other chronic medical conditions that prevent cardiovascular workout;
- be 18 to 50 years old.

Step 2: The participants then fill out an informed consent document. Following this, an assistant demonstrates the use of the rowing device/VR environment in the following manner. The assistant sits down on the rowing seat, positions his or her feet in the foot holder, puts on a pair of VR glasses, grasps the rowing handle with both hands, and begins the exercise session. The assistant pulls the rowing handle toward the chest while pushing the feet against the foot holder. The assistant demonstrates how the rowing device controls movement in the VR environment. The session lasts about 10 minutes. The assistant then takes off the VR glasses and gets up from the rowing seat.

Step 3: The participant then tries out the rowing device/VR environment. After about 10 minutes, the participant ends the session and fills out a questionnaire. If the participant has a physical disability, all steps will be the same as for other participants except for the following:

1. The rowing seat is removed and is replaced by a wheelchair to directly access the rowing device handle. Two options are pursued: If the wheelchair has enough clearance at the bottom to slide on top of the rowing machine guide bars, then it is directly used. If the wheelchair does not have enough clearance, then a ramp and platform is used.
2. The assistant demonstrates the use of the rowing device/VR environment using a wheelchair. It is important that the brakes on the wheelchair are in a locked position during the session so that the participant is stable.

Prior to, during, and following the exercise sessions, subjects are told to note the following conditions:

1. An unusual heartbeat, such as skipped beats or a very rapid pulse
2. Dizziness, light-headedness, feeling off balance, shortness of breath, nausea, or pain in any part of the body
4. Any loss of vision

The presence of any of these conditions is taken as an indication to terminate the subject's participation in the exercise.

Step 4: The last step consists of a postexperiment participant questionnaire based on certain relevant features from the design framework described in Witmer and Singer (1998). The first set of questions about the experiment, as listed in the appendix to this chapter, compare VR and desktop monitor experiences. The second set of questions, also listed in the appendix, attempts to capture background information on the participant, which helps us in normalizing the responses and in overcoming some biases.

Figures 5 through 9 show the results based on 33 participants in our Institutional Review Board–approved study comparing the described 3-D environment with a VR system using a regular monitor.

It is clear from the results that on most counts the 3-D immersive environment was better appreciated by the participants. In most cases, the standard deviation of the responses for the regular monitor was higher than that of the VR system responses,

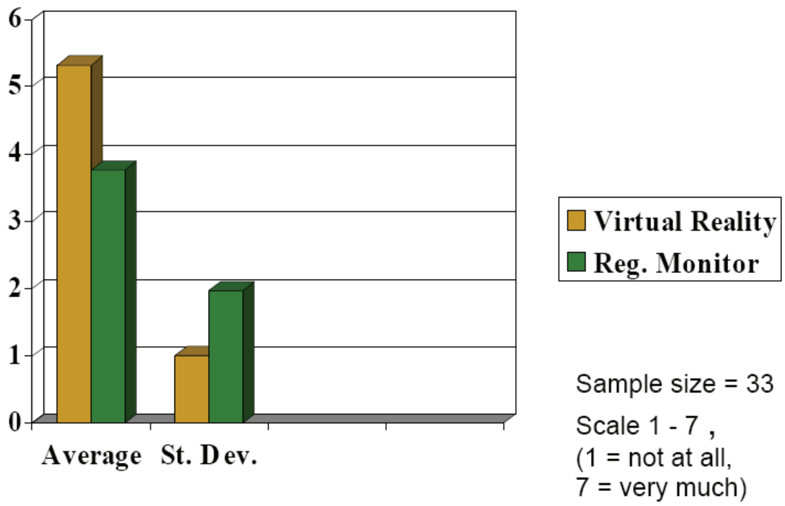

Figure 5. Responses for "How responsive was the environment to actions that you initiated?"

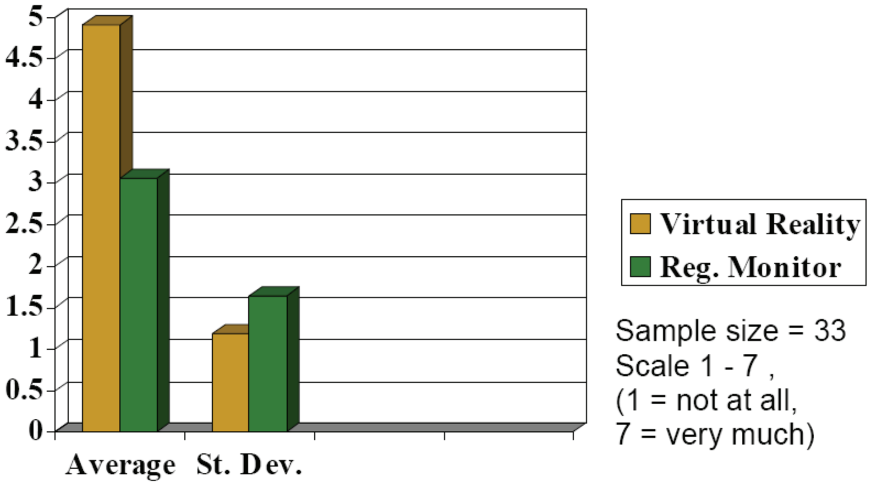

Figure 6. Responses for "How natural did your interactions with the environment seem?"

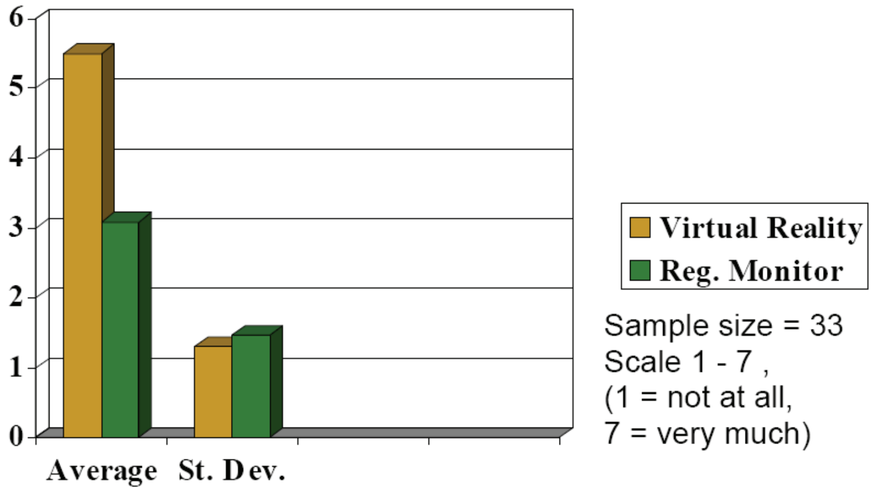

Figure 7. Responses for "How much did the visual aspects of the environment involve you?"

indicating that the responses for the VR system were not only better but also more consistently better.

5 Conclusion

The development of open standards for immersive VEE is an ongoing effort using the prototype rowing VEE. Immersive virtual environments are still in their infancy because compelling imagery and content creation for 3-D immersive environments is

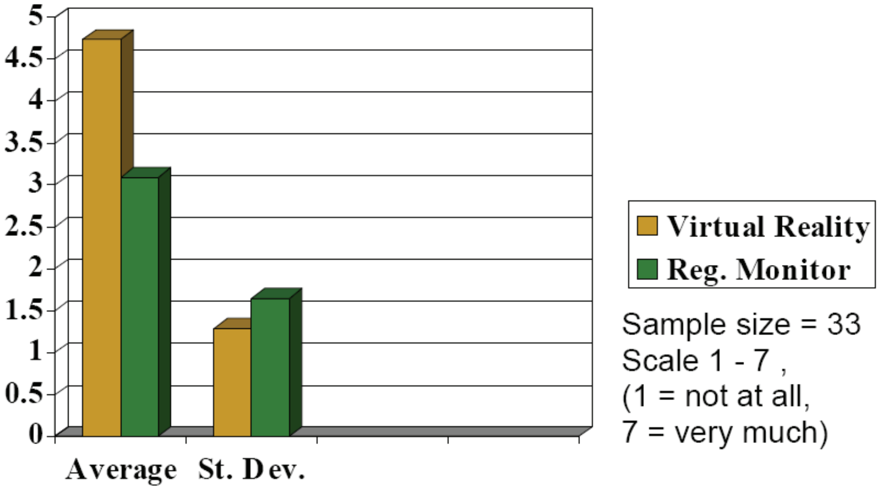

Figure 8. Responses for “How much did your experiences in the virtual environment seem consistent with your real-world experiences?”

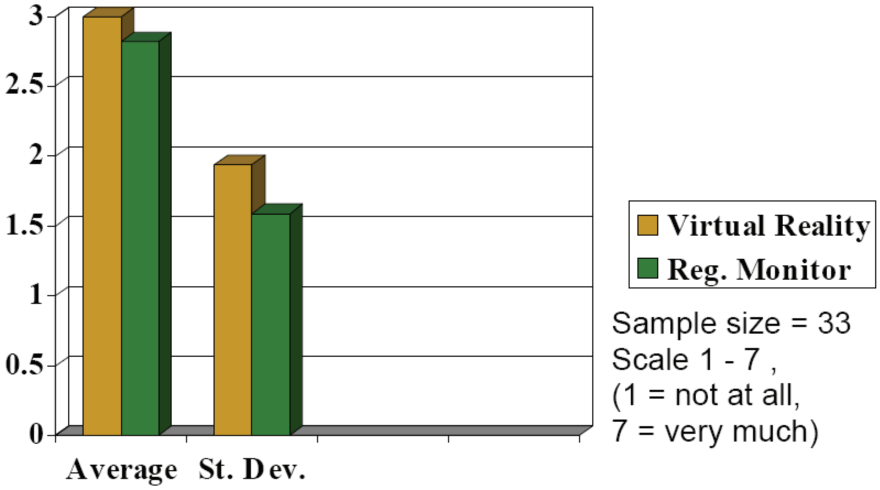

Figure 9. Responses for “How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?”

a topic of active research and will take a few years to evolve. The nonimmersive content is more mature, but a direct conversion of nonimmersive to immersive content, as we have done here, is the very first step. Engaging immersive content will have to be developed independent of conversion from nonimmersive to immersive, and we hope to undertake this as a future research topic.

A further goal for wheelchair-based rehabilitation is to study the impact of VR and a companion rower on the cardiovascular workout. For this, we need to develop an augmented reality interface for a pair of rowers to exercise side by side. This concept can also be extended for rowers at geographically dispersed locations but connected through a teleimmersive VR environment.

Acknowledgments

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Appendix

Questionnaire

The first set of questions:

1. How responsive was the environment to actions that you initiated (or performed)?
2. How natural did your interactions with the environment seem?
3. How much did the visual aspects of the environment involve you?
4. How much did your experiences in the virtual environment seem consistent with your real-world experiences?
5. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

The second set of questions:

1. Do you easily become deeply involved in movies or TV dramas?
2. How frequently do you find yourself closely identifying with the characters in a story line?
3. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?
4. Do you ever become so involved in a daydream that you are not aware of things happening around you?
5. How well do you concentrate on enjoyable activities?
6. Have you ever gotten excited during a chase or fight scene on TV or in the movies?