IMPROVEMENT IN BALANCE WITH A COST-EFFECTIVE VIRTUAL ENVIRONMENT

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ABSTRACT

Falling is a major risk to the health and quality of life for the elderly and for those with sensorimotor impairment. Virtual environments (VE) have been investigated in the past for their potential for vestibular and balance rehabilitation as well as with stroke patients. In this study, a virtual reality game was evaluated with respect to its effect on the user for improving scores on standard balance tests. The environment focuses on lateral movement, which is a major cause of falls in the elderly, and poses challenges for better posture control on the user. Two levels of difficulty were used in the training, and immediate feedback was provided. Training was conducted in nine sessions over the course of three weeks. Preliminary results indicate that the subjects were able to improve their performance on these balance tests after training. This suggests that this virtual reality environment could be used in balance rehabilitation and to improve posture control in elderly. It is particularly suitable for home based training. Future studies will be performed to validate the program with specific impairment conditions.

INTRODUCTION

Elderly people are at high risk of falls due to sensory impairment or weakening of muscles. For maintaining posture and balance, vision, vestibular, proprioceptive and somatosensory sensors each play an important role. It has been well established that visual cues are the dominant cues in postural stabilization and they attenuate self-generated body sway by 50 percent [1, 2, 3]. Visual information is also important to acquire spatial information about the environment. In older subjects, dependence on visual inputs becomes more profound, as the Vestibulo-Ocular Reflex (VOR) mechanisms are reduced with age. The vestibular system is located in the inner ear and senses head motion. The VOR is a reflex that stabilizes the eyes during head movements to enable clear vision. Studies show that in normal healthy older subjects, other types of eye movements such as smooth pursuit and saccades are relatively maintained while those related to vestibular function decline with age [4].

For falls associated with aging, one of the most common problems is impaired lateral balance involving the frontal plane [5,15]. In this paper, a virtual reality environment that encourages lateral head and body movements was evaluated for improving balance. Virtual Reality (VR) provides an ideal opportunity to examine the role of the different senses on balance through visual and audio cues. Ultimately it will be possible to include other sensory inputs such as vestibular (through moving platforms) and force feedback (through hand controls). Virtual Environments (VE) can also be used to enhance or limit the role of one or more cues for balance. Adaptations in a virtual environment to unexpected perturbations or situations that encourage lateral body movements might provide a solution in improving lateral balance for the elderly and in those with sensorimotor impairment.

METHODS

System

The VE used in this study was a hover-board game in which the user controls movement along roadways and rails and through the air with his/her own body motion. The user is represented by a cartoon avatar in the game. This system takes inputs from the user's head and arm movements, by imaging them with a small video camera mounted above the display, using software to identify and quantify head and arm movements. Each user is individually calibrated before each session, to account for height differences and range of head motion. This is a simple system operating in the lateral plane, requiring no body markers to track body position [10]. A regular 27" TV was used as a display. A picture of the VE display is shown in Figure 1.

Figure 1: Virtual hover-board environment. The environment encourages the user to move his/her head and body to navigate through the environment. The difficulty level, path and speed in the environment can be manipulated.

The environment requires the user to move laterally, jump, reach out for objects, avoid obstacles, crouch etc; activities that are very similar in day-to-day life. These requirements are hypothesized to encourage more lateral movements and reflex actions in everyday situations, such as reaching and catching as well as in balance maintenance.

Subjects

The VE training was tested in ten healthy subjects and compared to balance testing in 7 healthy control subjects (nine male, eight female; ages 22-45 years, height 155 cm -180 cm, weighing 50 kg-90 kg). All subjects were right handed. One of the test subjects did not complete the experiment so the data is not included for that subject. The subjects were asked to complete a questionnaire before the beginning of the experiment, in which they reported no medical conditions affecting balance. Each subject provided informed, written consent to comply with ethics approval granted by the institutional review board.

Experimental protocol

Balance was measured at the beginning of the experiment and after the training period using a Balance Board, which is a board mounted on an inverted half sphere. In this test, the subject is required to maintain balance on the board, with feet 10 cm apart, eyes open and arms on the side. A stopwatch was used to record the time the subject maintained the posture (to the point of losing balance or grasping a support). The training and the testing were done with shoes off.

The subjects attended nine training sessions in the Virtual Environment over the course of three weeks. Each session was half an hour in duration. The training was given for two 15 minute blocks. After the first 15 minutes, a rest of 10 minutes was provided. The subject was then asked to navigate through the same VE (for 15 minutes), or based on the performance in the first session, the subject was moved to the next level, hence increasing the difficulty. The first training session each day was always at the lowest level of difficulty. A Simulator Sickness Questionnaire (SSQ) was completed during the break and after the training protocol each day. The SSQ contains 16 items on which the subjects rate their responses (on a scale of 1-4; 0 (none), 1 (slight), 2 (moderate), 3 (severe)) [12].

RESULTS

The results of the SSQ revealed that subjects experienced slight fatigue and sweating during the trials. This was attributed to the game requiring active head and body movements to hit targets and to navigate the game, and it would be expected that the user experience some degree of fatigue. The effect of rest intervals on fatigue was not investigated, but based on initial results; a ten minute rest was felt to be appropriate between the two trials. Also, consistent with previous studies [6,13,14], one subject experienced slight simulator sickness symptoms (fullness sensation in the head, nausea and stomach awareness) after the first training session. On subsequent trials, the symptoms subsided. Two subjects felt slight headaches after training. The users felt very immersed in the environment and none of the simulator sickness symptoms were severe.

Performance on the Balance Board test improved over the course of the training period. Figure 2 shows the difference in times that each subject was able to maintain balance before versus after the training period. The test was discontinued after three minutes, as after this time the effect of muscle fatigue started to affect the results.

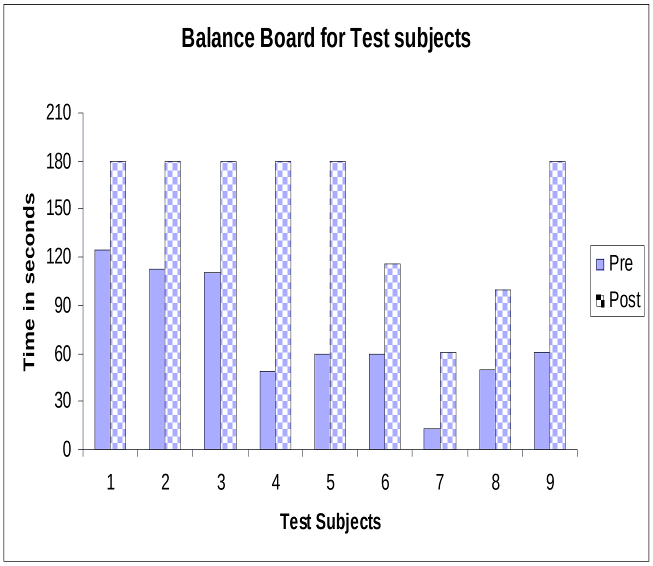

Figure 2 (a): The graph shows the performance on Balance Board tests of the test subjects before (filled bars) and after (checkered bars) training.

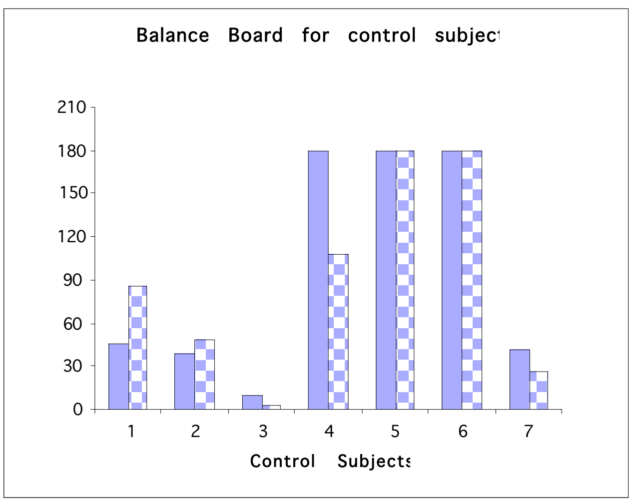

Figure 2 (b): The graph shows the performance on the Balance Board test of the control subjects before (filled bars) and after (checkered bars) the three week period without training.

DISCUSSION

The results above indicate that subjects improved in Balance Board timing. Some of the individuals had better balance to start with. The performance of each subject was compared to his or her own time at the beginning of the study. The improvement could be attributed to the fact that the user is on a virtual hover-board in the VE and the training game puts challenging demands on the lateral balance of the user. Hence, the user is able to transform the VR experience into the real world.

The high-speed forward travel of the avatar creates a novel combination of visual and vestibular cues, as the vestibular inputs are limited to only those generated by the user side-to-side or up and down. These movements in the lateral plane have an effect on the speed and direction of forward motion, which is fed back through the user via the visual system only. While this situation does not translate directly to the real world, it decouples the learned pattern of visual-vestibular interaction, and is hypothesized to allow for re-learning or re-weighting of the combination of sensory inputs.

In addition to improving time on the balance test, the users also improved in their scores in the virtual environment. This could be attributed to better understanding and recognition of the environment, anticipation, cognitive decisions and strategies used by the subjects. Hitting the targets requires a quick and efficient response from the users, while they are speeding in the environment. This indicates an improvement in the reaction time of the users in the game. The transference of this learning will be evaluated in future studies. In the current study, this learning effect was controlled to some extent by using two levels of training. Additionally, the complexity of the environment, with several possible paths to navigate in each level, maintained the challenge throughout the training period.

Performance on balance tests suggests an improvement over the course of the training. These preliminary data show that this game could be used in balance improvement or balance rehabilitation. The impact of this training on elderly adults and adults with vestibular impairment will be evaluated. Even though this experiment was not conducted on these specific populations, it provides support for using a cost effective VE in balance rehabilitation. For future work, the balance strategies used with different combinations of sensory inputs in the virtual environment will also be explored.

CONCLUSIONS

The purpose of this experiment was to investigate use of a low cost Virtual Environment for balance rehabilitation. It was found that balance test results and game scores improved over the course of the training. The results suggest that such a low cost VE could be used in improving balance. In particular, the system tested, could improve lateral balance control.

The Virtual Environment chosen for this study is a challenging and enjoyable game with progressive difficulty levels. As an inexpensive solution that could be applied for home use, it has the advantage of allowing those concerned about their risk of falls to train themselves in a safe home environment.

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