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Communications.

A New Rehabilitation Training System for Postural Balance Control Using Virtual Reality Technology

Nam Gyun Kim, Choong Ki You, and Jae Joong Im

Abstract—A new rehabilitation training system, designated as a virtual cycling system, was developed to improve postural balance control by combining virtual reality (VR) technology with a bicycle. Several parameters including path deviation, path deviation velocity, cycling time, and head movement were extracted and evaluated to quantify the extent of control. The system was effective as a training device and, in addition, the technology might have a wider applicability to the rehabilitation field.

Index Terms—Postural balance, rehabilitation, virtual cycling system, virtual reality (VR).

I. INTRODUCTION

The number of individuals who lack good postural control is increasing [1]-[2] due to an increased survivorship from traumatic brain injury, neurological changes due to aging, and neuropathologies caused by various diseases [3]-[4]. Thus, the necessity to develop effective postural rehabilitation training systems has increased. Current techniques include using biofeedback to improve postural balance control on forceplate measuring systems [2]. Yet these protocols are insufficient because all senses for keeping postural balance are not simulated sufficiently. Also, since most such systems force the user to fix their gaze on a monotonous computer screen, then it is important for efficiency to maintain interest in the training and to give adequate impetus to all of the relevant senses.

We have developed a virtual cycling system that combines virtual reality (VR) technology with a bicycle. From the following reasons, the rehabilitation training effect for the developed system represents a marked improvement over current techniques. First, the technology can stimulate a number of senses simultaneously and make the subject react with the virtual space as if he/she were in the real world [5]-[6]. Second, cycling requires combining visual, vestibular, and somatic senses with muscular strength so that the senses and muscles work in a coordinated manner while cycling. The aim of this study is therefore to develop a virtual cycling system and examine whether the system is useful in balance rehabilitation training.

II. SYSTEM CONFIGURATION AND METHODS

The system built to study the virtual cycling training effect is shown in Fig. 1. Subjects wore an HMD (head mounted display) which is a one-glass unit (DO company) and provides virtual stimuli with maximum resolution of 640 × 480 pixels at 8 to 11 frames per second. It was light (250 g) and comfortable to use. The images from the controlling computer (Pentium MMD) went through a converter (TVCoder, CREATIVE) that changes RGB signal to NTSC signals. One receiver of a FASTRAK (Polhemus) positioning sensor was mounted on the center of the helmet, and then the subjects cycled in virtual space, riding a fixed bike.

Fig. 1. Overall system configuration for the experiment.

Fig. 2. Flowchart of VR program.

The FASTRAK system was used to measure the movement of the head in a noncontact method as a position and angle of a separate object via electronic tracking. FASTRAK has two main parts: a fixed transmitter that produces a magnetic field and a remote receiver that detects a displacement of up to 350 cm with a resolution of 0.0005 cm/cm where the distance from the transmitter to the receiver was within 78 cm and where the sampling frequency was set at 35 Hz. Data were transmitted serially (RS232) to the computer. The forward orientation angle of the handle bars was also measured by using a

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Fig. 3. Variations in path deviation before and after training.

Fig. 4. Variations in path deviation velocity before and after training.

Fig. 5. Variations in head movement deviation before and after training.

illustrates the flow chart of the VR program. First of all, a road map was loaded as a trajectory and then a bicycle velocity, a handle angle and head position were measured. Road images were generated using the previous samples until the map ended. The input sequence was repeated until the map did end. The subjects were 30 healthy men and women grouped by age with ten each in their 20’s, 30’s, and 40’s. After two or three exercises to adapt to the roads, they cycled on both roads four times repeatedly. By moving the handle in the horizontal plane, the subjects were able to adjust the red spot that indicates the bike position in virtual space relative to the central line marked on the road. The task was to track central line as best as they could. Several parameters were measured during cycling such as deviation from the central line, path deviation velocity, cycling velocity and head movement. These were used to quantify the grade of postural balance control. Finally, t-tests were applied to find the significance level in differences between before and after training.

Our hypothesis was that subjects with postural instabilities would have larger deviations from the central line and handle angle could change suddenly. Path deviation velocity was used as a basis to judge a stability of cycling. Cycling velocity was used as another estimation index representing the training effect of virtual cycling.

III. RESULTS

To explain the training effect simply, the results of one male subject, who was 28 years old are presented (see Figs. 3 to 6). Figs. 3 and 4 show the path deviation and the path deviation velocity, respectively, before and after virtual cycling training. Here, the cycling before and after training means the first and last times among the four cycling trials. As expected, each value is reduced after training and could be one of the standard parameters estimating the training effect. Specially, path deviation before and after training showed significant differences at $p < 0.01$. Moreover, it took less time to complete the map after training (i.e., on the fourth attempt). Note also that when cycling on the curved road, both the deviation and the deviation velocity varied more widely. Subjects appeared to have difficulty following the red spot on the curved road, because
continuous handle control was needed. This suggests that the subjects should be initially trained on the straight road. After that training is completed well, they can be trained on the curved road.

Fig. 5 indicates the left-right movement of the head measured with the FASTRAK where a positive value representing a left movement

of the head. Although the range of the movement was small, it did decrease after training. However, result of t-test did not show significant differences between before and after training even in the level of $p < 0.05$. Protecting the bicycle from inclination when turning or swaying may have had caused such results. If the bicycle were free to incline, the head movement range would increase. Fig. 6 shows variations in cycling velocity before and after training, which revealed significant differences at $p < 0.01$. Maximum velocity was reached sooner after training, suggesting that training enabled a subject to control the handle and balance more easily, and therefore to reduce the time that took to reach a normal cycling velocity and the maximum velocity.

Fig. 7 presents each cycling time average, path deviation, cycling velocity and head movement while cycling on the virtual straight road repeatedly. Each average tended to improve as the test was repeated and each age bracket had the same tendency. However, as the age group increased, the average except cycling velocity tended to increase. Cycling on the virtual curved road (Fig. 8) showed similar results as in the case of the straight road (Fig. 7). Comparing the two figures, both the averages of path deviation and of head movement were greater on the curved road. That is, cycling on the virtual curved road proved harder in keeping balance.

IV. Discussion

Our study showed an improvement of cycling velocity and a reduction of path deviation after virtual cycling training. Thus these parameters could be used to analyze a training effect on balance rehabilitation. In such training, however, we should take a few parameters as proper estimation basis. For one example, accepting cycling velocity as the only estimation basis might fail to separate the
velocity itself from a training effect. If path deviation increases with the velocity, we assume that problems in postural balance control exist. But a complete assessment should involve other parameters such as path deviation, path deviation velocity, and head movement. With respect to head movement, there were no significant differences before and after training. Thus, for the fixed bicycle, head movement itself was not an important parameter in judging the rehabilitation effect. But as mentioned before, it might be a meaningful parameter if the bicycle were to be incline when turning a curve.

We should also consider several conditions not mentioned above in interpreting the results. For example, some path deviation could have been caused by the movement of the body itself. Also, subjects might also have varied in their perceptual ability in virtual space. The whole system might be better if the bicycle were oscillated vertically to simulate road surfaces and to simulate the skin senses. Auditory data could be provided into the virtual space. The VR program could be improved to provide more realistic situations. Finally, the weight and resolution of the HMD are other problems that should be resolved, as well as the eye fatigue that accompanies long duration HMD use.

REFERENCES


