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Proprioception rehabilitation training system for stroke patients using virtual reality technology

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***Abstract*— We investigated a virtual reality (VR) proprioceptive rehabilitation system that could manipulate the visual feedback of upper-limb during training and could do training by relying on proprioception feedback only. Virtual environments were designed in order to switch visual feedback on/off during upper-limb training. Two types of VR training tasks were designed for evaluating the effect of the proprioception focused training compared to the training with visual feedback. In order to evaluate the developed proprioception feedback virtual environment system, we recruited ten stroke patients (age: 54.7± 7.83years, on set: 3.29± 3.83 years). All patients performed three times PFVE task in order to check the improvement of proprioception function just before training session, after one week training, and after all training. In a comparison between FMS score and PFVE, the FMS score had a significant relationship with the error distance(r = -.662, n=10, p = .037) and total movement distance(r = -.726, n=10, p = .018) in PFVE. Comparing the training effect between in virtual environment with visual feedback and with proprioception, the click count, error distance and total error distance was more reduced in PFVE than VFVE. (Click count: p = 0.005, error distance: p = 0.001, total error distance: p = 0.007). It suggested that the proprioception feedback rather than visual feedback could be effective means to enhancing motor control during rehabilitation training. The developed VR system for rehabilitation has been verified in that stroke patients improved motor control after VR proprioception feedback training.**

I. Introduction

The rehabilitation training is essential to most stroke patients who have symptoms as a declined and unnatural motor control by brain damage [1]. Motor control amends the motion by interaction between visual feedbacks that cognize the external space or movement of oneself through vision and proprioception feedback that refers information about movement and position of body, which transverse from muscle spindles into Central Nervous System (CNS) [2]. In particular, stroke patients showed lower accuracy of motor control compared with healthy control in situation without visual feedback than in situation with visual feedback of movement [3]. In spite of these previous researches, conventional rehabilitation therapy have mainly focused on strength exercise with occupational therapist's support and motor control training by the external stimuli as TMS or FES [4]. However, it was reported that the training effect of stroke patients was reduced by reliance of visual feedback of movement during training because vision of patient little damaged than proprioception [5].

Proprioception are evaluated by tests which measure a subject's ability to detect an externally imposed passive movement, or the ability to reposition a joint to a predetermined position[6]. In order to improve proprioception, sensorimotor training programs have been suggested to facilitate joint position sense and dynamic joint stability using rhythmic active motion, angle repositioning and standing on an air cushion with support to stimulate muscular coactivation [7]. Despite recently shedding the light on the proprioception in rehabilitation, there are few studies related to rehabilitation system focusing on the improvement of proprioception itself.

Virtual Reality (VR) technique can provide the various virtual environments and has been used in rehabilitation therapy that provides interaction between virtual object and motion using motion tracking [8]. It is more suitable for the proprioception rehabilitation of stroke patients because the VR is able to manipulate the visual feedback of virtual object. In addition, the VR technique enable an objective assessment as well as efficient rehabilitation training because a patient confirms the motion of themselves without assistance of therapist and look at training results in near real time,.

In this study, we investigated a VR proprioceptive rehabilitation system that could manipulate the visual feedback of upper-limb during training and could do training by relying on proprioception feedback only. We also demonstrated the proprioception training effects on stroke patients using developed VR system that provides proprioception feedback.

II. Methods

A. VR system

Virtual environments were designed in order to switch visual feedback on/off during upper-limb training. The participants could not see their own arm blocked with upper board. The hand positions were tracked with magnetic 3D

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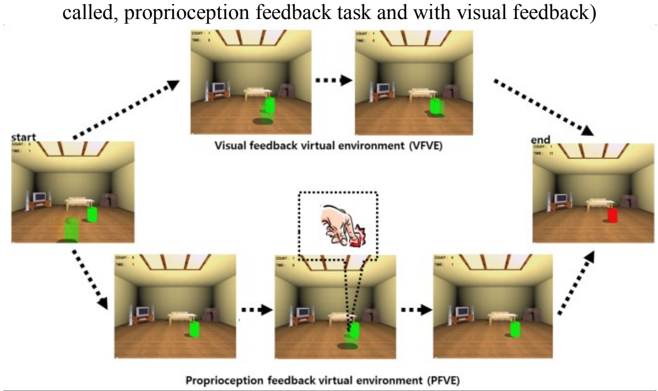
position sensor (patriot 6-DOF tracker, POLHEMUS, USA). In screen, virtual cylinder followed the position as the participants moved the hand under the board. On the other hand side, button was installed in order for participants to response to designed tasks. Virtual reality tasks were programmed with “A6” software (3dgamestudio, co., USA).

B. VR proprioception rehabilitation tasks

Two types of VR training tasks were designed for evaluating the effect of the proprioception focused training compared to the training with visual feedback. In visual feedback virtual environment (VFVE) task, at starting point, there were semi-transparent cylinder showing the present position of hand and opaque cylinder as a target position. The subjects were required to move their hand into opaque cylinder. The subjects could see the semitransparent cylinder following to their arm’s movement as a visual feedback as shown in Fig. 1. When the subjects thought that movement position was corresponding to target position, they were required to press mouse button. If the difference between hand position and target position was within predefined criterion, opaque cylinder reappeared on next target position. If fail, they tried again. The same procedure was repeated until success.

Figure 1. Two virtual rehabilitation tasks (without visual feedback, we called, proprioception feedback task and with visual feedback)



On the contrary, in proprioception feedback virtual environment (PFVE) task, although semi-transparent cylinder and opaque cylinder were shown at starting point, the initial transparent cylinder disappeared as soon as when they moved their hand their into target position. Thus, they had to estimate the target position by relying on their own proprioceptive feedback information. Just like VFVE, when the subjects thought that movement position was corresponding to target position, they pressed mouse button. If fail, semi-transparent cylinder was shown for 500 msec in order to check the current hand position. Then they tried again until success. In both environments, twenty target positions were provided. For performance analysis, total number of trials was counted during twenty target tasks, which was total number of mouse button clicks. In addition, total error distance was calculated by accumulating the distance between movement position and target position whenever the subjects pressed mouse button as a confirmation. Lastly, the movement distance was measured by summing the trajectory from start position until last movement position when succeed.

C. Subjects

In order to evaluate the developed proprioception feedback virtual environment system, we recruited ten stroke patients (age: 54.7± 7.83years, on set: 3.29± 3.83 years). The stroke patients; (1) showed no deficits in vision, auditory, with a Mini-Mental Status Examination score > 22; (2) can perform the flexion of damaged elbow > 50°; (3) showed no neglect syndrome by Albert test; (4) showed no serious depression by the Back depression inventory test; (5) had no pain and dysfunction of upper extremity by peripheral neuropathy, the rotator cuff tear of shoulder and complex regional pain syndrome; and (6) showed no cyber-sickness in virtual reality. All subjects that consented to participate in this study were informed about the experimental protocol, which were approved by the department of rehabilitation of Eulji Hospital.

D. Experiments

- In order to evaluate which parameters measured in PFVE is significantly related to proprioception, all subjects performed PFVE task. In addition, occupational therapist measured the FMS (Fugl-meyer assessment Scale) [9] for stroke patients to investigated the relationship between stroke severity and those of PFVE.

- Ten stroke patients participated in the experiment for evaluation of the effects of proprioception feedback virtual environment training. They were randomly assigned into two groups (five patients per group). One group performed VFVE five times during first week. And then, for next week, the group did PFVE training five times. The other group did vice versa. All patients performed three times PFVE task in order to check the improvement of proprioception function just before training session, after one week training, and after all training.

E. Data analysis

In this study, the pearson’s correlation has been used to compare between FMS score or error angle and parameters measured in PFVE using the SPSSWIN 18.0 software package. In addition, the paired T-test and one sample T-test have been used in order to compare the training effect between VFVE and PFVE.

III. RESULTS

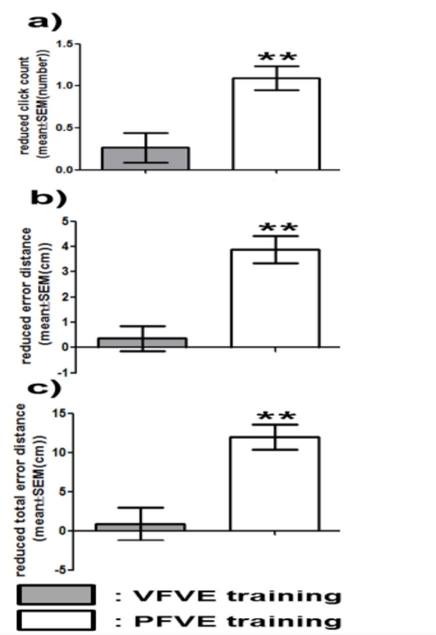
A. Characteristics of proprioception feedback virtual environment

In a comparison between FMS score and PFVE, the FMS score had a significant relationship with the error distance($r = -.662$, $n=10$, $p = .037$) and total movement distance($r = -.726$, $n=10$, $p = .018$) in PFVE. In addition, FMS score correlated with total error distance ($r = -.714$, $n=10$, $p = .002$) and click count ($r = -.659$, $n=10$, $p = .038$) except movement distance among the parameters measured in PFVE.

B. Therapeutic effect of proprioception feedback virtual environment rehabilitation

In order to evaluate the therapeutic effect of PFVE, we compared VFVE and PFVE after training stroke patients for two weeks. In pre-test, there was no statistical difference in all parameters between VFVE and PFVE. Error distance has decreased after VFVE training. Comparing the error distance in VFVE training and PFVE training, significantly more error distance was reduced in PFVE than in VFVE ($t= 4.01$, $df = 9$, $p = 0.003$). Comparing the training effect between in virtual environment with visual feedback and with proprioception, the click count, error distance and total error distance was more reduced in PFVE than VFVE. (Click count: $p = 0.005$, error distance: $p = 0.001$, total error distance: $p = 0.007$).

Figure 2. Improvement effect of upper-limb of stroke patients according to two virtual environments (*: $p < 0.05$, **: $p < 0.01$) a) comparison reduced click count between VFVE and PFVE ($p = 0.005$), b) comparison reduced error distance between VFVE and PFVE ($p = 0.001$), c) comparison reduced total movement distance between VFVE and PFVE ($p = 0.007$).



IV. Discussion

In this study, we developed new type of rehabilitation system to focus the proprioception of stroke patient using virtual reality technology. The system was designed for patients to move their arm to target position depending on their proprioception by blocking them to see their arm movement. When they reached to the target position, the patients could recognize the error between estimate position and target position by confirm their arm's current position. With repeating this procedure, stroke patients could adjust the proprioception of their arm. As far as our knowledge, there are few rehabilitation systems in this way focusing on enhancing proprioception itself. VR rehabilitation system was previously used to evaluate stroke patients in cognitive rehabilitation, motor rehabilitation. VR technology enables to control the visual feedback like blocking or presenting virtual object during rehabilitation training. It makes stroke patients, who usually use intact visual function as a feedback in the correction of their arm movement, rely on proprioception feedback during training.

The other advantage of computerized VR rehabilitation system is to get objective parameters for evaluating the behavioral characteristic during training. Five parameters were extracted in our virtual rehabilitation environment such as click count, error distance, movement distance, total error distance, and total movement distance. First, error distance among those significantly correlated with FMS score, which was correspond to the previous report [3]. Second, total movement distance among those significantly correlated with FMS score. Stroke patients moved their arm to the target in a longer way at a first trial as shown in movement distance parameter in PFVE. Total movement distance was accumulated through all trials to target position. That seemed to explain why it could be sensitive to the functionality of upper limb and could be used index parameter to evaluate proprioception of stroke patients.

In our analysis, the significant decrease of error distance and the total error distance were shown after PFVE rehabilitation training. It suggested that the proprioception feedback rather than visual feedback could be effective means to enhancing motor control during rehabilitation training [10]. However, the careful consideration should be needed for these interpretation because the PFVE used as same as evaluation tool after training session. There was a possibility that subjects could be accustomed to the PFVE and knew how to adjust their arm to target with visual feedback to get a good score. Nevertheless, their endeavors to try to get to target without visual feedback could lead to a therapeutic effect.

Despite of our experiment to show the therapeutic effect of PFVE, in order to confirm the therapeutic effect of PFVE, further study such as the comparison with conventional therapeutic method should be needed in the future.

V. Conclusion

VR technique can provide proprioception feedback in rehabilitation training of stroke patients in real-time. The developed VR system for rehabilitation has been verified in that stroke patients improved motor control after VR proprioception feedback training.

References

[1] A. Doğan, B. Mulgrew, and P. M. Grant, "The rehabilitation results of hemiplegic patients," *Turkish Journal of Medical Sciences*, vol. 34, pp. 385–389, 2004.

[2] S. J. Sober and P. N. Sabes, "Multisensory integration during motor planning," *Journal of neuroscience*, vol. 23, pp. 6982–6989, 2003.

[3] N. Leibowitz et al., "Automated measurement of proprioception following stroke," *Disability and Rehabilitation*, vol. 30, pp. 1829–1836, 2008.

[4] J. Kim and C. M. Sapienza, "Implications of expiratory muscle strength training for rehabilitation of the elderly: Tutorial," *Journal of rehabilitation Research & Development*, vol. 42, pp. 211–224, 2005.

[5] I.V. Bonan et al., "Reliance on visual information after stroke. Part I: Balance on dynamic posturography," *Archives of physical Medicine Rehabilitation*, vol. 85, pp. 268–273, 2004.

[6] L. M. Carey, L. E. Oke and T. A. Matyas, "Impaired limb position sense after stroke: a quantitative test for clinical use," *Archives of physical Medicine Rehabilitation*, vol. 77, pp. 1271–1278, 1996

[7] T.E. Hewett, M.V. Paterno, and G.D. Myer, "Strategies for enhancing proprioception and neuromuscular control of the knee," *Clinical Orthopaedics and Related Research*, vol. 402, pp. 76–94, 2002.

[8] D. Reid, "Virtual reality and the person-environment experience," *Cyberpsychology and Behavior*, vol. 5, pp. 559–564, 2002.

[9] A.R. Fugl-Meyer et al., "The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance," *Scandinavian Journal of Rehabilitation Medicine*, vol. 7, pp. 13–31, 1975.

[10] L.B. Bagesteiro, F.R. Sarlegna, and R.L. Sainburg, "Differential influence of vision and proprioception on control of movement distance," *Experimental Brain Research*, vol. 171, pp. 358–370, 2006.