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Development of virtual reality proprioceptive rehabilitation system for stroke patients

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ABSTRACT

In this study, the virtual reality (VR) proprioception rehabilitation system was developed for stroke patients to use proprioception feedback in upper limb rehabilitation by blocking visual feedback. To evaluate its therapeutic effect, 10 stroke patients (onset > 3 month) trained proprioception feedback rehabilitation for one week and visual feedback rehabilitation for another week in random order. Proprioception functions were checked before, a week after, and at the end of training. The results show the click count, error distance and total error distance among proprioception evaluation factors were significantly reduced after proprioception feedback training compared to visual feedback training (respectively, $p = 0.005$, $p = 0.001$, and $p = 0.007$). In addition, subjects were significantly improved in conventional behavioral tests after training. In conclusion, we showed the effectiveness and possible use of the VR to recover the proprioception of stroke patients.

1. Introduction

Rehabilitation training is essential for most stroke patients who have symptoms such as declined or abnormal motor control due to brain damage [1]. Generally, the elements needed for normal physical activities are motor control modulating movement in real time as well as strength. Motor control amends the motion by interaction between visual feedback that recognizes 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 [2–4]. Stroke patients have difficulty in conducting exact motor control due to declined strength as well as ability to utilize feedback [5]. In particular, stroke patients showed lower accuracy of motor control compared to healthy individuals in situations without visual feedback of movement rather than with visual feedback [6,7]. In spite of these previous studies conventional rehabilitation therapy have mainly focused on strength exercise with occupational therapists support and motor control training using external stimuli with robotic or functional electrical stimulation [8,9]. Moreover, it was reported that the training effect of stroke patients could be reduced by reliance of visual feedback of their movement during training because

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the vision of patient were intact rather than proprioception [10,11].

Proprioception is 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 [5]. 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 co-activation [12,13]. Despite recently shedding a light on the proprioception in rehabilitation, there are few studies related to rehabilitation systems focusing on the improvement of proprioception itself [14,15].

The virtual reality (VR) technique can provide various virtual environments and has been used in rehabilitation therapy that provides interaction between virtual objects and motion using motion tracking [16–22]. This technique would be more suitable for the proprioception rehabilitation because of its ability to manipulate the visual feedback of virtual objects [23]. In addition, the VR technique allows an objective assessment as well as efficient rehabilitation training because a patient can confirm his own movement without the assistance of a therapist and also view the training results in near real time.

In this study, we developed a VR proprioceptive rehabilitation system that could manipulate the visual feedback during upper-limb training and ask the subject to rely only on proprioception feedback. We also demonstrated the effect of proprioception training on stroke patients using a developed VR system that provides proprioception feedback.

2. Methods and materials

2.1. Subjects

In order to evaluate the developed proprioception feedback virtual environment system, we recruited 10 stroke patients (age: 54.7 ± 7.83 years, onset: 3.29 ± 3.83 years) as shown in Table 1 and 10 healthy age-matched subjects (age: 56.4 ± 4.53 years). The stroke patients; (1) who had suffered a primary ischemic or hemorrhagic stroke as diagnosed by magnetic resonance imaging image scans or computed tomography; (2) presented mild to severe paresis of the upper extremity and lacked any additional neurological disease causing motor deficits; (3) can perform the active flexion of affected elbow more than 50°; (4) who was in more than 10 weeks from stroke onset because most motor recovery is almost completed within 10 weeks poststroke [24,25]; (5) showed no deficits in visual field by visual field examination; (6) showed no severe defects in cognitive function with a Mini-Mental Status Examination score [26] >24; (7) showed no neglect by Albert test [27] or apraxia [28]; (8) showed no serious depression by the Beck Depression Inventory test [29]; (9) had no pain and dysfunction of upper extremity by peripheral neuropathy, a rotator cuff tear of shoulder and complex regional pain syndrome; and (10) A summary of demographic variables and clinical measure for the stroke group is included in Table 1. Most patients had low BDI scores (9–28). All subjects that consented to participate in this study were informed about the experimental protocol,

Table 1 – Demographics and clinical results of stroke patients.

	Sex	Age	Area of Lesion	Infarction/ hemorrhage	Time After Stroke (month)	MMSE score	FMS score	Proprioception function test error angle (degree)	Box and Block test		Jebsen-Taylor hand function test-writing subtest (sec) in pre-test	
									Affected hand	Unaffected hand	Affected hand	Unaffected hand
P1	M	50	Lt. BG (subcortical)	Hemorrhage	6.3	29	49	5.41	30	53	45.47	44.66
P2	M	62	Rt. CR (subcortical)	Infarction	74.1	25	55	7.32	27	40	54.28	11.50
P3	F	58	Lt. pons	Infarction	5.2	28	47	8.91	42	50	85.16	94.18
P4	M	63	Lt. pons	Infarction	9.0	27	40	8.01	17	43	142.10	76.50
P5	M	40	Lt. CR (subcortical)	Infarction	3.3	29	62	4.82	33	45	52.38	17.34
P6	M	58	Lt. MCA (subcortical)	Infarction	24.0	25	19	7.32	4	46	–	41.93
P7	M	46	Lt. BG (subcortical)	Hemorrhage	65.1	25	18	17.23	6	45	–	50.19
P8	F	64	Lt. CR (subcortical)	Infarction	53.2	26	55	8.77	27	38	40.12	42.10
P9	F	53	Lt. CR (subcortical)	Infarction	146.3	30	51	5.79	26	51	72	28
p10	M	52	Lt. BG (subcortical)	Hemorrhage	8.1	29	66	11.62	30	51	29.85	22.97

Rt, right; Lt, left; MCA, middle cerebral artery; BG, Basal ganglia; CR, corona radiate; FMS, affected upper limb score of Fugl-Meyer Assessment (out of 66); MMSE, Mini-Mental State Examination (out of 30).