Effects of Promoting Stereognosis and Two-Point Discrimination on Upper Limb Function and Performance of Activities of Daily Living of Stroke Patients with Accompanying Unilateral Neglect and Sensorimotor Deficits

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Purpose This study investigated the correlation among the manual function test (MFT), Korean version of the modified Barthel index (K-MBI), two-point discrimination (TPD), and stereognosis (ST) through tactile feedback training of the hands and upper limbs. ***Methods*** Patients with motor impairment were recruited and divided into two groups as part of a longitudinal study of effects on hand function and activities of daily living during two-point discrimination and stereognosis recovery. Inclusion criteria were unilateral neglect, combined sensory deficits and motor weakness. Patients participated in 4 weeks of physical therapy and occupational therapy involving tactile feedback training for the upper limbs using sensory information. ***Results*** In the unilateral neglect group, functioning statistically improved for TPD, ST, MFT, and K-MBI. In the sensorimotor deficit group, functioning statistically improved for MFT, and K-MBI. TPD and MFT results significantly improved between the groups. The relationship between MFT, ST, and TPD was negative. ***Conclusion*** tactile feedback training for stroke patients with accompanying unilateral neglect or somatosensory impairment may be used clinically as an important way to promote upper limb function and performance of activities of daily living. In addition, stereognosis and two-point discrimination may be used as important sensory indices for functional task performance.

Key Words Stroke, Tactile feedback training, Upper limb function, Activities of daily living, Unilateral neglect

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Ⅰ. Introduction

The upper limbs(U/L), including the hands, are very important body parts for the performance of meaningful activities and contribute to various human functions. They allow appropriate movement for task performance through varying and efficient degrees of joint freedom. Furthermore, the hands and UL perform the functions of reaching forward and manipulating objects and the upper limbs assist in physical control by maintaining posture for easier movement of the center of gravity.[1, 2] The hands contain more somatosensory receptors than other body parts and thus have excellent sensory function; they sense and perceive information from objects they contact through somatosensory input from the skin, muscles, and joint receptors.[3] This means they play an important role in allowing sensations from the characteristics of objects they contact and in helping to recognize and process information unlike any other body parts. These characteristics are not dependent on visual information. UL and hands can be used for task performance by correctly sensing the size, material, weight, and temperature of the objects they contact. This ability to assess the shape and characteristics of objects through tactile sensation alone without visual assistance is called stereognosis (ST).[4] Sensory impairment to the hands and UL from various causes can negatively affect UL motor function, activities of daily living (ADL), and job performance.[5] Stroke can cause various symptoms such as impairment of the senses, motor skills, cognition, perception, and language function and can cause changes in levels of consciousness.[6] Impairments of proprioception and tactile sensation are present in

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50% of stroke patients with accompanying dual sensory impairment. Stroke patients with accompanying sensory and motor impairments have worse prognoses for recovery than patients with only accompanying motor impairment.[7] Moreover, impairments of the somatic senses and ST in stroke patients decrease manipulation ability, make it difficult to control hand strength when grasping objects, and negatively affect posture control due to the reduced postural body scheme, resulting in difficulties in activities of daily living.[8] The purpose of this study was to discover what differences occur in UL function and ADL performance of hemiplegic patients with accompanying unilateral neglect and somatosensory deficits due to stroke by promoting ST and two-point discrimination (TPD) through tactile training. Tactile training was implemented for 4 weeks and changes in TPD and ST were measured. Touch sense is normally classified into its most basic elements to test physical awareness. It is also used as an index to test recovery prognosis after surgery of the UL or hands and treatment effects through rehabilitation of cerebral or spinal impairment. Results of TPD testing for cerebral palsy patients with quadriplegia or paraplegia showed lower than normal sensory ability for 50–72% of patients; sensory abnormalities were observed in 50% of all patients with epilepsy due to parietal lobe tumors in TPD testing of the fingers.[9, 10] TPD has also been reduced in cases of central nervous system impairment due to traumatic brain damage.[11, 12] Methods of testing the sense of touch include static touch perception, discernment of brush movement direction, and TPD. TPD, with its clinically proven dual reliability, is used to predict recovery of UL function.[13, 14] ST is an important sensory index for perception of the characteristics of objects that are touched and appropriate task performance based on this; similar to TPD, it is used as criteria to predict recovery of UL function.[15] This study aimed to discover the relationship between ST and TPD for hemiplegic patients with accompanying unilateral neglect and sensorimotor deficits due to stroke and changes in UL function and performance of ADL. The study also aimed to discover correlations between TPD, ST, UL function, and performance of ADL.

II. Materials and Methods

Out of 25 subjects, including 13 hemiplegic patients with accompanying unilateral neglect and 12 with accompanying sensory impairment, 3 patients with accompanying unilateral neglect and 2 with accompanying sensory impairment were excluded from secondary selection due to hospital discharge. The final 20 gave autonomous consent to participate after an explanation of the study's purpose, contents, and methods. The study was conducted with the approval of the Institutional Review Board at Kangwon National University (approval number KWNUIRB–2015-03-006-002) and in accordance with the ethical standards of the Declaration of Helsinki (1975, revised in 1983). Criteria for subject selection were as follows: diagnosis of concurrent hemiplegia and unilateral neglect or hemiplegia and sensory deficits after stroke by neurological or rehabilitative medicine experts and disease that had not recurred 3–12 months after first occurrence; younger than age 60 years and could sit or walk independently; no other diseases such as visual impairment and a score of at least 21 out of 26 points on the Korean version of the Mini Mental State Examination (K-MMSE); and able to precisely articulate the researcher's tactile feedback. After subject selection, subjects diagnosed with concurrent hemiplegia and unilateral neglect were tested using the Albert test and star cancellation test, which are separate unilateral neglect selection tests, to distinguish the degree of motor impairment and unilateral neglect. Subjects with left unilateral neglect were classified as the unilateral neglect group (UNG), whereas hemiplegic subjects with accompanying sensory impairment were classified as the sensorimotor deficit group (SMDG) based on the number of stars they crossed out on the left and the number they crossed out overall during the star cancellation test. Both groups underwent physical and occupational therapy 5 times per week for 4 weeks. They also separately underwent tactile feedback and ST training for 40 minutes 3 times per week for 4 weeks. Tactile feedback training was created by referencing the proposals of Smania et al. (2003)[16] and Song (2013)[17] Subjects sat upright, lifted their affected forearms onto the treatment table, and then lengthened their extrinsic muscles to place their fingers on the floor. Therapeutic tools were used within a range that did not cause pain to implement training with tactile stimulation and tactile discrimination. Patients were permitted to see during weeks 1 and 2 of the tactile feedback training, when tactile feedback using touch and vision was implemented. Tactile feedback training was repeated after obstructing the vision of the patients to promote contact sensation feedback through stimulation during weeks 2 and 3. During week 4, patients were made to recognize the act of holding through active assistive activities during which patients reached out their hands to hold wooden blocks and objects of various shapes and sizes. This promoted ST through tactile feedback training while holding various objects. TPD test, ST test, manual function test (MFT), and the Korean version of the modified Barthel index (K-MBI) were used for evaluation to discover the differences and correlations between TPD, ST, UL function, and performance of ADL. Descriptive analysis was used to analyze data to discover the averages and standard deviations of subject characteristics and tests implemented for each group. The Wilcoxon signed-rank nonparametric test was performed to compare TPD, ST, UL function, and performance of ADL between the two groups. The Mann-Whitney test was conducted to discover differences in TPD, ST, UL function, and performance of ADL between the two groups. Spearman's correlation coefficient was used to discover correlations between these same four items. SPSS 12.0 was used for analysis and all data were tested with a significance level of 0.05.

Ⅲ. RESULTS

Among the 20 subjects participating in this study with changes in TPD and ST after 4 weeks of training, 7 were male and 13 were female. Ten were hemiplegic with accompanying unilateral neglect and 10 were hemiplegic with accompanying sensory and motor impairment. The average age of subjects was 49.35 years, with an average height of 163.4 cm, average weight of 60.95 kg, and average disease duration of 10.3 months. Eight patients had right hemiplegia and 18 had left hemiplegia. Ten experienced cerebral infarction and 10 experienced cerebral hemorrhage. Among the UNG, three subjects were male and seven were female. The average age of this group was 56.20 years, average height was 162.5cm, average weight was 60.71kg, and averaged is ease duration was 10.6 months. All 10 patients had left hemiplegia; of these patients, five had cerebral infarctions and five had cerebral hemorrhages. Among the SMDG, four subjects were male and six were female. The average age was 45.0 years, average height was 164.2cm, average weight was 61.19kg, and average disease duration was 10 months. Five subjects had left hemiplegia and five had right hemiplegia. Five patients experienced cerebral infarctions and five experienced cerebral hemorrhages (Table 1). As shown in Table 2, there were significant differences in the forearm ($p<0.01$) during TPD, with forearm scores changing from 17.60±3.13mm to 15.50±3.57mm, thenar eminence scores changing from 15.30±3.43mm to 14.80±4.02mm, hypothenar eminence scores changing from 14.40±3.24mm to 13.10±3.00mm, thumb tip scores changing from 13.70±3.43mm to 12.50±3.06mm, and index finger tip scores changing from 12.50±3.34mm to 11.70±3.27mm. Statistically significant differences also appeared during TPD of the SMDG, with forearm scores ($p<0.00$) changing from 16.80±3.97mm to 13.00±4.64mm, thenar eminence scores ($p<0.01$) changing from 13.40±5.21mm to 11.00±3.80mm, hypothenar eminence scores ($p<0.00$) changing from 13.00±4.64mm to 10.50±3.50mm, thumb tip scores ($p<0.01$) changing from 9.90±4.15mm to 7.90±3.51mm, and index finger tip ($p<0.01$) scores changing from 8.70±3.34mm to 7.90±3.51mm. ST scores of the UNG increased from 2.90±5.93 to 3.70±6.31, which was a statistically significant difference ($p<0.01$), and the scores of the SMDG increased from 5.50±5.60 to 8.40±6.59, which was also a statistically significant difference ($p<0.01$). Furthermore, the

Table 1. General subject characteristics

Characteristics		UNG (n=10)	SMDG (n=10)
Age (year)		56.20±09.53	45.00±17.83
Height (cm)		162.50±08.08	164.20±06.32
Weight (kg)		60.71±05.65	61.19±06.62
Duration (month)		10.60±02.12	10.00±02.70
Type	Infarction	5	5
	Hemorrhage	5	5
Paretic side	Right	0	5
	Left	10	5
Gender	Male	3	4
	Female	7	6

Mean±SD: mean and standard deviation. UNG: unilateral neglect group; SMDG: sensorimotor deficit group.

Table 2. Comparison of the TPDT, ST, MFT, and K-MBI within the groups

Variable			Before test	After test	Z
			Mean±SD	Mean±SD	
UNG	TPDT (mm)	F†	17.60±3.13	15.50±03.57	-2.54
		T	15.30±3.43	14.80±04.02	-1.41
		HT	14.40±3.24	13.10±03.00	-1.90
		TH-T	13.70±3.43	12.50±03.06	-1.29
		IN-T	12.50±3.34	11.70±03.27	-1.10
	ST† (point)		02.90±5.93	03.70±06.31	-2.27
	MFT (point)		08.90±8.20	11.20±09.37	-2.72
	K-MBI† (point)		61.10±7.82	72.80±11.19	-2.86
SMDG	TPDT (mm)	F‡	16.80±3.97	13.00±4.64	-2.81
		T†	13.40±5.21	11.00±3.80	-2.65
		HT‡	13.00±4.32	10.50±3.50	-2.87
		TH-T†	09.90±4.15	07.90±3.51	-2.75
		IN-T†	08.70±3.34	06.80±6.59	-2.57
	ST† (point)		05.50±5.60	08.40±6.59	-2.68
	MFT† (point)		10.00±7.18	11.70±7.13	-2.56
	K-MBI† (point)		62.60±9.77	74.30±8.03	-2.82

Mean ± SD: mean and standard deviation.
‡p<.00. †p<.01. UNG: unilateral neglect group, SMDG: sensorimotor deficit group, TPDT: two-point discrimination test, ST: stereognosis test., MFT: manual function test, K-MBI: korean version modified barthel index, F: forearm, T: thenar, HT: hypothenar, TH-T: thumb tip, IN-T: index finger tip

MFT score of the UNG increased from 8.90±8.20 to 11.20±9.37 and the performance of activities of daily living K-MBI score increased from 61.10±7.82 to 72.80±11.19; these were also statistically significant differences (p<0.01). The MFT score of the SMDG increased from 10.00±7.18 to 11.70±7.13 and the K-MBI score increased from 62.60±9.77 to 74.30±8.03; both of these were statistically significant differences (p<0.01) (Tables 2). When comparing differences in TPDT, ST, MFT (upper limb function), and K-MBI (performance

Table 3. Comparison of TPDT, ST, MFT, and KMBI between the two group

Variable		UNG	SMDG	z
TPDT	F	-2.10±1.85	-3.80±2.78	-1.50
	T†	-0.50±1.08	-2.40±2.17	-2.52
	HT	-1.30±1.95	-2.50±2.01	-1.65
	TH-T	-1.20±2.57	-2.00±2.36	-1.26
	IN-T	-0.80±1.87	-1.90±2.60	-1.40
ST*		00.80±0.79	02.90±2.92	-2.19
MFT		02.30±2.91	01.70±1.25	-0.20
K-MBI		11.07±6.07	11.70±4.81	-0.23

Mean ± SD: mean and standard deviation.
†p<.01 *p<.05. UNG: unilateral neglect group, SMDG: sensorimotor deficit group, TPDT: two-point discrimination test, ST: stereognosis test., MFT: manual function test, K-MBI: korean version modified barthel index, F: forearm T: thenar HT: hypothenar TH-T: thumb tip, IN-T: index finger tip

of activities of daily living) between the two groups, there were statistically significant differences in thenar eminence of TPD (p<0.01) and ST (p<0.05), before and after tactile feedback training, as shown in Table 3. However, there were no statistically significant differences in MFT or K-MBI (p>0.05). Finally, analysis of correlations between TPD, ST, MFT, and K-MBI of the two groups showed that MFT and ST were negatively correlated with TPDT (Table 3).

Ⅳ. DISCUSSION

The purpose of this study was to investigate how TPD and ST promoted through tactile feedback training improved UL function and performance of ADL in hemiplegic patients with accompanying unilateral neglect, sensory deficits, and/or muscle deterioration after stroke. Stroke patients were divided into two groups according to their impairment: the UNG and SMDG. Physical therapy and occupational therapy were administered 5 times per week for 4 weeks, along with separate tactile feedback training 3 times per week for 4 weeks. Disease duration was used as the main variable for somatosensory recovery after stroke. It has been reported that TPD and ST can be increased through systematic tactile feedback training even in chronic stroke patients more than 6 after onset.[15-17, 19] Therefore, positive changes in TPD and ST were found even in chronic stroke patients after systematic sensory training for 4 weeks. Patient age, area of impairment, recovery period after disease onset, and systematic sensory training appropriate for patient characteristics can be considered important elements in somatosensory recovery after stroke. This study also aimed to determine the effects of TPD and ST training after the use of tactile feedback training for UL function and performance of ADL of hemiplegic patients with accompanying unilateral neglect or sensory deficits after stroke. Tactile feedback training was found to improve UL function and performance of ADL in both groups. The hand functions of reaching and grasping are primarily processed through visual information for characteristics such as location of an object in space. At these times, somatosensory information from the hands sends precise information, such as the location of the object in space, to the central nervous system to allow UL to move accurately.[4] Vision, the hand's awareness of contact, TPD, and ST can be considered essential elements in correcting and accurately assessing the spatial location of an object and conditions for performing tasks.[20] Furthermore, the lateral corticospinal descending pathway, a descending motor nerve involved in hand action, is responsible for 31% of primary motor areas, 29% of premotor and supplementary motor areas, and

40% of the parietal lobe and primary sensory areas; this motor processing is important for explaining correlations between UL motor and sensory function.[21)] Impairment of the central nervous system attributable to stroke is accompanied by visual perception and somatosensory impairment, thereby creating difficulty in recognizing the location and movement of each part of the body and reducing somatosensory input and feedback to increase visual compensation. This means the patient uses the unaffected UL to perform ADL, thus impeding efficient, independent use through learned nonuse.[22)] Therefore, visual information is adjusted and damaged UL used for task performance in regard to increasing somatosensory information feedback, performing tactile feedback training, and increasing the use of inefficient and dependent activities. It is important to repair damaged sensations to avoid learned nonuse; therefore, TPD, ST, and similar high-level sensory awareness are promoted. The TPD and ST promoted after tactile feedback training for this experiment can be considered important factors for improving UL function and performance of ADL. The affected UL and hand functions of hemiplegic patients after stroke greatly affect the performance of ADL. UL and hands are the body parts that contribute most to task performance in daily life, decreased posture maintenance and UL function due to muscular deterioration and decreased sensation cause difficulties in living independently.[23)] Improved sensation and UL function were found to help in the performance of ADL in this study. There are limits to independent activity, but improved sensation and restoration of UL function must be the focus of approaches to improve the daily lives of stroke patients after disease onset. In this study, subjects were classified into the UNG or SMDG depending on their impairment after stroke and their TPD, ST, UL function, and performance of ADL. This was performed to investigate changes in the sensory function and differences in UL function and performance of ADL for hemiplegic patients with impairments such as unilateral neglect and sensory deficits after stroke. Results of tactile feedback training confirmed differences between treatment groups during thumb TPD and ST; however, no particular differences in UL function or performance of ADL were found. Meaningful spatial stimulation was proposed on the damaged side of patients with unilateral neglect after stroke, usually with cognitive impairment, because normally there are symptoms of difficulty with sense, response, and spatial awareness; these problems negatively affect the prognoses for functional activities[24)]. Unilateral neglect most commonly appears in the right posterior parietal lobe but can also appear in the right frontal lobe, thalamus, and basal ganglia.[25)] ST means the ability to discern the shape and characteristics of objects through touch alone without visual assistance and is handled by the cerebral cortex association areas, which detect, transmit, and integrate sensory information from the skin receptors; this is closely related to parietal lobe function.[4)] The inferior parietal lobe was confirmed to be greatly activated during TPD, more so than during one-point stimulation, in studies of parietal lobe activation using TPD and functional magnetic resonance imaging (fMRI) studies of the changing brain activation with one-point and two-point stimulation using electric pads transmitting electric signals to the forearm at 4-cm intervals. This suggests that there is a greater response to two-point than to one-point stimulation in the upper sensory area.[26)] Significant differences in TPD and ST through upper sensory area response were found in the SMDG compared to the UNG in this study as well. This can be considered a result of clinical symptoms due to sensory and spatial recognition deficits in damaged areas, mainly the parietal lobe, of patients in the UNG. These results show that methods to promote sensation according to impairment must be created for stroke patients and that not only sensory stimulation training but also treatment with more systematic processes to detect and integrate these methods must be created for stroke patients with accompanying visual and cognitive impairment. Putting on clothes and other ADL are, in fact, complex tasks involving physical, cognitive, and perceptual elements. To improve the performance of these tasks, acquisition of assistive technology, systematic repetition of planned training for ADL, recovery, and determination of the presence or absence of perceptual and cognitive impairments are needed. To independently and effectively perform ADL, sensory and motor functions, perceptual and cognitive functions, and systematic motor learning are necessary.[27)] Therefore, systematic training processes are needed to promote TPD, ST, and other sensory functions as well as the cognitive function required to perform these tasks well and to restore various patterns in the upper limbs. Studies of correlations between TPD, ST, MFT, and K-MBI before and after training have found negative correlations between MFT, ST, K-MBI, and TPD. These results suggest that TPD after tactile feedback training for hemiplegic patients after stroke may be used to promote ST, UL function, and performance of ADL required for complicated tasks. Therefore, tactile feedback training for stroke patients with accompanying unilateral neglect or somatosensory impairment may be used clinically as an important way to promote UL function and performance of ADL. In addition, ST and TPD may be used as important sensory indices for functional task performance. Limitations of this study included difficulty controlling the environment outside of tactile feedback times and the low number of subjects, thus making it difficult to generalize the findings to all stroke patients.

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