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Effect of a Combined Functional Electrical Stimulation with Action Observation Training on the Upper Limb Global Synkinesis and Function of Patients with Stroke

Background: Multifaceted approaches will be needed, such as global synkinesis (GS) achieve functional improvements in the arms of stroke patients from involuntary movements during exercise.
Objective: To identify changes in arm GS and muscle activity, functional evaluation and the correlation with variables through action observation training, combined with functional electrical stimulation (FES), thereby verifying the effect on stroke patients.
Design: A quasi-experimental study.
Methods: The subjects of this study were 20 stroke patients who were divided into two groups: Control group (n=10) and experimental group (n=10). Before the intervention, arm GS and muscle activity were measured using surface electromyography (EMG), and arm function was evaluated using the Fugl-Meyer Assessment (FMA) scale. At the end of the intervention, which lasted 4-wk, arm GS and muscle activity were measured again using the same scale.
Results: There was a decrease statistically significant difference in GS during the bending action in experimental group ($P<.01$). Both groups showed a significant difference increased only in the activity of the anterior deltoid (AD) and biceps brachii (BB) ($P<.05$). The results of the arm functional assessment revealed a significant difference increase in both groups ($P<.05$). In the between-group comparison, there was a significant difference decrease in GS during the bending action ($P<.05$). Only the muscle activity of the AD and BB were significantly increase different ($P<.05$). There was a significant between-group difference increase in the arm functional assessment ($P<.05$). There was a positive correlation between GS and muscle activity on the FMA in the control group ($r=.678$, $P<.05$). In experimental group, GS during the bending arm action exhibited a negative correlation ($r=-.749$, $P<.05$), and the muscle activity of the AD and BB showed a positive correlation ($r=.701$, $P<.05$). Furthermore, in experimental group, the activity of the extensor carpi radialis increased, and the activity of the flexor carpi radialis decreased, which exhibited a negative correlation ($r=-.708$, $P<.05$).
Conclusion: These results suggest that brain plasticity could be more efficiently stimulated by combining surface stimulation in the affected arm of stroke patients.

Keywords: *Stroke; Upper limb; Functional electrical stimulation; Action observation training; Global synkinesis*

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INTRODUCTION

A stroke is a disease in which the oxygen and nutrients supplied to the brain are blocked, with the result that brain tissues are damaged, leading to physical disabilities and even death in severe cases.[1] Functional disabilities due to stroke include paralysis, coordination disabilities, and abnormal muscle tone, which hinder the body's functional movements and reduce the motor ability of the paralyzed arm, causing difficulties in daily living activities.[2] Therefore, improving arm function is very important for the return to daily life. In this regard, exercise is thought to aid recovery.[3,4] However, there are limitations in providing intensive care to all stroke patients because arm exercise therapy involves difficulties in one-on-one manual interactions with the therapist.[5] Therefore, interest in cognitive movements based on the principle of brain plasticity has been increasing recently.[6] Action observation training is a training method in which observed behaviors are imitated to execute exercise based on mirror neurons that are fired when observing the movements performed by oneself or others. Action observation training facilitates the treatment of motor deficits because not only diverse senses, such as visual, auditory, and proprioceptive, are used in this method but also neural networks that are already learned.[7,8] Functional electrical stimulation (FES) therapy promotes neurological recovery by repetitive muscle contraction, so that motor skills are learned, thereby activating brain plasticity.[9] Global synkinesis (GS), which refers to symmetrical involuntary movements in the same muscle of the arm on the opposite side when excessive voluntary movements of one arm occur, is common among patients with central nervous system disorders.[10] As GS affects the muscle tone of stroke patients, improvements in GS can be used to determine whether motor functions have been re-learned and functional impairments have improved.[11,12] Many studies have focused on ways to achieve functional recovery in stroke patients and improve muscle weakness and abnormal movements of the paralyzed arm in stroke patients. However, major recovery cannot be expected, as opportunities for sensory inputs into the paralyzed arm are rare because stroke patients utilize the non-paretic side more frequently than the paretic side in daily life. Some studies on muscle activity and functional changes in stroke patients have employed a combination of action observation training and FES as methods to stimulate the mirror neuron system by inducing active movements. Studies on changes in latent motor sensations, such as GS, are necessary. The aim of this study was to compare changes in arm GS, muscle activity, and functional assessment following a combination of action observation training and FES to figure out the resultant correlations between dependent variables, thereby providing data that can be clinically used for the recovery of arm functions in stroke patients.

SUBJECTS AND METHODS

Subjects

This study was approved by the institutional bioethics committee (SH-IRB 2018-12). The study comprised 20 stroke patients who had been admitted to and treated in J Hospital in Jeollanam-do for 8 month from November 2018 to June 2019. A group of 10 subjects who simultaneously mediated functional electrical stimulation and motion training was control group, ten groups who simultaneously intervened functional electrical stimulation and action observation training were randomly assigned to the experimental group. The patients were advised about the purpose of this study, and all the patients agreed to participate in this study. The criteria for selection of the subjects were patients with hemiplegia who had been diagnosed with a stroke at least 6 month earlier but not more than 2 year earlier and showed no particular limitation in a test of the range of passive motion of the joint of the paralyzed arm. Additional inclusion criteria were no other neurological or orthopedic diseases, no hearing problems, and no hemi-neglect in a motor-free visual perception test. In addition, all the patients included had arm recovery Brunnstrom stage 3-4 and hand recovery Brunnstrom stage 3-4. The general characteristics of the subjects are shown in Table 1.

Outcome Measures

Two channels of a surface electromyography MP 100 system (Biopac, USA) were used. The sampling rate for signal collection was set to 1,000 kHz, and the frequency band filter was set to 30-450 kHz. The recording electrodes were attached to the centers of the biceps muscle and the triceps muscle of the paralyzed arm, and the ground electrode was attached to a nearby area that would not interfere with movements. Each subject sat on a chair with a back and armrests, placed his/her legs in contact with the ground, maintained his/her non-paralyzed arm at a

Table 1. General characteristic.

Items	Control (n=10)	Experimental (n=10)	P
	M ± SD	M ± SD	
Gender (male/female)	5/5	6/4	
Age (years)	71 ± 9.7	73.3 ± 9.44	.835
Height (㎝)	163.48 ± 12.03	163.91 ± 11.74	.093
Weight (㎏)	72.31 ± 9.37	76.43 ± 7.99	.355
BMI (㎏/㎡)	27.68 ± 4.56	28.7 ± 4.6	.071
MMSE–K (point)	27.2 ± 2.53	26.2 ± 2.28	.084
Paretic side (right/left)	8/2	9/1	
Etiology (infraction/hemorrhage)	6/4	7/3	

BMI: Body Mass Index, MMSE–K: Mini Mental State Examination–Korea version

0° angle with the shoulder joint and a 90° angle with the elbow joints, while keeping the forearm in supination. The subject wore an aid on the trunk to restrict movements in order to prevent compensation. The subject performed movements of the non–paretic arm in the directions of elbow joint flexion and extension, applying maximum contraction for 3 sec. While the subject was performing the foregoing three times repeatedly, the excited signals were collected from the paralyzed arm. While maintaining a comfortable sitting position, the signals from the reference point of the paralyzed arm were collected three times, with a total of 3 sec each time.[10]

The Fugl-Meyer Assessment (FMA) scale was used to assess the degree of functional recovery of the stroke patients. In this study, the Upper Extremity Fugl–Meyer Assessment (UE–FMA), a commonly used arm functional disability assessment scale, was applied. The scale includes 33 items on arm movements proximal and distant to the body. The reliability, validity, and sensitivity of the UE–FMA have been proven in many studies that assessed the arm functions of stroke patients.

Interventions

Functional Electrical Stimulation

The FES treatment was applied using a four–channel stimulator, with a frequency of 35 Hz and output of 10-20 mA. The electrodes were attached to the anterior deltoid (AD) muscle, triceps muscle of the arm, flexor carpi ulnaris muscle, and extensor carpi radialis brevis muscle. The therapist selectively adjusted the strength and alternating output of the electrodes during the functional arm movements necessary during the various interventions and 30 min for the intervention.[13,14]

Movement Training

In control group, the patients observed a white screen at a height parallel to their eyes, without viewing any video. For the movement training session, they sat in a comfortable sitting position on a chair with a backrest in front of a desk. They then executed three different exercises, performing each exercise for 5 min (15 min in total) in response to oral instructions of the therapist. Each movement training exercise was repeated two times, giving a total of 30 min for the intervention.[12]

Action Observation Training

In experiment group, the patients observed a video for 3 min at a height parallel to their eyes. They sat in a comfortable sitting position on a chair with a backrest in front of a desk while the therapist briefly explained the movements at the side of the patient. Thereafter, imitation training was conducted for 2 min, with the therapist's guidance. The patient was instructed to carry out each movement alone while watching the video. A total of 15 min was taken to carry out the three types of movements, and each movement was repeated twice, giving a total time of 30 min for the intervention.[7]

Experimental Procedures

The two experimental groups carried out the following movements in sequence. The research participants were asked to straighten their upper body in a chair. The patient extended their arm to hold a water bottle, maintained the position, and then returned to the starting position. The patient extended their arm to hold a water bottle, brought the water bottle (functional movement) to their mouth, and then returned to the starting position. The patient extended their arm to hold a water bottle, drank the water (functional movement), and then returned to the starting position.

Data and Statistical Analysis

SPSS 20.0 for Windows was used to test the normality of data. The Shapiro-Wilk test and Levene's equal variance test were used to test for homogeneity between the two groups. Paired t-tests were carried out to compare changes in the groups, and a covariance analysis (ANCOVA) was conducted to compare changes between the two group. Pearson's correlation analysis was conducted to assess correlations among the dependent variables by group. The significance level was $\alpha=.05$.

RESULTS

Comparison of arm GS changes, muscle activity, and changes in functional assessments within each of the two groups

In terms of the changes in GS, decrease statistically significant differences in GS were observed during bending movements only in experimental group ($P<.01$) (Table 2). Regarding changes in muscle activity, there were increase statistically significant differences in the AD muscle and triceps muscle of the arm in both groups ($P<.05$) (Table 2). In the assessment of arm functions, statistically increase significant differences were shown in both groups ($P<.05$, $P<.01$) (Table 2).

Comparison of arm GS changes, muscle activity, and changes in functional assessments between the two groups

In terms of changes in GS, statistically decrease

Table 2. Comparison of arm GS changes, muscle activity, and changes in functional assessments within groups and between groups.

Items		Group	Pre-test	Post-test	*P*
GS (Hz)	Flexion	Control	.099 ± .054	.114 ± .036	.043†
		Experimental	.134 ± .056	.107 ± .044*	
	Extension	Control	.076 ± .038	.075 ± .050	.515
		Experimental	.074 ± .034	.090 ± .054	
%RVC (%)	AD	Control	189.90 ± 28.44	199.46 ± 27.05*	.020†
		Experimental	187.59 ± 21.05	212.46 ± 26.27**	
	BB	Control	136.25 ± 15.13	143.52 ± 17.00*	.044†
		Experimental	136.90 ± 13.22	160.92 ± 24.65*	
	FCR	Control	88.71 ± 6.96	91.98 ± 18.33	.260
		Experimental	94.42 ± 18.26	100.53 ± 9.61	
	ECR	Control	65.99 ± 8.00	68.24 ± 7.43	.073
		Experimental	67.20 ± 10.12	135.69 ± 38.42	
FMA (point)		Control	27.60 ± 6.57	29.20 ± 7.28*	.015†
		Experimental	31.00 ± 9.43	36.10± 8.86*	

*Paired t-tests, *$P<.05$, **$P<.01$
†ANCOVA, †$P<.05$
GS: Global synkinesis, RVC: Reference voluntary contraction, FMA: Fugl-Meyer Assessment
AD: Anterior deltoid, BB: Biceps brachii, FCR: Flexor carpi radiaris, ECR: Extensor carpi radiaris

significant differences in GS appeared during bending movements ($P<.05$) (Table 2). Regarding changes in muscle activity, there were increased statistically significant differences in the AD muscle and triceps muscle of the arm ($P<.05$) (Table 2). There were also statistically increase significant differences in arm function ($P<.05$) (Table 2).

Correlation between GS and Muscle activity FMA in Contral group

Muscle activity was positively correlated only with the AD muscle and triceps muscle of the arm (r=.678, $P<.05$) (Table 3).

Correlation between GS and Muscle activity and FMA in Experimental group

During the arm bending movements, GS was negative correlated with the muscle activity of the AD muscle (r=−.749, $P<.05$), positively correlated with the muscle activity of the AD muscle and the biceps muscle of the arm (r=.701, $P<.05$), and negatively correlated with the muscle activity of the flexor carpi radialis muscle and muscle extensor carpi radialis brevis (r=−.708, $P<.05$) (Table 4).

Table 3. Correlation between GS and Muscle activity FMA in Control group.

Items		GS		%RVC				FMA
		Flexion	Extension	AD	BB	FCR	ECR	
GS (Hz)	Flexion	1						
	Extension	−.196	1					
%RVC (%)	AD	.128	−.232	1				
	BB	−.516	.133	.678*	1			
	FCR	−.025	.309	−.365	.216	1		
	ECR	.364	.196	.186	−.313	.375	1	
FMA (point)		.078	.056	.020	.133	.066	.157	1

*$P<.05$
GS: Global synkinesis, RVC: Reference voluntary contraction, FMA: Fugl-Meyer Assessment
AD: Anterior deltoid, BB: Biceps brachii, FCR: Flexor carpi radiaris, ECR: Extensor carpi radiaris

Table 4. Correlation between GS and Muscle activity and FMA in experimental group.

Items		GS		%RVC				FMA
		Flexion	Extension	AD	BB	FCR	ECR	
GS (Hz)	Flexion	1						
	Extension	.170	1					
%RVC (%)	AD	−.749*	−.076	1				
	BB	−.548	.058	.701*	1			
	FCR	.055	.364	−.444	−.428	1		
	ECR	−.235	−.334	.472	.353	−.708*	1	
FMA (point)		−.311	−.348	.237	.016	−.076	.065	1

*$P<.05$
GS: Global synkinesis, RVC: Reference voluntary contraction, FMA: Fugl-Meyer Assessment
AD: Anterior deltoid, BB: Biceps brachii, FCR: Flexor carpi radiaris, ECR: Extensor carpi radiaris

DISCUSSION

Stroke patients have difficulties in performing arm functions due to loss of selective suppression of agonistic and antagonistic muscles during arm movements.[4] Thus, they show abnormal movements and spasticity due to increased muscle tone,[5] which leads to difficulties in daily living activities and negatively affects their recovery.[16] Chen et al[17] reported that GS was more closely related to spasticity in patients where GS was not suppressed than in patients where GS was suppressed. Hwang et al[10] indicated that functional recovery in stroke patients was more effective when GS changed a lot after exercise. In this study, in the within-group comparison, there were decrease statistically significant differences in GS during the bending movements only in experimental group. This finding indicated that the intervention in experimental group simultaneously stimulated the peripheral nervous system and the central nervous system, thereby accelerating the activity of the premotor cortex of the cerebrum, which is closely associated with movements and imitation, leading to positive changes in GS decrease. It is needed on observing and stimulating the mirror neuron system during 'active movements' for clinical findings, but we focused motor function for the shoulder and elbow joints and coordination of the upper limbs for primary interests.

Kang and Nam[18] reported that when the level of GS was lowered, the excitability of the central nerves decreased, which had a positive impact on the muscle function of stroke patients. In the between-group comparison of changes in GS in this study, we found decreased statistically significant differences in GS during bending movements in accordance with the findings of previous studies. The positive decrease changes in GS in experimental group can be attributed to sensory feedback from the exercise through action observation training, which activated mirror neurons and improved the coordination ability of muscles. Rueda et al[19] examined muscle activity during drinking movements and found that maximum flexion and abduction occurred the shoulder joint during the drinking phase, with marked muscle activation in the AD muscle. Yun et al[20] suggested that the maximum bending of the elbow joint occurred during the stage where the arm was brought to the mouth during drinking movements, leading to muscle activation of the biceps muscle of the arm. In this study, in the comparison of changes in muscle activity within each group, we detected increase statistically significant differences in the AD muscle and biceps muscle of the arm in both groups. This finding supports the findings of previous studies. The results can be attributed to the action observation training stimulating the central nervous system while the FES stimulated the peripheral nervous system and the effector through repetitive muscle contraction during drinking movements. This had a positive impact on increase the muscle activity of the AD muscle and the biceps muscle of the arm. Kim et al[21] applied two or more exercises in parallel to effectively recover arm functions of stroke patients and found that smoother movements appeared thanks to positive changes in the muscles around the paralyzed arm in the action observation training combined with FES rather than general exercises. In this study, when changes in muscle activity were compared between the groups, there were increase statistically significant differences in the AD muscle and biceps muscle of the arm in accordance with the findings of the Kim et al[21] The results suggested that FES was effective for functional recovery of stroke patients when combined with active arm movements.[13] Previous research indicated that action observation training appeared to be more effective because visual information led to increased muscle activity and suppression of shoulder movements.[21] In this study, in experimental group the motor ability of the arm improved because the observation of drinking movements through the action observation training and imitation learning aroused interest, leading to motivation, and the continuous repeated training promoted brain plasticity. Peppen et al[22] reported that repetitive task training was effective in improving arm functions by inducing smooth contraction and relaxation of the muscles around the arm. In other research, action observation training resulted in a clear improvement in arm functions of stroke patients, as assessed by the FMA scale.[6]

Those findings of this study support those in the literature, with increase statistically significant differences in the arm functions of the stroke patients in the between-group comparison. The improvement in arm functions can be attributed to FES enhancing muscle strength and sensation by activating neurotransmitters, leading to the recovery of neurological functions,[23] and repetitive movements improving functional movements by stimulating the cerebral cortex.[24] In addition, action observation training via videos likely had increase positive effects on functional recovery by inducing the activation of the premotor cortex through the observation of purposeful activities related to daily living through videos.[25] Furthermore, action observation training induced the plasticity of damaged brain nerves to emphasize cognitive elements, thereby promoting the activation of the cerebral cortex.[26] Therefore, the effects of the exercise were superimposed to produce better effects on the recovery of arm functions, indicating that the intervention in experimental group was more effective than the intervention in control group in promoting the recovery of arm functions. Previous research proposed that FES should be applied to a paralyzed arm to suppress abnormal movements and improve muscle strength for functional recovery of the arm.[27] In this study, when the correlation between the dependent variables of control group was analyzed, there was a positive correlation, with an increase in the muscle activity of the AD muscle associated with an increase in the muscle activity of the biceps muscle of the arm. Suiter et al[28] and Kern[29] reported that FES with frequencies in the range of 30-80 Hz and repetitive muscle contraction stimulated and mobilized fast twitch muscle fibers type II, leading to muscle strengthening. Yang et al[30] reported that during drinking movements, especially bending movements of the shoulder joint and elbow joint, led to large changes in muscle activity. Based on these results, it is assumed that the correlation between the AD muscle and the biceps muscle of the arm appeared in the drinking movements in the intervention in this study because the bending movements of the shoulder joint and elbow joint mainly occurred during the drinking movements, and the relevant muscles were continuously stimulated, and the movements were actively trained repeatedly through FES. Based on previous studies, in a study conducted by Moon,[31] different exercise methods were combined and applied to stroke patients, and the results presented more effective functional recovery and correlations between dependent variables. In this study, in experimental group during bending movements, GS showed a negative correlation with the AD muscle because as GS decreased, the muscle activity of the AD muscle also increased. Furthermore, the AD muscle showed a positive correlation with the biceps muscle of the arm, with an increase in the muscle activity of the AD muscle associated with an increase in the muscle activity of the biceps muscle of the arm. The flexor carpi ulnaris muscle showed a negative correlation with the muscle extensor carpi radialis brevis. As the activity of the flexor carpi ulnaris muscle increased, the muscle activity of the muscle extensor carpi radialis brevis decreased. This was due to the action observation training activating the primary motor area of the cerebrum on the basis of mirror neurons[32] and GS contributing to an improvement in cerebral plasticity, leading to reconstruction through the activation of the normal cerebral cortex.[33] Based on the correlation between the activity of the muscles around the arm and GS, Kang et al[34] argued that abnormal contraction of the arms of stroke patients should be suppressed to promote smooth antagonism. Chen et al[17] stated that the muscle tone of the flexor muscles of the arms of stroke patients should be reduced and that GS should be reduced during bending movements to enable smooth movements related to daily living activities. In this study, smooth antagonism was achieved through accurate imitation and exercise learning consisting of diverse sensory and visual feedback. Previous research concluded that for smooth arm movements of stroke patients, the flexion and extension of each muscle should be selectively activated to enable functional activities.[35] The shoulder joint and elbow joints of the arm are maximally bent during drinking movements.[20] The cerebral cortex was activated when functional drinking movements were observed and imitated, leading to the promotion of the recovery of motor functions so that smooth movements were formed and a positive correlation appeared between the AD muscle and biceps muscle of the arm. Previous research showed that action observation training concretely provided standard movements required when performing tasks, thereby enabling more precise imitations.[36] Further-more, action observation training induced the antagonistic muscle of the muscle with spasticity to suppress excessive co-contraction, with the result that active motor control was reestablished.[37] The provision of information on the timing of movements and visual information through action observation training enabled the imitation of movements and mobilization of the motor system. In this way, co-contraction of antagonistic muscles was suppressed, leading to a negative correlation between the flexor carpi ulnaris muscle and the muscle extensor carpi radialis brevis.

CONCLUSION

In this study, an intervention consisting of a combination of active movements and FES stimulated brain plasticity effects and led to changes in the activity of arm muscles of the paralyzed arms of stroke patients. In experimental group the intervention provided diverse sensory stimuli and visual information to facilitate accurate arm movements and improve the mutual suppression function. Thus, the intervention was effective in improving the recovery of arm functions to enable smooth movements in drinking movements. Therefore, applying FES based on action observation to the paralyzed arm of stroke patients can improve the co-suppression of agonistic and antagonistic muscles and promote the neurological recovery of muscle contraction. This can facilitate the acquisition of motor skills and stimulate brain plasticity.

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REFERENCES

1. World Health Organization. Stroke, Cerebrovascular accident. 2014.
2. Rand D. Proprioception deficits in chronic stroke Upper extremity function and daily living. *PloS one*. 2018;13(3).
3. Franck JA, Smeets RJEM, Seelen HAM. Changes in arm-hand function and arm-hand skill performance in patients after stroke during and after rehabilitation. *PloS one*. 2017;12(6).
4. Lang CE, Bland MD, Bailey RR, Schaefer SY, Birkenmeier RL. Assessment of upper extremity impairment, function, and activity after stroke: foundations for clinical decision making. *J Hand Ther*. 2013;26(2):104-114.
5. Knippenberg E, Verbrugghe J, Lamers I, Palmaers S, Timmermans A, Spooren A. Markerless motion capture systems as training device in neurological rehabilitation: a systematic review of their use, application, target population and efficacy. *J Neuroeng Rehabil*. 2017;14(1):61.
6. Sugg K, Müller S, Winstein C, Hathorn D, Dempsey A. Does action observation training with immediate physical practice improve hemiparetic upper-limb function in chronic stroke? *Neurorehabil Neural Repair*. 2015;29(9):807-817.
7. Sale P, Franceschini M, Mazzoleni S, Palma E, Agosti M, Posteraro F. Effects of upper limb robot-assisted therapy on motor recovery in subacute stroke patients. *J neuroeng Rehabil*. 2014;11:104.
8. LagoRodríguez A, Cheeran B, Koch G, Hortobagy T, FernandezdelOlmo M. The role of mirror neurons in observational motor learning: an integrative review. *European J Human Movement*. 2014;32:82-103.
9. Dobkin BH, Dorsch A. New evidence for therapies in stroke rehabilitation. *Curr Atheroscler Rep*. 2013;15(6):331.
10. Hwang IS, Tung LC, Yang JF, Chen YC, Yeh CY, Wang CH. Electromyographic analyses of global synkinesis in the paretic upper limb after stroke. *Phys Ther*. 2005;85(8):755-765.
11. Boissy P, Bourbonnais D, Gravel D, Arsenault AB, Lepage Y. Effects of upper and lower limb static exertions on global synkineses in hemiparetic subjects. *Clin Rehabil*. 2000;14(4):393-401.
12. Ejaz N, Xu J, Branscheidt M, et al. Finger recruitment patterns during mirror movements suggest two systems for hand recovery after stroke. *bioRxiv*. 2017;129510.
13. Mangold S, Schuster C, Keller T, Zimmermann-Schlatter A, Ettlin T. Motor training of upper extremity with functional electrical stimulation in early stroke rehabilitation. *Neurorehabil Neural Repair*. 2009;23(2):184-190.
14. You DH, Lee JS, Jeon BJ, et al. Effect of task-oriented training on upper extremity during functional electrical stimulation in stroke patients. *Korean J of Occup Ther*. 2011;19(4):25-39.
15. Yang DJ, Uhm YH, Kim JH. The biofeedback scapular stabilization exercise in stroke patients effect of muscle activity and function of the upper extremity. *J Kor Phys Ther*. 2015;27(5):325-331.
16. Robson N, Faller II, Ahir V. Creating a Virtual Perception for Upper Limb Rehabilitation. *Stroke*. 2017;12:15.
17. Chen YT, Li S, Magat E, Zhou P, Li S. Motor overflow and spasticity in chronic stroke share a common pathophysiological process: analysis of within-limb and between-limb EMG-EMG coherence. *Front Neurol*. 2018;9.
18. Kang KK, Nam KW. Effect of the increased sympathetic outflow on the changes of muscle tone and central nervous system excitability in chronic Stroke patients. *J Korea Academia-Industrial*. 2011;12(11):5019-5026.
19. Rueda FM, Montero FR, de Heredia Torres MP, Diego IA, Sánchez AM, Page JM. Movement analysis of upper extremity hemiparesis in patients with cerebrovascular disease: a pilot study. *Neurología*. 2012;27(6):343-347.

20. Yun SY, Lee TY, Park SY, Yi JB, Kim JH. Muscle Activity and a Kinematic Analysis of Drinking Motion. *Korean J of Occup Ther*. 2008;16(1):77-88.
21. Kim T, Kim S, Lee B. Effects of action observational training plus brain-computer interface-based functional electrical stimulation on paretic arm motor recovery in patient with stroke: A randomized controlled trial. *Occup ther Int*. 2016;23(1):39-47.
22. Van peppen RP, Kwakkel G, Wood-Dauphinee S, Hendriks HJ, Van der Wees PJ, Dekker J. The impact of physical therapy on functional outcomes after stroke: what's the evidence? *Clin rehabil*. 2004;18(8):833-862.
23. Davis GM, Hamzaid NA, Fornusek C. Cardiorespiratory, metabolic, and biomechanical responses during functional electrical stimulation leg exercise: health and fitness benefits. *Artif organs*. 2008;32(8):625-629.
24. Mathieson S, Parsons J, Kaplan MS. Combining Functional Electrical Stimulation with Mirror Therapy for the upper limb in people with stroke. *Critical Reviews Phys Rehabil Med*. 2014;26(1-2).
25. Small SL, Buccino G, Solodkin A. The mirror neuron system and treatment of stroke. *Dev Psychobiol*. 2012;54(3):293-310.
26. Kim JY, Ko YM, Park JW. Comparison of EEG Changes Induced by Action Execution and Action Observation. *J Kor Phys Ther*. 2017;29(1):27-32.
27. Alon G, Levitt AF, McCarthy PA. Functional electrical stimulation enhancement of upper extremity functional recovery during stroke rehabilitation: a pilot study. *Neurorehabil Neural Repair*. 2007;21(3):207-215.
28. Suiter DM, Leder SB, Ruark JL. Effects of neuromuscular electrical stimulation on submental muscle activity. *Dysphagia*. 2006;21(1):56-60.
29. Kern H. Functional electrical stimulation on paraplegic patients. Euro J Transla Myology. 2014;24(2).
30. Yang SH, Rhee WI, Son SG, Kwon SY, Kim MG. Analysis of Upper Extremity Motion during Drinking Using Virtual Reality Motion Analysis System (VRMAS). *J Kor Academy Rehabil Med*. 1998;22(1):204-209.
31. Moon YJ. *The Effect of Dynamic Neural Mobilization on Arm Nerve Conduction Velocity, Functions and Cerebral Cortex Activity for Patients with Stroke* [thesis]. Yeongam: Sehan University; 2018.
32. Buccino G, Binkofski F, Fink GR, et al. Action Observation Activates Premotor and Parietal Areas in a Somatotopic Manner: An fMRI Study. *Eur J neurosci*. 2001;13(2):400-404.
33. Nelles G, Cramer SC, Schaechter JD, Kaplan JD, Finklestein SP. Quantitative assessment of mirror movements after stroke. *Stroke*. 1998;29(6):1182-1187.
34. Kang J, Kim H, Jeong D. Correlation between Affected Arm Muscle Activity and Global Synkinesis in Patients with Stroke. *IAPTR*. 2019;10(3):1856-1861.
35. Canning CG, Ada L, O'Dwyer NJ. Abnormal muscle activation characteristics associated with loss of dexterity after stroke. *J Neurol Sci*. 2000;176(1):45-56.
36. Lacourse MG, Orr EL, Cramer SC, Cohen MJ. Brain activation during execution and motor imagery of novel and skilled sequential hand movements. *Neuroimage*. 2005;27(3):505-519.
37. Ellis MD, Carmona C, Drogos J, Dewald J. Progressive abduction loading therapy with horizontal-plane viscous resistance targeting weakness and flexion synergy to treat upper limb function in chronic hemiparetic stroke: a randomized clinical trial. *Front Neurol*. 2018;9:71.