ORIGINAL ARTICLE

Effects of purposeful activity-based electrical stimulation therapy for a stroke patient with severe upper-limb paresis on cerebral hemodynamics: trial of a home-based support program

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Abstract

Objective: This investigative study aimed to elucidate the effects of purposeful activity-based electrical stimulation therapy on brain function using functional near-infrared spectroscopy (fNIRS) of a chronic stroke survivor.

Method: The sole study participant was a female patient in her late 70s who presented with right hemiplegia with a history of putaminal hemorrhage four years prior. She participated in the purposeful activity-based electrical stimulation therapy program for three months, after which she underwent assessment of motor, and cognitive functions. Pre- and post-program intervention assessments were conducted using fNIRS, Fugl-Meyer assessment, motor activity log, goal attainment scaling-light, and mini-mental state examination.

Results: fNIRS results confirmed significant differences in the increases in oxyhemoglobin concentration. For dorsiflexion movements, there was significant increase in the left-hemisphere palm region (p=0.004) and right-hemisphere finger (p=0.002)/palm regions (p=0.001); while for hand extension movements, there was significant difference in the left-hemisphere finger (p=0.018)/palm region (p=0.002) and right hemisphere palm region (p=0.001). Meanwhile, although target achievement scales had some point increases (outcome measures), they did not reach the level of effective improvements in motor functions.

Conclusion: The effects of the purposeful activity-based electrical stimulation therapy program in a chronic stroke survivor with severe upper limb paralysis suggests the influence of an ipsilateral descending pathway on the processes of brain function activation that occurred before effective motor-function improvements.

INTRODUCTION

In Japan, use of neuromuscular electrical stimulation is considered to be reasonable for the rehabilitation of moderately-to-severely paralysed lateral upper limbs (UL) following a stroke (Stroke Guidelines, 2021). Neuromuscular electrical stimulation of the peripheral nerves accompanied by evoked myoelectricity is suggested to affect motor function in patients after a stroke, and to cause changes in cortical excitability (Kimberley, 2004). An investigation into the functional recovery of the hemiplegic UL in chronic stroke patients showed, based on fMRI and other results, that Neuromuscular electrical stimulation can both restore hand functions and alter cortical activation patterns (Shin, 2008). Another study reported using functional electrical stimulation via fMRI improvements in UL functions and cortical activation effects in patients with UL paralysis at Brunnstrom recovery stages III-IV after a chronic stroke (Sasaki, 2021).

Similarly, although functional recovery has been observed in cases of severe hemiplegic UL due to chronic stroke, it is difficult to achieve increases in daily UL usage (Debbie, 2012). Moreover, if there are fewer opportunities to move the paralysed side in daily life, the UL can easily deteriorate to a level of disuse, resulting in a major reduction in quality of daily life (Duncan, 2000; Lai, 2002). Thus, to determine the effectiveness of electrical stimulation therapy for a severe hemiplegic UL after a chronic stroke, in addition to changes of brain function, increased use of the paralysed UL also requires wide demonstration.

In a recovery program for severe hemiplegia of the UL after chronic stroke, purposeful activity-based electrical stimulation therapy (PA-EST) (Minami, 2020a; 2020b; 2021a) combines electrical stimulation therapy with purposeful activities to elicit patient autonomy. PA-EST has been shown to shorten the latency of auditory event-related potentials, suggesting changes in brain function (Minami, 2021b). However, previous studies of PA-EST have not examined changes in the areas of brain function in conjunction with improvements in motor functions of the paralysed UL, and/or with the frequency and quality of its daily use.

In the Single-case interventional study, fNIRS (FOIRE-3000, Shimadzu Corporation, Kyoto, Japan) was used to examine the cerebral hemodynamics via post-PA-EST changes in oxyhaemoglobin (oxy-Hb). Also investigated were the relationships between PA-EST, motor functions and frequency of daily use of the UL on the side severely paralysed by chronic stroke.

METHODS

Participant

The sole study participant was a woman in her early 70s who presented with right hemiplegia. Four years earlier, she had been urgently admitted to hospital after putaminal haemorrhage (Fig. 1). After intensive rehabilitation, she was later discharged to her home and then immediately began attending day care twice a week. For approximately two years prior to presentation, due to the global spread of COVID-19 infection, she had been moving only between her home and the day care facility, with repeated short stays at a health facility. The patient lived at home with her husband, close to her son and young family. She stated that her goal for activities of daily living (ADLs) was to be able to cook for her grandchildren.

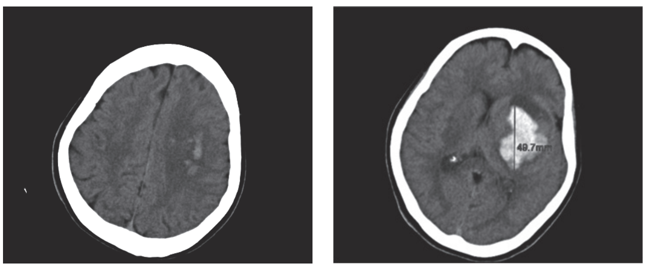


Figure 1. Initial computed tomography
The CT image was taken when she developed after putaminal haemorrhage. The size of the hematoma was approximately 49.7 mm. She did not undergo a craniotomy to remove the hematoma because she did not have increased intracranial pressure.

PA-EST intervention

In PA-EST, specific movements extracted from analysis of the targeted activity are performed in conjunction with partial movements due to electrical muscle stimulation (EMS) (Minami, 2020b). EMS is applied to the forearm of the paralysed UL to the extent that it does not reach the pain threshold, and is adjusted to the extent that dorsiflexion movements of the wrist joint can be confirmed. It is recommended that a stress-free program be carried out, from wrist dorsiflexion to full-body movement. The program is divided into three steps: training to improve UL function, training to improve the patient's ability to meet their own targeted activities, and training to improve adaptation to daily life activities (Minami, 2022a, 2022b) (Fig. 2).

The purposeful PA-EST activity used in this case study was to extend the paralysed UL to a washbasin in a setting that enables hand-washing before cooking. The program consisted of Step 1 for one month and Step 2 for two months (Fig. 2). The electrostimulator (NESS H200W, NESSH200, Bioness Co., Ltd., Valencia, CA, USA) was applied to the paralyzed side. The patient sat at the time of performance, during which the dorsum of the forearm was stimulated to the extent that finger extension occurred, but within parameters such that there was no pain due to usage intensity. This was performed approximately twice for 20 minutes per day. During the first month, this was performed such that the patient would become used to the EMS. From the second month onwards, the same intensity was used, with the patient imagining reaching her hand to the washbasin. The hand on the paralysed side was placed on the patient's knee, and she was encouraged to extend the elbow joint. The PA-EST program was carried out for three months, with evaluation of performance before and after the program. The study was approved by the Gunma Paz University Research Ethics Review Committee (approval number: PAZ21-8), and written informed consent was obtained from the study participant. The study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research involving Human Subjects.

Outcome measures

For UL motor functions, the Fugl-Meyer assessment was used for upper extremities (Gregson, 1999; Bohannon, 1987) and the motor activity log (MAL) was used for goal attainment assessment

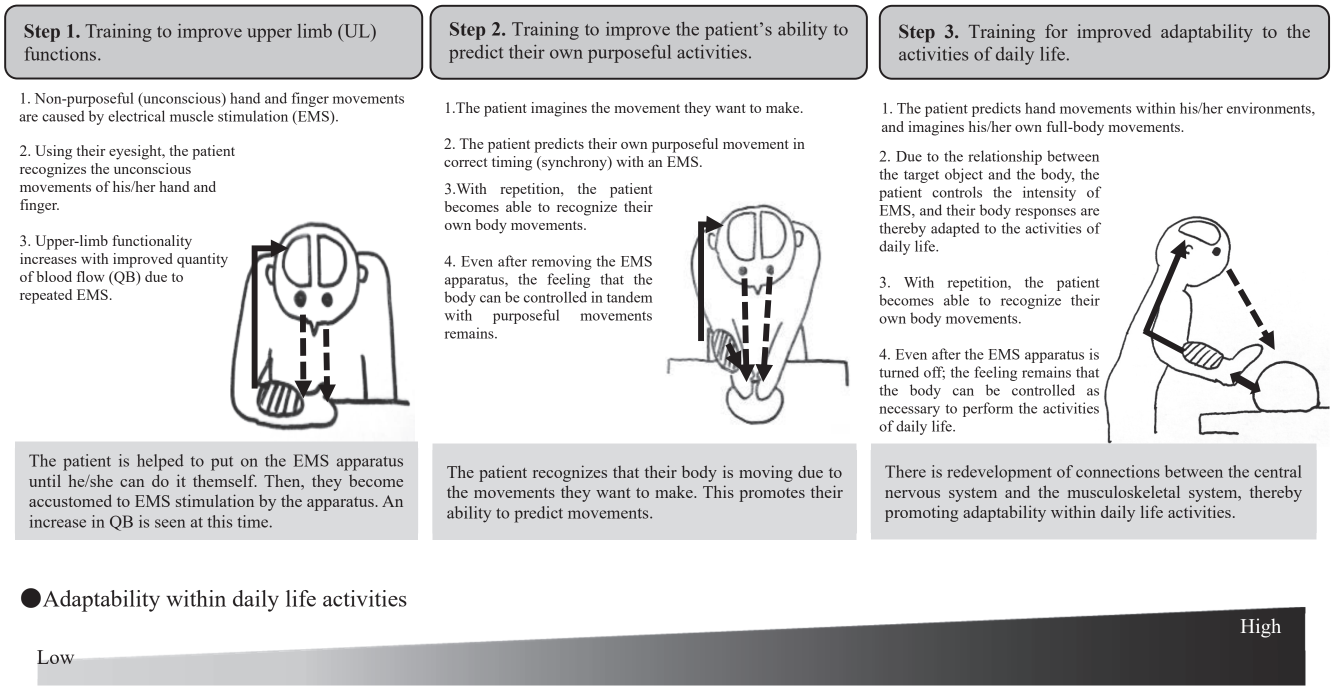


Figure 2. Configuration for the performance of purposeful activity-based electrical stimulation therapy (PA-EST) (Minami, 2021a, 2021b)
The practice of purposeful activity-based electrical stimulation therapy (PA-EST) is divided into three steps. Here, the patient undergoing PA-EST is assumed to be a chronic stroke patient with severe hemiplegic upper limb (UL). Step 1 involves familiarization of the patient with electrical muscle stimulation (EMS) and improvements in UL function. Step 2 aims to improve the patient's ability to predict their own purposeful activity. Step 3 aims to improve the patient's adaptation to the activities of daily life.

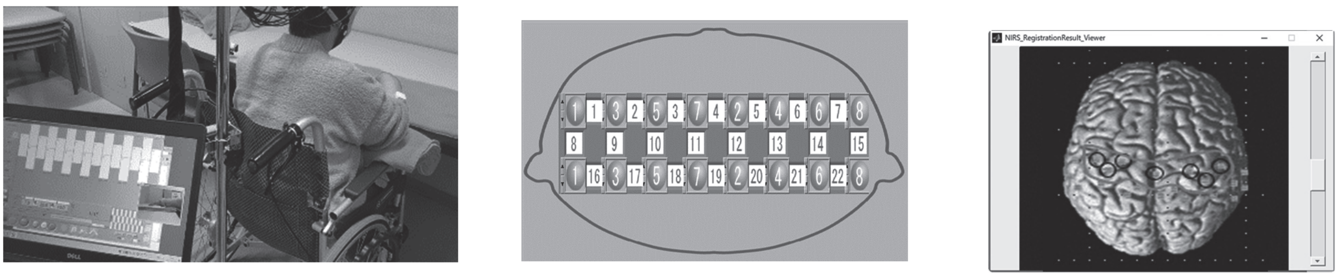


Figure 3. NIRS attachment and location

(Taub, 1993; Van der Lee, 2004). Goal attainment scaling-light (GAS-L) (Lynne, 2009; 2020) was used to assess ADLs, while the functional independence measure (FIM) (Data management, 1990; Tsuji, 1995; Yamada, 2006) was used for assessment of cognitive function. The mini mental state examination, Japanese version (MMSE-J) (Folstein, 2001, 1975; Sugishita, 2018) was used for brain function assessment, and fNIRS (FOIRE-3000, Shimadzu Corporation, Kyoto, Japan) was used for measure changes in the levels of oxygenated hemoglobin in the brain.

fNIRS fibre coupling portions (motor areas) were used to measure the nasal root and occipital protuberance, and the left and right preauricular points, with calculation of the vertex (Cz) from the midpoint of each. Electrodes were divided into 10, 20, 20, 20, 20, 20, and 10% segments between the nasal root and occipital tubercle, as well as between the left and right preauricular points (Jasper, 1958; Klem, 1999) (Fig. 3). Measurements were made in accordance with Brodmann functional localization, with the finger region as CH2 contralateral and CH6 ipsilateral, the palm region as CH10 contralateral and CH13 ipsilateral, and the wrist-joint region as CH3 contralateral and CH5 ipsilateral. Dorsiflexion exercise of the paralysed wrist was repeated 10 times, with a set consisting of 10 s rest, followed by 20 s execution and then 10 s rest. Finger-opening movements were performed in the same pattern. fNIRS data were measured during each activity using the absolute measurement method, and corrected using time-resolved measurements, and data were analysed using the t-test with SPSS Statistics 26.0 (IBM, Armonk, NY, USA) (p<0.05).

RESULTS

Outcome changes following PA-EST implementation (Table 1) included partial, but not effective, motor improvement in the UL motor functions of the shoulder girdle and shoulder (FMA: pre =9/66, post=11/66, MAL: amount of use pre=0.14, post=0.14; quality of movement pre=0.14, post=0.14). In the goal-achievement assessment, a sense of elbow extension was obtained and the adaptability to life increased (GAS-L: pre=25.19, post=37.21). No specific changes were observed in cognitive function or daily life assessment (MMSE-J: pre=26, post=26, FIM: pre=109, post=109). The fNIRS results for brain function assessment showed significant differences in dorsiflexion movements in the left-hemisphere palm region (p=0.004) and right-hemisphere finger (p=0.002)/palm regions (p=0.001), and in hand extension movements in the left-hemisphere finger (p=0.018)/palm region (p=0.002) and right hemisphere palm region (p=0.001), with significant differences confirmed in the right-hemisphere palm area (p=0.001) (Table 2). Unfortunately, probes CH16 and CH19 were out of order at the time of the post of this study, so data could not be obtained.

Table 1. Results of motor function, cognitive function, and daily life after PA-EST

FMA-upper		MAL(AOU)		MAL(QOM)		GAS-L		MMSE		FIM	
pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
9	11	0.14	0.14	0.14	0.14	25.19	37.21	26	26	109	109

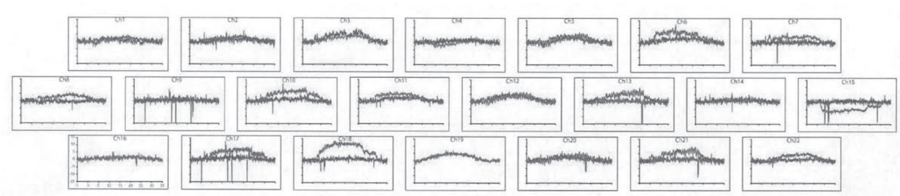
FMA: Fugl Meyer Assessment, MAL: Motor Activity Log, AOU: Amount of Use, QOM: Quality of Movement, GAS-L: Goal attainment scaling-Light, MMSE: Mini Mental State Examination, ERPs: Event-Related Potential

Table 2. fNIRS results

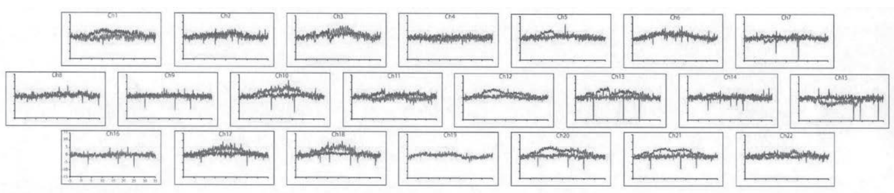
fNIRS				Pre		Post		*t*-value	*p*-value
				Mean (z-value)	SD	Mean (z-value)	SD		
Wrist dorsiflexion exercise	Finger area	CH2	Contralateral side	20.371	17.597	8.631	4.082	2.047	.071
		CH6	Ipsilateral	47.628	18.325	17.907	8.359	4.302	.002*
	Palm area	CH10	Contralateral side	43.898	21.893	11.012	8.385	3.840	.004*
		CH13	Ipsilateral	2.597	5.496	34.382	20.267	-4.607	.001*
	Wrist area	CH3	Contralateral side	30.179	21.441	33.171	24.852	-.253	.806
		CH5	Ipsilateral	11.558	15.986	26.859	14.905	-1.904	.089
Finger extension exercise	Finger area	CH2	Contralateral side	5.023	12.493	14.488	8.231	-2.898	.018*
		CH6	Ipsilateral	21.793	16.963	19.206	9.900	.446	.666
	Palm area	CH10	Contralateral side	30.940	18.865	4.993	10.434	4.459	.002*
		CH13	Ipsilateral	.528	4.021	29.499	18.554	-4.643	.001*
	Wrist area	CH3	Contralateral side	13.620	23.345	16.607	24.496	-.320	.756
		CH5	Ipsilateral	4.593	14.614	21.298	21.421	-2.173	.058

＊p<0.05

Wrist dorsiflexion exercise



Finger extension exercise



Left-brain Right-brain

Grey: pre, black: post ※Data from fNIRS converted to Z-scores and tabulated mean values

DISCUSSION

Recovery of motor function in the severe hemiplegic UL after a chronic stroke is not easy (Nakayama, 1994). This study aimed to clarify the effects of PA-EST on motor and brain functions in the severe hemiplegic UL after a chronic stroke. PA-EST has been shown to increase ADLs and adaptation to daily life in the UL with severe hemiplegia after a chronic stroke after evaluation over a period of three months (Minami, 2021a). Over the approximately three months of the current study, no effective improvement in motor (movement) functions could be confirmed. Changes in oxy-Hb concentrations were observed, however, and points also increased on the target achievement scales.

Notably, in this study, oxy-Hb concentrations decreased at contralateral CH10 in the palm region, while oxy-Hb concentration increased at ipsilateral CH13 with wrist-joint extension movements and finger extension movements. Furthermore, with wrist-joint extension movements, oxy-Hb concentrations decreased at the ipsilateral CH6 in the finger region, while with finger extension movements, oxy-Hb concentration increased at ipsilateral CH2 in the finger region. The involvement of the ipsilateral descending tract in recovery of the severely paralysed side of stroke was previously suggested (Netz, 1997). Regarding extension of the PA-EST program for purposeful activity and functional electrical stimulation to whole-body movements, previous studies have suggested an increase in cognitive processing speed due to deliberate motor planning by the brain, depending on the environment surrounding the patient and intentions to act/move wilfully, due to constant processing (Minami, 2021b). The present study suggests the influence of the ipsilateral descending pathway on the process of brain function activation for the UL with severe hemiplegia after a chronic stroke. In addition, the three-month PA-EST program in the present case showed no effective improvement in motor function, although there were initially some changes in brain function. As in previous studies, however, goal attainment increased, suggesting that extending the PA-EST program may increase the improvements in motor function (Minami, 2020b).

The primary limitation of this study is that it includes the evaluation results of just one patient. These findings cannot therefore be generalized, and further studies with a larger number of participants, such as randomised controlled trials, are needed for validation of the findings. While fNIRS confirmed the oxy-Hb levels of cerebral circulatory dynamics caused by the task on the paralysed UL, we also observed the oxy-Hb of cerebral circulatory dynamics caused by the task on the non-paralysed UL, suggesting that this might also have had effects.

CONCLUSION

The effects of the purposeful activity-based electrical stimulation therapy program in a chronic stroke survivor with severe upper limb paralysis suggests the influence of an ipsilateral descending pathway on the processes of brain function activation that occurred before effective motor-function improvements.

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