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Deficit of Motor Skill Acquisition on the Upper Limb Ipsilesional to the Injured Hemisphere in Individuals with Stroke

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Background: Movement deficits in limbs ipsilesional to the damaged hemisphere in individuals with stroke have been established through various motor tasks. Nevertheless, there has been little evidence regarding hindrance of motor skill acquisition on the ipsilesional limb in patients with stroke. Therefore, we attempted to demonstrate whether the characteristics of ipsilesional deficits involved motor learning insufficiency in stroke survivors with unilateral brain damage.

Material/Methods: Thirty-six participants (18 patients with stroke and 18 normal individuals) were recruited. Patients with stroke performed a visuo-spatial tracking task in the upper limb ipsilesional to the injured hemisphere, and normal participants did the same task with the upper limb matched for the same side. The participants were required to track a target sine wave as accurately as possible while the wave was displayed on the computer screen for 15 seconds. An accuracy index was calculated for each of the trials.

Results: We found that motor skill learning improved in both stroke and normal groups with repetitive practice. However, the normal group exhibited greater motor skill acquisition than in comparison the stroke group for motor skill improvement. Statistical analyses revealed significant differences in time effects and time x group interactions.

Conclusions: Our findings provide evidence that individuals with stroke might have difficulty in performing visuo-spatial movements and acquiring motor skills with the ipsilateral upper limb. Improvement of ipsilesional limb function increases self-care activity in daily life. Therefore, we recommend that clinicians adopt remedial strategies for ipsilesional limbs.

MeSH Keywords: Learning Disorders • Motor Skills Disorders • Task Performance and Analysis

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Background

Stroke is a major health issue that leads to long-term disability due to neurological dysfunction, including abnormal motor function, sensory deficits, and cognitive insufficiency [1,2]. Above all, sensorimotor dysfunction commonly prevents patients with stroke from performing normal movement patterns and functional activities, and patients with stroke from moving with a symmetrical gait [3,4]. In general, motor dysfunction appears in the upper and lower limbs that are contralesional to the damaged hemisphere [5,6]. Most rehabilitative approaches are applied to the affected side of limbs in order to restore movement abnormalities. However, several recent studies reported that subtle motor deficits appear on the non-affected side, contrary to the previously held notion that only the opposite-sided limbs were involved and that same-sided limbs were considered normal [7–9].

Ipsilesional motor deficits have been measured through a number of motor tasks in both clinical and experimental settings. Among clinical features, abnormalities in ipsilesional limbs present as sensorimotor deficits in terms of muscular weakness, sensory losses, and impaired manual dexterity [10–12]. There is a growing body of evidence to suggest that kinematic processing deficits are founded in various-specific motor tasks, ranging from simple basic elements to complex tasks, including tapping, step-tracking, goal directional aiming, and iso- (and non-) directional interlimb coordination [12–14]. These deficits are influenced by such factors as cognition [10,15], rate of recovery [16,17], and motor function of the affected limbs [18].

It is evident that the ipsilesional limb is no longer recognized as the non-affected side in patients with stroke, contrary to the pre-existing notion. Nevertheless, there is little evidence to suggest that patients with stroke have difficulty learning novel motor skills using their ipsilesional upper limb. Incompetence of motor skill acquisition on ipsilesional limbs is a crucial factor since new strategies are required to learn new motor skills using the non-paralyzed limb instead of the paralyzed limb. Therefore, we investigated whether the characteristics of ipsilesional deficits involve motor learning insufficiency in stroke survivors with unilateral brain damage.

Material and Methods

Participants

We recruited a total of 36 participants (18 patients with stroke and 18 normal individuals) who were shown to be right-handed by the modified Edinburg Handedness Inventory [19]. Signed informed consent to participate in the experiment was given by all individuals, in accordance with the ethical standards of the Declaration of Helsinki. The Institutional Review Board of Cheongju University (1041107-201706-HR-002-01) approved the protocol of this experiment.

Chronic stroke patients who were over 6 months past their stroke onset were recruited from November 2018 to December 2018. The group included 8 patients with right brain damage and 10 patients with left brain damage. Unilateral hemispheric injury due to first-ever stroke was confirmed by analysis of their medical histories and brain magnetic resonance imaging (MRI). To offset the known functional difference of hand asymmetry, an equal number of participants were matched for the non-stroke (normal) groups: 10 and 8 individuals who were tested using right and left limbs, respectively. Exclusion criteria included the following 1) hemianopsia and unilateral spatial neglect; 2) Wallenberg's syndrome; 3) severe aphasia; 4) impairment of cognitive function (below 24 points with mini-mental status examination) [20]; 5) sitting balance problems; 6) previous neurologic or psychiatric disease; and 7) presence of apraxic behavior (below 27 points on Florida Apraxia Screen) [21]. The normal elderly group was in good health and without previous symptoms or diagnoses of neurological problems. Normal participants were matched to stroke group participants according to gender and age distribution. Table 1 indicates demographic data in the patients and normal participants.

Measurement and data acquisition

Tracking data were collected using a personal laptop computer (NT950XBE, Samsung, South Korea), rotatory potentiometer (6639s, Bourns Inc., USA), I/O device (USB-6008, National Instruments, USA), and data analyzing software (Labview ver 3.8, National Instruments, USA). A plastic plate implanted with the potentiometer was used to quantify range of motion in flexion and extension of the metacarpophalangeal (MP) joints. The data were transferred to the computer through an analogue-to-digital converter that collected oscillation of 120 Hz frequency, with a 1.5 Hz low-pass filter.

Patients with stroke performed a visuo-spatial tracking task with the ipsilesional upper limb, and normal individuals performed the same task with the corresponding upper limb of the same side. Participants were seated in front of a table, with the elbow flexed at approximately 90° and the forearm supported on comfortable foam. The top and bottom peaks of sinusoidal signal were matched to the actual movement of the MP joint of each participant, with the range set within 80% of actual motion. The sensitivity of the potentiometer was calibrated at 0° and 150° when the MP joint was positioned in full flexion and extension, respectively.

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Table 1. The general characteristics of the 2 groups.

	Stroke patient group (n=18)	Normal elderly group (n=18)	*P*
Male/Female	7/11	7/11	
Age (years)	64.50±6.62	66.94±4.67	0.209
Height (cm)	166.22±5.95	164.00±6.76	0.303
Weight (kg)	63.11±7.80	61.44±9.35	0.565
Test upper limb side (right/left)	10/8	10/8	
Paralysis side (left/right)	8/10		
Time since stroke (month)	29.06±17.90		

Table 2. Means of accuracy index measures for the normal elderly group and the stroke group during 50 trials tracking task.

	10	20	30	40	50	Time	Interaction Group*Time
Stroke patient group (n=18)	4.03±1.08	4.08±1.11	4.12±1.07	4.13±1.05	4.17±1.06	F=13.66 *P*=0.000	F=4.45 *P*=0.017
Normal elderly group (n=18)	4.42±1.01	4.60±1.00	4.67±1.02	4.81±1.00	4.95±1.04		

The task required the participant to track the targeted sinusoidal wave as precisely as possible for 15 seconds. Various ranges of velocity were presented by varying amplitudes within 1.5–3 Hz. The response wave that the participant made was presented as a red line and the target wave was marked as a black line on the computer screen. The red response wave was chased up with the MP joint extended and chased down with the MP joint flexed. All participants were given 5 practice trials after 1 demonstration, with an alternative sine wave that was dissimilar to the sinusoidal wave in the actual trial to preclude habituation of the task. In the actual trial, 3 trials were recorded, with resting periods of 3 minutes between individual trials.

Data and statistical analysis

The accuracy of performance in the tracking task was estimated with an accuracy index (AI): AI=100(P–E)/P, where E was the root mean square (RMS) error between the response and the target signal, and P was the bulk of the participant's target pattern, gauged as the RMS value between the target signal and the perpendicular line splitting the top and bottom phases of the target signal [22]. The size of P was determined by the scale of the perpendicular line which is participant's range of the MP joint. The AI score ranged from 100 to –100, where negative scores indicated the participant's response signal was so far away from the perpendicular line of the target signal.

Statistical analysis was performed with SPSS (Version 22.0, IBM, NY, USA) for Windows. The independent *t*-test was performed to compare the significances of differences between the "normal elderly" group and "stroke patient: " group, in terms of baseline data (age, height, and weight). The Shapiro-Wilk test was used to check normality of distributions, and 2-way repeated-measures analysis of variance [2 groups (normal elder versus stroke patient)*5 blocks (10 trails/block)] with least significant difference (LSD) post-hoc test used to compare accuracy indexes during tracking. The level of significance was set at 0.05 as the *P* value.

Results

Table 1 shows the demographic data of both groups. No intergroup significant differences were found for age, height, or weight (*P*>0.05). For the stroke patient group, the 10, 20, 30, 40, and 50 trials of accuracy index for tracking task were 4.03±1.08, 4.08±1.11, 4.12±1.07, 4.13±1.05, and 4.17±1.06, respectively. For the normal elderly group, the 10, 20, 30, 40, and 50 trials of accuracy index for the tracking task were 4.42±1.01, 4.60±1.00, 4.67±1.02, 4.81±1.00, and 4.95±1.04, respectively. Statistical analyses revealed significant differences in time effect (f=13.66, *P*=0.00), and the time x group interaction (f=4.45, *P*=0.017) (Table 2). Several comparisons with LSD post hoc testing demonstrated that differences in time existed between the 10, 20, 30, 40, and 50 trials in the

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Table 3. Multiple comparisons with LSD post hoc test of accuracy index in the normal elderly group and the stroke group.

	(I) time	(J) time	Mean difference (I-J)	SD	*P*
Stroke patient group (n=18)	1	2	–.052	.060	.393
		3	–.098	.070	.168
		4	–.108	.087	.223
		5	–.141	.110	.206
	2	3	–.046	.041	.272
		4	–.056	.057	.333
		5	–.089	.077	.258
	3	4	–.010	.051	.846
		5	–.043	.067	.525
	4	5	–.033	.045	.472
Normal elderly group (n=18)	1	2	–.183	.060	.005
		3	–.254	.070	.001
		4	–.386	.087	.000
		5	–.527	.110	.000
	2	3	–.071	.041	.094
		4	–.203	.057	.001
		5	–.343	.077	.000
	3	4	–.132	.051	.014
		5	–.272	.067	.000
	4	5	–.141	.045	.004

normal elderly group. However, time differences were not observed between the 10, 20, 30, 40, and 50 trials in the stroke patient group (Table 3).

Discussion

The purpose of our study was to determine whether the stroke group showed less efficient motor skill acquisition while performing a visuo-spatial tracking task using the non-paralyzed side limb, compared with an age- and gender-matched normal elderly group. We found that motor learning improved for both the stroke group and the normal elderly group with repetitive practice over a short period. However, with respect to the degree of improvement in motor learning, the normal elderly group exhibited greater motor skill acquisition than the stroke group. Therefore, our outcomes indicate that individuals with stroke show less efficient motor learning in the ipsilesional upper extremity than the normal population.

Our finding of ipsilesional movement disorders in individuals with unilateral hemispheric stroke accords with findings of many previous studies. To our knowledge, the first scientific evidence was presented by Smutok et al. [23] who reported 51 patients with stroke showed ipsilateral motor deficits in visual motor reaction times for grip and pinch strength, finger tapping, and the Purdue Pegboard test. In addition, Subramaniam et al. [24] found that 13 chronic stroke survivors demonstrated significantly reduced performance of muscular activation as measured by surface electromyography (EMG) analysis during functional reaching tasks in terms of reaction time, burst duration, movement time, and movement initiation, compared to age-similar healthy adults. Movement deficits of the ipsilesional upper limb were observed in kinematic analyses as well as in clinical assessments [11,18,22,25–29].

Accordingly, it is evident that motor deficits of the upper and lower limb ipsilesional to the damaged hemisphere have already been demonstrated in laboratory and clinical studies. In addition to these movement abnormalities on the ipsilesional limb, we found that the amount of improvement of motor skill learning was comparatively unequal between patients with stroke and the matched normal elderly group. To our knowledge, there has been no evidence regarding disability of motor

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skill acquisition in upper extremities ipsilesional to the injured hemisphere in patients with stroke. Nevertheless, the present study expands on several studies, suggesting differences in motor skill learning between individuals with stroke and normal adults [30–32]. Wadden et al. [32] reported that patients with stroke showed significantly slower increases in implicit sequence skill acquisition of the paralyzed upper limb, compared with healthy participants. Deuschl et al. demonstrated that patients with isolated cerebellar injuries had less steep skill learning than did normal individuals in a target-aiming task that required participants to adapt ballistic movement to a changing target signal. Furthermore, learning ability was less efficient in hemiparetic stroke patients than in patients with Parkinsonism while performing a postural control task demanding precise coordination in standing posture [30]. A clear explanation of the differences in the rate of motor skill acquisition between patients with stroke and that of healthy individuals has not been presented in prior studies. Nevertheless, we believe that the comparatively diminished ability of motor skill acquisition might be attributed to several possible causes: ipsilesional motor deficits in terms of interrupted-counterbalanced functions of each hemisphere; impaired function of ipsilateral corticospinal tracts from the damaged hemisphere; or hindrance of lateralized hemispheric function.

Our findings provide novel evidence that patients with stroke have ipsilesional motor deficits related to accuracy of visiospatial coordination function, as reported in several previous studies [17,33]. We acknowledge that this study had several limitations. The study included a small number of participants. We identified motor skill acquisition in only MP joints of the ipsilesional upper limb, with avoidance of learning effect by performing similar tasks repetitively. Therefore, we cannot generalize these findings to other joints, such as the ipsilateral proximal parts or lower limbs. Furthermore, it is difficult to explain ipsilesional deficits in long-term motor learning capacity, because we observed repetitive movement only during short periods. Finally, in order to identify motor learning improvement manifestly, we did not execute evaluations other than a tracking task that required visuomotor function. Therefore, future studies will be required to investigate the various motor learning tasks of other joints over longer periods with larger sample size.

Conclusions

Individuals with stroke had impaired short-term motor skill learning in the upper limb ipsilesional to the injured hemisphere. This suggests that the ipsilesional limb should no longer be recognized as a non-affected limb in patients with stroke, in contrast to pre-existing notions. Therefore, clinicians should be aware that patients with stroke, even when performing tasks with the ipsilesional upper limb, might have difficulty in performing functional activities because of movement deficits and motor learning disorders.

Conflicts of interest

None.

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