

Effects of cognitive-motor dual-task training combined with auditory motor synchronization training on cognitive functioning in individuals with chronic stroke

A pilot randomized controlled trial

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Abstract

Background: Preservation and enhancement of cognitive function are essential for the restoration of functional abilities and independence following stroke. While cognitive-motor dual-task training (CMDT) has been utilized in rehabilitation settings, many patients with stroke experience impairments in cognitive function that can interfere with dual-task performance. In the present study, we investigated the effects of CMDT combined with auditory motor synchronization training (AMST) utilizing rhythmic cues on cognitive function in patients with stroke.

Methods: The present randomized controlled trial was conducted at a single rehabilitation hospital. Thirty patients with chronic stroke were randomly divided an experimental group (n = 15) and a control group (n = 15). The experimental group received 3 CMDT + AMST sessions per week for 6 weeks, whereas the control group received CMDT only 3 times per week for 6 weeks. Changes in cognitive function were evaluated using the trail making test (TMT), digit span test (DST), and stroop test (ST).

Results: Significant differences in TMT-A and B ($P = .001$, $P = .001$), DST-forward ($P = .001$, $P = .001$), DST-backward ($P = .000$, $P = .001$), ST-word ($P = .001$, $P = .001$), and ST-color ($P = .002$, $P = .001$) scores were observed in both the control and experimental groups, respectively. Significant differences in TMT-A ($P = .001$), DST-forward ($P = .027$), DST-backward ($P = .002$), and ST-word ($P = .025$) scores were observed between the 2 groups. Performance speed on the TMT-A was faster in the CMDT + AMST group than in the CMDT group. Moreover, DST-forward and DST-backward scores were higher in the CMDT + AMST group than in the CMDT group. Although ST-color results were similar in the 2 groups, ST-word scores were higher in the CMDT + AMST group than in the CMDT group.

Conclusion: This finding indicates that the combined therapy CMDT and AMST can be used to increase attention, memory, and executive function for people with stroke.

Abbreviations: AMST = auditory motor synchronization training, CMDT = cognitive-motor dual-task training, DST = digit span test, MMSE-K = mini mental status examination-Korean, ST = stroop test, TMT = trail making test.

Keywords: auditory motor synchronization, cognition, cognitive motor dual task, stroke

1. Introduction

Stroke occurs when blood flow to the brain is impeded due to blockage or rupture of vessels, often leading to long-term

disability.^[1] Approximately 25% of patients with stroke experience severe cognitive impairment (eg, dementia), while between 50% and 75% experience mild-to-moderate cognitive impairment.^[2] Preservation and enhancement of cognitive function are essential for the restoration of functional abilities and independence following stroke.^[3] Indeed, previous studies have indicated that both loss of motor function and cognitive are closely associated with functional recovery in activities of daily living such as walking, standing, etc.^[4] Many previous studies have demonstrated that cognitive-motor dual-task training (CMDT) is effective in promoting the recovery of both cognitive and motor functions following stroke.^[5,6]

The CMDT is the therapeutic method of promoting the recovery of both motor and cognitive functions from neurologic damage. CMDT is a training technique of performing a cognitive task during the execution of a motor task. It has usually been applied to the patients with stroke, brain damage, and Parkinson's disease to improve their balance and walking ability, and has actively been researched so far.^[7]

However, patients with stroke or neurologic impairment exhibit dual-task interference due to difficulties in performing cognitive and motor tasks simultaneously,^[8] which manifests as reduced performance on the primary motor task when a

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secondary cognitive task is introduced.^[9] The ability to perform 2 tasks simultaneously is significantly associated with attentional capacity and the allocation of cognitive resources.^[10,11] Previous research has indicated that patients with stroke exhibit decreased attentional capacity, concentration, memory function, and executive function relative to healthy controls, contributing to poor functioning in activities of daily living.^[12,13] After brain damage has occurred, most patients recover the ability to concentrate on simple tasks, although more complex/multidimensional tasks require further improvement.^[14] Some studies have suggested that attention improvement training involving various types of feedback (eg, auditory feedback) during task performance may improve functional outcomes following stroke.^[15–17] For example, Rossignol and Jones reported that training based on rhythmic auditory stimulation contributed to the activation of neural networks involved in the sequential processing of external auditory signals.^[18] During motor performance, auditory stimulation with a constant tempo is first transmitted to the temporal lobe, following which the movement is planned by the prefrontal cortex and accomplished via the cooperation of the premotor cortex, primary motor cortex, and supplementary motor area.^[19] Timing training using repeated rhythms with a constant tempo helps the brain process information sequentially and improves cognitive functioning associated with motor planning and sequencing, as well as motor performance.^[20] Rochester et al reported that such rhythmic external auditory cues are effective in reducing dual-task interference on functional performance in patients with Parkinson's disease.^[17] Furthermore, in the Choi et al's study compared the effects of dual tasks using external auditory cue and simple task without auditory cue on balance in patient with stroke. The results suggested that the dual tasks accompanied by external auditory cues were more effective in increasing balance.^[21] However, previous studies have failed to investigate cognitive changes during such tasks. Thus, it remains to be determined whether auditory cues presented at a rhythmic tempo exert these effects by enhancing motor as well as cognitive functions.

Based on the aforementioned evidence, we hypothesized that CMDT combined with auditory motor synchronization training (AMST) using rhythmic auditory cues would significantly improve cognitive function in patients with stroke. Therefore, we aimed to compare the effects of CMDT and CMDT with AMST on cognitive functioning in individuals with chronic stroke.

2. Material and methods

2.1. Study design

The present randomized control trial was approved by the institutional ethics committee of Soonchunhyang University (1040872-201605-BM-014). The study was performed at Glory Rehabilitation Hospital in Inchen, South Korea, from March to September 2016. About 42 eligible participants were firstly recruited. However, 8 participants did not meet inclusion criteria, and 4 participants refused to perform in the study. Finally a total of 30 participants were randomly divided an experimental group or control group at an equal ratio of 1:1.

2.2. Participants

Inclusion criteria were as follows: diagnosis of stroke with cerebral hemorrhage and cerebral infarction by a medical doctor

specialized in rehabilitation medicine or neurology; stroke occurrence more than 6 months prior to enrollment; score ≥ 21 on the Korean version of the mini mental status examination (MMSE-K), adequate understanding of the purpose of the study, capability to respond to oral instructions; upper and lower extremity recovery of Brunnstrom stage 4 or greater to ensure ability to perform dual tasks. Exclusion criteria were as follows: secondary diagnoses such as dementia; history of seizure; history of high blood pressure or angina preventing long-term participation in activity; and visual or auditory impairments that would interfere with task performance.

2.3. Randomization and blinding

Participants were allocated by a study coordinator into 2 groups using a computerized randomization table: an experimental group (n = 15) and a control group (n = 15) (true random number generator, www.random.org). Initially, 1 was entered as the minimum number, 30 as the maximum number, and the patients corresponding to the calculated numbers were randomly assigned to the experimental group. Next, the maximum number was replaced by 29, and the patients corresponding to the calculated numbers were randomly assigned to the control group. This process was repeated step by step, decreasing the maximum number at each iteration. Allocation of groups was sequentially numbered and sealed with black envelopes. Outcome assessors were not informed whether a patient was assigned to the experimental or the control group. Also, the data analyst was blinded to the intervention allocation. The study protocol followed the recommendations outlined in the Consolidations Standards of Reporting Trials (CONSORT) (Fig. 1).

2.4. Intervention methods

2.4.1. Control group. Participants of the control group received three 30-minute sessions of CMDT per week for 6 weeks. CMDT was comprised of motor tasks associated with balance and posture while sitting and standing, which were performed simultaneously with cognitive tasks associated with attention, memory, and executive function. For example, participants were required to count backwards from a specific number while sitting

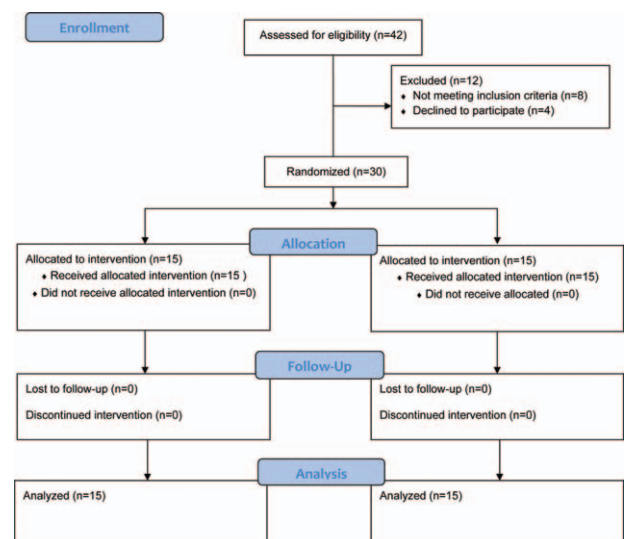


Figure 1. Flow diagram of the study process for the 2 groups.

Table 1**Comparison of CMDT and CMDT+AMST programs.**

CMDT	Motor task	CMDT group underwent only CMDT (30 min/subject) Sitting on chair and hitting a small balloon Sitting on chair and wiping the windows Sitting on an unstable surface (therapeutic ball), and building a static corn Balancing on both feet, moving the ring in a standing posture Balancing for 5 min or more in semi-tandem posture Repeating sit-up 10 times
	Cognitive task	Name words: Patients were instructed to name food, states, and family members Counting numbers backward: Patients were instructed to recite numbers from ten to zero Backward counting days and months: Patients were instructed to recite days from Sunday to Monday, and months, from December to January Listening to a number and counting backward: by twos and threes Tell daily story: Patient were instructed to tell stories about their daily life, such as what they ate for breakfast and so on Spell the word backward: Patients were instructed to spell a word backward (such as "water," "tree," and "person") Continuous subtraction of 7 from 100 Stroop task: Patients were instructed to name a word or color, ignoring the meaning of the word
CMDT + AMST		CMDT + AMST group underwent the CMDT program (15 min/subject) in addition to AMST (15 min/subject) AMST was conducted using the Interactive Metronome program: <i>Both hand task</i> Hitting the trigger with both hands rhythmically, while making a semi-circular motion in accordance with the reference sound <i>Right hand task</i> While wearing a trigger on the right hand, hitting the top of the right thigh rhythmically, so as to draw a semi-circular motion to match the reference sound <i>Left hand task</i> While wearing a trigger on the left hand, hitting the top of the left thigh rhythmically, so as to make a semi-circular to match the reference sound

AMST = auditory motor synchronization training, CMDT = cognitive-motor dual-task training.

up, and to name the days of the week in reverse order from Monday to Sunday during trunk rotation (Table 1).

2.4.2. Experimental group. Participants of the experimental group received CMDT combined with AMST (CMDT + AMST). They enrolled intervention in the separated room from control group. The CMDT and AMST components of each session lasted 15 minutes each, for a total session time of 30 minutes. The CMDT portion of the combined training was conducted in the same manner as described for the control group. AMST consisted of tasks performed using an interactive metronome (IM pro 9.0, Interactive Metronome, Sunrise, Florida).^[2] The intervention environment consisted of a computer equipped with the interactive metronome, additional hardware, software, a headset, a hand trigger, and a foot trigger. Participants performed 13 motor tasks while pressing the trigger at an appropriate interval from the reference sound, which was played through the headset. The following AMST tasks were selected based on their appropriateness for patients with stroke: 2-hand task, right-hand task, and left-hand task. The 2-hand task involved tapping both hands in time to the reference sound while performing a semi-circular movement, while each single-handed task involved pressing the right or left trigger in response to the reference sound (Table 1, Fig. 2).

2.5. Outcome measures

The primary outcome was the attention changes in the 2 groups. The secondary outcome was the cognitive control and flexibility based on executive function. To evaluate primary and secondary outcomes, participants were assessed using sub-items included in the Seoul Neurocognitive Screening Battery developed by Kang et al, as follows: trail making test (TMT; A and B), stroop test (ST;

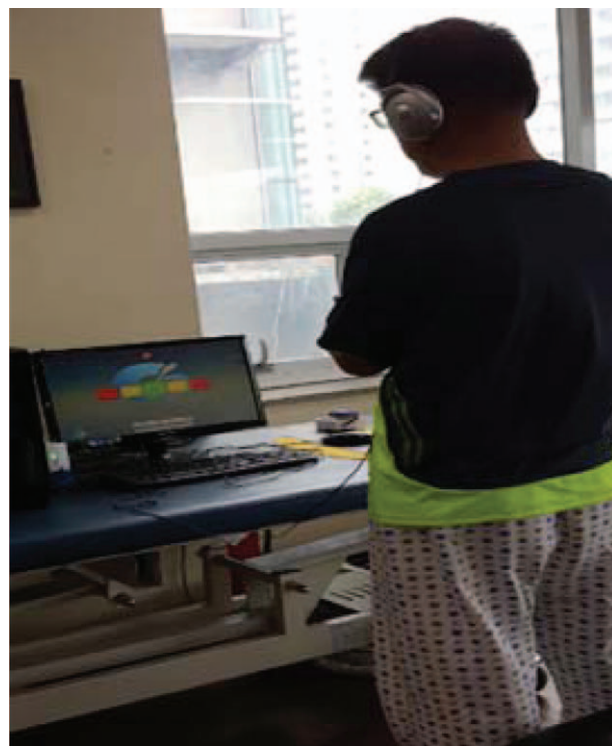


Figure 2. Auditory motor synchronization training of the experimental group. Auditory motor timing training used interactive metronome. Experimental group received cognitive motor dual task training with auditory motor synchronization training.

word and color), and digit span test (DST; forward and backward).^[22] The TMT is designed to assess psychomotor speed, divided attention, and cognitive flexibility based on visual-motor tracking ability. The ST is designed to measure frontal lobe functions such as inhibitory function, cognitive control, cognitive flexibility. The DST is designed to evaluate attention for auditory input and is not influenced greatly by age, education, or intelligence. All tests were administered both prior to and 6 weeks following the first day of the intervention to evaluate changes in cognitive function in both groups.

2.6. Statistical analysis

All statistical analyses were performed using Statistical Package for the Social Science (SPSS) software v.20.0 (IBM, North Castle, NY). The sample size was calculated by mean difference in the TMT score between groups, as reported in the study by Choi et al^[21] The effect size was 1.1, calculated by G*Power software version 3.1, with $\alpha=0.05$ and $\beta=0.8$. Kolmogorov–Smirnov test analyzed data normality. The Mann–Whitney *U* test was used to analyze differences in continuous variables between the CMDT and CMDT + AMST groups, while χ^2 test and Fisher's exact test were used to compare categorical variables. The Wilcoxon signed rank test was used to analyze changes within each group. Analysis of covariance was used to compare changes between pre- and post-intervention between the 2 groups. The level of statistical significance was set at $P < .05$ level. All *P*-values were 2-tailed.

3. Results

Between March and September 2016, a total of 42 participants with stroke were initially assessed for entry in the study (Fig. 1). Twelve participants, who did not meet the inclusion criteria of the study ($n=8$) or disagreed to participate in the study ($n=4$), were excluded. Finally, 30 participants were included in the study and randomly assigned to the experimental ($n=15$) or control group ($n=15$). All 30 participants completed the intervention (Fig. 1).

The demographic characteristics of the participants in each group at base line are shown in Table 2. No significant differences in median age were observed between the CMDT+AMST group (54 years; range: 45–69 years) and CMDT group (52 years; range: 42–67 years) ($P=.851$). In addition, no significant differences in sex, stroke hemisphere, MMSE-K scores, or Brunnstrom recovery stage of the upper and lower extremities were observed (Table 2).

The normality of the primary data for each group at baseline is shown in Table 3. The data showed normality only for TMT-A ($P=.200$), TMT-B ($P=.200$), and ST-color ($P=.200$) in the CMDT group. While in the CMDT+AMST group, it showed normality only for ST-word ($P=.107$) and ST-color ($P=.096$). Since normality was not observed for both groups on the same data set, non-parametric methods analyzed results (Table 3).

The cognitive changes within each group are shown Table 4. In the CMDT group, there were significant changes in TMT-A and B ($P=.001$), DST-forward ($P=.001$), DST-backward ($P=.000$), ST-word ($P=.001$), and ST-color ($P=.002$) scores following the intervention (Table 2). In the CMDT + AMST group, there were also significant changes in TMT-A and B ($P=.001$), DST-forward, DST-backward ($P=.001$ each), ST-word, and ST-color ($P=.001$) scores following the intervention (Table 4).

The cognitive changes between 2 groups are shown Table 5. Significant differences in TMT-A ($P=.001$), DST-forward ($P=.027$), DST-backward ($P=.002$), and ST-word ($P=.025$) scores were observed between the groups (Table 5). No significant difference were found between 2 groups in TMT-B, ST-color after intervention ($P > .05$, Table 5).

4. Discussion

Complex environments and multitasking may interfere with an individual's ability to focus attention following stroke, limiting the use of attentional strategies in specific situations.^[17] Therefore, external cues, such as rhythmic auditory stimulation at a constant tempo, may require less effort and attention, and their use during more complex activities may facilitate dual-task

Table 2

Demographic characteristics of the study groups.

	Experimental group (n=15) median [range]/n (%)	Control group (n=15) median [range]/n (%)	<i>P</i>
Age (year)	54 [45–69]	52 [42–67]	.851
Sex			
Male	8 (53.3)	9 (60.0)	.713
Female	7 (46.7)	6 (40.0)	
Stroke hemisphere			
left	8 (53.3)	11 (73.3)	.450
right	7 (46.7)	4 (26.7)	
Brunnstrom recovery stage upper extremity			
III	6 (40.0)	3 (20.0)	.458
IV	5 (33.3)	4 (26.7)	
V	2 (13.3)	3 (20.0)	
VI	2 (13.3)	5 (33.3)	
Brunnstrom recovery stage lower extremity			
III	3 (20.0)	0 (0)	.124
IV	5 (33.3)	5 (33.3)	
V	6 (40.0)	5 (33.3)	
VI	1 (6.7)	5 (33.3)	
MMSE-K (score)	25 [20–28]	27 [23–30]	.103

Experimental group: CMDT+AMST group, Control group: CMDT group.

AMST=auditory motor synchronization training, CMDT=cognitive-motor dual-task training, MMSE-K=mini mental status examination-Korean.

Table 3
Normality of the primary data on the groups.

		Kolmogorov–Smirnov		
		Statistics	df	P
TMT-A	CMDT	0.180	15	.200
	CMDT + AMST	0.258	15	.008
TMT-B	CMDT	0.120	15	.200
	CMDT + CMDT	0.242	15	.018
DST-forward	CMDT	0.301	15	.001
	CMDT + AMST	0.234	15	.027
DST-backward	CMDT	0.514	15	.000
	CMDT + AMST	0.251	15	.012
ST-word	CMDT	0.252	15	.011
	CMDT + AMST	0.201	15	.107
ST-color	CMDT	0.130	15	.200
	CMDT + AMST	0.203	15	.096

AMST = auditory motor synchronization training, CMDT = cognitive-motor dual-task training, DST = digit span test, ST = stroop test, TMT = trail making test.

performance.^[23,24] In the present study, we examined the effect of CMDT + AMST involving the use of such cues on dual-task performance and cognitive functions such as attention, processing speed, and executive functioning.

Our findings indicated that the combined CMDT and AMST intervention was more effective in improving cognitive function than CMDT alone. Combined CMDT and AMST intervention

resulted in significant improvement of DST-forward and DST-backward scores. These results indicated that the combined CMDT and AMST intervention, using rhythmic tempo, was effective in improving the concentration and auditory attention span. Although the TMT-B and ST-color scores was not significantly different after intervention, the TMT-A and ST-word scores was significant improved in the CMDT + AMST group. Also, it was more effective in improving attention capacity and attention. However, these results had limitation due to the small number of participants. Choi et al reported that the application of auditory feedback during dual-task training enhances cognitive attention and executive function in patients with stroke.^[21] Similarly, our findings revealed that combined CMDT and AMST using rhythmic auditory cues exerted a positive effect on attention, memory, and executive function.

According a study by Moucha and Kilgard, the use of rhythmic cues with a constant tempo allows the listener to experience a pattern between sensory input and motor output that facilitates the production of neurotransmitters, increases cerebral cortical plasticity, and enhances cognitive processing.^[25] Moreover, Rochester et al reported that motor dual-task training based on a rhythmic cue had positive effects on attentional capacity and motor performance in patients with Parkinson’s disease.^[26] Baker et al further reported that cues combining attentional strategy with a rhythmic beat improved executive functioning in patients with Parkinson’s disease engaged in dual-task training.^[24] Our findings are in accordance with the results of these

Table 4
Changes in cognitive functions within each groups.

	Experimental group (n = 15)				Control group (n = 15)			
	Pre-intervention median (IQR)	Post-intervention median (IQR)	Z	P	Pre-intervention median (IQR)	Post-intervention median (IQR)	Z	P
TMT-A	80.0 (122.0–55.0)	42.0 (56.0–32.0)	–3.410	.001*	63.0 (105.0–29.0)	45.0 (78.0–25.0)	–3.412	.001*
TMT-B	150.0 (195.0–131.0)	92.0 (150.0–75.0)	–3.408	.001*	119.0 (146.0–85.0)	98.0 (122.0–75.0)	–3.415	.001*
DST-forward	4.0 (5.0–4.0)	7.0 (7.0–6.0)	–3.443	.001*	5.0 (5.0–3.0)	5.0 (6.0–5.0)	–3.269	.001*
DST-backward	3.0 (4.0–3.0)	5.0 (6.0–5.0)	–3.335	.001*	3.0 (3.0–3.0)	4.0 (5.0–4.0)	–3.626	.000*
ST-word	80.0 (108.0–54.0)	95.0 (123.0–65.0)	–3.409	.001*	62.0 (108.0–58.0)	84.0 (112.0–72.0)	–3.153	.002*
ST-color	25.0 (50.0–13.0)	58.0 (75.0–28.0)	–3.411	.001*	46.0 (72.0–21.0)	56.0 (82.0–40.0)	–3.411	.001*

Experimental group: CMDT + AMST group, Control group: CMDT group.
DST = digit span test, ST = stroop test, TMT = trail making test, IQR = inter quartile range (Q₃–Q₁).
Wilcoxon signed rank test: *P < .05.

Table 5
Comparison of changes in cognitive functions between the 2 groups.

	Experimental group (n = 15)	Control group (n = 15)	Source	Sum of squares	df	F	P
	mean ± SD	mean ± SD					
TMT-A	47.86 ± 23.22	50.53 ± 31.31	Covariance (Pre-TMT-A)	18,506.606	1	179.850	.000*
			Group	1512.598	1	14.702	.001*
TMT-B	105.66 ± 41.02	97.40 ± 31.83	Covariance (Pre-TMT-B)	26,309.655	1	62.109	.000*
			Group	1621.200	1	3.827	.061
DST-forward	6.53 ± 1.24	5.53 ± 1.24	Covariance (Pre-DST-forward)	16.371	1	16.313	.000*
			Group	5.488	1	5.468	.027*
DST-backward	5.26 ± 0.88	4.33 ± 0.48	Covariance (Pre-DST-backward)	0.185	1	0.355	.556
			Group	6.168	1	11.827	.002*
ST-word	92.60 ± 33.45	87.93 ± 25.09	Covariance (Pre-ST-word)	22,597.066	1	322.906	.000*
			Group	394.662	1	5.640	.025*
ST-color	51.40 ± 24.54	56.53 ± 22.89	Covariance (Pre-ST-color)	14,035.104	1	217.757	.000*
			Group	197.574	1	3.065	.091

Experimental group: CMDT + AMST group, Control group: CMDT group CMDT = cognitive-motor dual-task training, DST = digit span test, SD = standard deviation, ST = stroop test, TMT = trail making test.
Analysis of covariance (ANCOVA); *P < .05.

previous studies, which collectively indicate that combined CMDT and AMST may be more effective than CMDT alone in improving attention, cognitive flexibility, and executive function following stroke.

This study applied the traditional CMDT method in addition to computer-based rhythmic tempo training. The study by De Luca et al provided evidence, although insufficient, to show that computerized cognitive rehabilitation is effective in improving the functioning of patients with severe acquired brain injury.^[27] However, a recent study has shown that standard cognitive training combined with semi-immersive virtual reality improved the functioning of patients with neglect.^[28] Therefore, it is necessary to verify whether applying the traditional CMDT method as a virtual reality-based cognitive training can positively affect the cognitive functions. The present study possesses some limitations of note. First, the sample size was relatively small because few patients at our institution were able to participate in the experimental condition. Second, this study did not examine long-term cognitive changes during a follow-up period. Therefore, further research in the form of long-term, multicenter studies is required to more fully elucidate the cognitive benefits of combined CMDT and AMST in patients with stroke. Third, this study examined the change of cognitive function using only the general assessment applied in the rehabilitation hospital setting. Therefore, further research will be necessary specific examination using f-MRI to know neural changes.

5. Conclusion

In summary, the combined intervention CMDT with AMST was shown to be an effective method for increasing cognitive functions of patients with stroke rather than only CDMT. Therefore, this method can be considered as a new approach to improve cognitive functions when try to CDMT training.

Author contributions

Conceptualization: Myoung-Ok Park, Sang-Heon Lee.

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Funding acquisition and investigation: Sang-Heon Lee

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Supervision: Sang-Heon Lee.

Validation: Myoung-Ok Park, Sang-Heon Lee.

Visualization: Myoung-Ok Park, Sang-Heon Lee.

Writing – original draft: Myoung-Ok Park.

Writing – review & editing: Myoung-Ok Park, Sang-Heon Lee.

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