Learning of the Bimanual Cup-Stacking Task in Individuals with Chronic Stroke Improved with Dyad Training Protocol

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Objective: *To compare the effects of dyad and individual training on the learning of bimanual cup-stacking in individuals with chronic stroke.*
Material and Method: *Twenty participants were divided into dyad and individual groups. The dyad group performed the task in pairs alternating between performing and observing, while the individual group performed individually. On the first day (acquisition phase: AP), all participants performed 20 trials. On the following day (retention phase: RP), they performed 10 trials; each participant individually performed five trials without verbal feedback followed by five trials with verbal feedback. The dependent measures were movement time (MT), which was a measure of motor execution, and reaction time (RT), a measure of motor planning.*
Results: *During the initial trials, the dyad group performed the task with longer MT. By the end of the AP, their time was significantly shorter. At the RP, only the dyad group maintained the improved MT of cup stacking. Although the RT was not different between the two groups at the RP, only the RT of the dyad group reduced significantly at the RP compared with block 1 of the AP.*
Conclusion: *In individuals with chronic stroke, the dyad training protocol greatly enhanced the execution speed of the bimanual cup-stacking task when compared with the individual training protocol. Planning the task also improves dyad training.*

Keywords: *Bimanual task, Dexterity, Observational learning, Stroke*

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Stroke is a leading cause of disability worldwide including Thailand[1,2]. Individuals after stroke have sensorimotor impairments in the contralateral upper and lower limbs[3,4]. Approximately 80% have residual upper extremity motor deficits[5] encompassing motor acquisition and motor learning[6]. The optimal intervention needs to enhance improvement in both aspects of movement[7,8]. One of several methods to enhance both motor acquisition and motor learning in non-disabled adults is dyad training[9,10].

Dyad training, performing in pairs, has been reported to enhance motor execution during the training day (acquisition phase) and the following day (retention phase)[9,10]. Granados and Wulf found that dyad training was more effective than individual training when performing a bimanual cup-stacking task[10]. They concluded that the benefits of dyad training might be a result from the following reasons: 1) helps the observer recognize the correct movement, 2) helps observe show possible errorsintheir partner, 3) determines the ways to correct the error, 4) provides twice as many practice trials combining observation and actual performance, 5) facilitates mental rehearsing of the task, and 6) increases the learners' motivation by adding a competitive component to the practice situation[10,11]. Observation activates mirror neurons in non-disabled individuals and those with stroke[12-14]. Mirror neurons have a beneficial effect in the learning of motor execution and motor planning[14-19].

The purpose of the present study was to compare the effects of dyad training with an individual training protocol on two aspects of motor learning: 1)

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motor execution (measured by movement time) and 2) motor planning (measured by reaction time).

Material and Method

Participants

Right-handed participants with stroke with mild to moderate impairment of upper extremity (the upper extremity Fugl-Myer Motor Assessment >36/66) were recruited. They were divided equally into individual group and dyad group by matched pair method relative to their paretic side, age and level of arm impairment. Within the dyad group, partners had equal level of arm impairment and opposite paretic arms. A written informed consent form approved by Siriraj Institutional Review Board (SIRB, COA: Si278/2009), Faculty of Medicine, Siriraj Hospital, Mahidol University was read and signed before enrollment.

Experimental set up and task

The experimental task was the bimanual cup-stacking task. All participants were asked to stack the cups in two phases: "up-stacking" (build three-cup towers in 3x6x3 pyramid stacks) and "down-stacking" (putting the 3 pyramid stacks into their original three towers) as quickly as possible. After the auditory signal each participant immediately started the task with their non-paretic hand and alternated hand movements until completing the task. Reaction time (RT) in each trial was measured in milliseconds from onset of auditory signal until the hand lifted off the starting switch. Movement time (MT) was the time the non-paretic hand lifted off the start switch until it returned to the switch at the end of the task. Participants in the individual group performed on their own, whereas participants in the dyad group performed in pairs and took turns with their partner.

Procedure

One trial of the task was demonstrated by the experimenter and followed by two practice trials. The testing sessions took place over two days. On day one, the acquisition phase (AP), all participants performed 20 physical trials of the task. In the individual group, participants had a 50-second break between trials, the approximate time of the trials, whereas participants in dyad group alternated between the physical performance trial and the observational trial. RT and MT were provided as feedback (FB) to both groups. On day two, the retention phase (RP), all participants individually performed the first five trials without FB followed by another five trials with FB.

Data analysis

The data were averaged every five trials, termed a block. Performance was evaluated in two phases; AP and RP. The AP compared the RT and MT in all blocks of day one by analysis of variance (ANOVA). The RP was analyzed in two different aspects: 1) retained capability and 2) retrieval capability.

The retained capability was assessed by comparing block four day one to block one day two. Retrieval capability compared block four of the day one to block 2 on day two. Multiple comparisons for repeated measures using Bonferroni correction compared MT and RT among the six blocks in the two groups and between the two groups in each block.

Results

Twenty right-handed participants with stroke with mild to moderate impairment of upper extremity (the upper extremity Fugl-Myer motor assessment >36/66) participated. The individual group was between 50 and 79 years and between 3 and 59 months after stroke onset. The dyad group was between 50 and 79 years and between 3 and 84 months after stroke onset.

Acquisition phase-day one

MT improved significantly across blocks in both groups (Table 1). Significant difference was found in the patterns of improvement between the dyad and individual groups as evidenced by block x group interaction (Table 1).

For RT, significant main effect of block ($p< 0.001$) with no main effect of group or block x group interaction (Table 2). This means that both groups improved in the reaction time in the same pattern across all blocks of the acquisition phase.

Retention test-day two

Retained capability

On average, the dyad group had shorter MT than the individual group (Table 1). When FB was not given, a significant difference was observed in retained capability between the dyad and the individual group as evidenced by block x group interaction (Table 1) resulting in the dyad group performing better.

Retrieval capability

When participants received FB in the retention test, they improved their performance back to the same level as the end of the acquisition phase (Table 1). Although, the difference between two groups was not significant, the participants in the two groups retrieved

Table 1. Mean (standard deviation) values in milliseconds of movement time in all blocks of the acquisition phase and retention test for the individual and dyad groups

	Blocks	Groups	
		Individual (n = 10)	Dyad (n = 10)
Acquisition phase (day 1)	1	65.51 (13.28)	70.81 (14.39)
	2	52.19 (11.60)	48.45 (15.17)
	3	46.41 (12.46)	39.99 (12.42)
	4	41.83 (11.50)	35.87 (9.44)[a,b]
Retention test (day 2)	1	51.84 (13.66)	40.14 (12.61)[c]
	2	47.34 (15.90)	34.59 (10.33)[d]

[a] significant main effect of blocks 1, 2, 3 and 4 of the acquisition phase at $p<0.05$
[b] significant interaction between blocks (1, 2, 3, 4 of the acquisition phase) and group at $p<0.05$
[c] significant interaction between blocks (block 4 of the acquisition phase and block 1 of the retention test) and group at $p<0.05$
[d] significant interaction between blocks (block 4 of the acquisition phase and block 2 of the retention test) and group at $p<0.05$

Table 2. Mean (standard deviation) values in milliseconds of reaction time in all blocks ofthe acquisition phase and retention test for individual and dyad groups

	Blocks	Groups	
		Individual (n = 10)	Dyad (n = 10)
Acquisition phase (day 1)	1	664.26 (212.46)	632.16 (177.39)
	2	620.54 (218.87)	510.52 (179.70)
	3	634.54 (204.93)	451.42 (153.32)
	4	530.26 (149.39)	483.30 (135.17) [a]
Retention test (day2)	1	620.64 (269.67)	521.22 (152.75)
	2	630.74 (318.00)	467.36 (89.28)

[a] significant main effect of blocks 1, 2, 3 and 4 of the acquisition phase at $p<0.05$

their ability to perform the task differently as evidenced by block x group interaction (Table 1). For RT, no main effect or interaction effect was observed for any of the variables (Table 2). This means that both groups retained and retrieved their reaction time in the same pattern during the retention test. Although no block X group interaction occurred, within the dyad group the RT improved significantly from the first block of the acquisition (650 ms) to the last block of the retention test (467 ms). This reduced RT in the dyad group was not observed in the individual group (Table 2).

Discussion

The purpose of our study was to compare effects of the dyad training and individual training on motor learning in individuals with chronic stroke. Overall, the results revealed that the dyad group initially performed with longer movement time but that time rapidly decreased at the end of the acquisition day, compared with the individual group. Moreover, the dyad group demonstrated better retained and retrieval capability in the retention test on the following day. Compared with the benefits on motor execution, measured by the movement time, the dyad training protocol showed less improvement in the planning of the task measured by the reaction time.

The possible benefits of dyad training to enhance the acquisition and learning to execute bimanual cup-stacking task might be through: 1) increasing memory, 2) promoting error detection and 3) facilitating motivation. Additionally, observing the partner performing the task during dyad training may allow a participant to understand better the skill[20-22]. Observation, termed action observation, facilitates the formation of motor memory[23-25]. Therefore, observing a task may reduce motor memory deficit in individuals

with stroke. Observation can also encourage error recognition[26-28]. The dyad group might be additionally motivated by observing another similarly involved individual perform the same task. We questioned the dyad group using a brief yes/no questionnaire regarding their perception of the advantages of dyad training. The participants reported a motivational effect. They wanted to out perform their partners after observing their partners' performance. The motivation might have caused learners to set higher goals than they normally would. Others have investigated effect of goal-setting on learning performance[29-32]. Competition between partners possibly led to a greater improvement of their skill in the dyad group.

The dyad training may increase activation in a neural network called mirror neuron system[18] resulting in improved motor behaviors. Mirror neurons are sets of visuo-motor neurons that are active both during the execution of a movement and during the observation of the same movement[33]. This system plays a key role in the rehabilitation of individuals with stroke who have motor impairment of their upper limbs. Activation of the mirror neuron system promotes action understanding, enhances learning of novel skills, improves motor imagery of observed actions and facilitates motor memory[17,34-36]. Within the dyad group the reaction time, representing motor planning, improved from the first block, an average of 650 ms to the last block, 467 ms. These reaction times are much slower than the 250-300 found in non-disabled adults. Observation duration greater than the one minute in the dyad training may engage the mirror neuron system further, enhancing movement planning. A few studies have reported that mirror neurons fired with sufficient duration of observation. The imaging study showed the benefit of action observation from video with the duration of 10-30 minutes to activated primary motor cortex in normal brain similar to that induced by practice[13]. Another study reported that alternating between observing and executing the same action about sixminutes activated sensory-motor network in individuals with stroke[18]. Further investigation of the effect of observation duration in dyad training on motor planning and motor learning of the bimanual task is needed.

In summary, in individuals with stroke, the dyad training protocol greatly enhanced the execution of the bimanual cup stacking when compared with the individual training protocol. Reaction time also improved within the dyad group. In the clinical environment, practicing in pairs would increase efficiency in terms of cost and time because two participants can be treated at the same time. Therefore, dyad training may be a beneficial protocol to rehabilitate persons with chronic stroke having mild to moderate impairment of the upper extremity.

What is already known on this topic?

Dyad training, performing in pairs, has been reported to enhance motor execution and motor learning for nondisabled adults. The dyad training was reported to be more effective than individual training when performing a bimanual cup stacking task. However, whether dyad training is beneficial to individuals who have impaired performance of upper extremity after stroke is still unknown.

What this study adds?

This is the first study to demonstrate that for individuals with chronic stroke, the dyad training protocol greatly enhanced the execution more than the planning of the bimanual cup-stacking, when compared with the individual training protocol.

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Potential conflicts of interest

None.

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การฝึกเป็นคู่ส่งเสริมการเรียนรู้ทักษะเรียงถ้วยด้วยมือสองข้างในผู้ป่วยโรคหลอดเลือดสมอง

จารุกูล ตรีไตรลักษณะ, สุวีณา ค้าเจริญ, วิมลวรรณ เหียงแก้ว, นาราพร ประยูรวิวัฒน์

วัตถุประสงค์: *เพื่อเปรียบเทียบผลการฝึกเป็นคู่และฝึกตามลำพังต่อการเรียนรู้ทักษะเรียงถ้วยด้วยมือสองข้าง ในผู้ป่วยโรคหลอดเลือดสมอง*

วัสดุและวิธีการ: *แบ่งผู้ฝึกออกเป็น 2 กลุ่ม กลุ่มฝึกเป็นคู่คือ ในขณะที่ผู้ฝึก 1 คนกำลังฝึกอยู่ ผู้ฝึกอีกคนนั่งสังเกต การเรียงถ้วย จากนั้นสลับกันฝึก ส่วนอีกกลุ่มฝึกเพียงลำพัง ในวันแรกทุกคนฝึก 20 ครั้งและในวันถัดไปทดสอบอีก 10 ครั้ง โดย 5 ครั้งแรกไม่ทราบเวลาเรียงถ้วยของตนหลังการฝึก และ 5 ครั้งหลังทราบเวลาหลังการฝึก ตัวแปรของการศึกษาคือ เวลาในการเรียงถ้วยซึ่งเป็นการประเมินกระบวนการสั่งการการเคลื่อนไหวและเวลาในการตอบสนอง ซึ่งเป็นการประเมินการวางแผนการเคลื่อนไหว*

ผลการศึกษา: *พบว่าในการฝึกวันแรกกลุ่มฝึกเป็นคู่ใช้เวลาในการเรียงถ้วยในช่วงแรกมากกว่ากลุ่มฝึกลำพัง จากนั้นพัฒนาจนเร็วกว่ากลุ่มฝึกลำพังเมื่อสิ้นสุดการฝึก ในวันถัดมากลุ่มฝึกเป็นคู่ยังคงความสามารถสั่งการเคลื่อนไหวได้ดี กว่ากลุ่มที่ฝึกลำพัง กลุ่มฝึกเป็นคู่ใช้เวลาในการตอบสนองลดลงเมื่อเทียบกับวันแรก*

สรุป: *ผลการศึกษาแสดงให้เห็นว่าการเรียนรู้ทักษะการเรียงถ้วยด้วยมือทั้งสองข้างในผู้ป่วยโรคหลอดเลือดสมอง การฝึกเป็นคู่ส่งเสริมกระบวนการสั่งการได้ดีกว่าการฝึกเพียงลำพัง การฝึกเป็นคู่ส่งเสริมการวางแผนการเคลื่อนไหวด้วย*