Dyad Training Protocol on Learning of Bimanual Cup Stacking in Individuals with Stroke: Effects of Observation Duration

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Objective: *To examine the effects of dyad training protocol with different observation-durations on the learning of bimanual cup stacking in individuals with chronic stroke*
Material and Method: *Participants (experimental and control groups) completed the task in pairs. On the first day (acquisition phase: AP), the experimental group observed their partner 6 minutes and alternately performed the task 6 minutes for 4 sessions. The control group underwent 1 minute of observing alternated with 1 minute of performing the task for 24 sessions. On the following day (retention phase: RP), both groups performed the task individually first without feedback, followed by with feedback. The dependent measures were movement time (MT), a measure of motor execution, and reaction time (RT), a measure of motor planning.*
Results: *In the AP, both groups completed the task with decreased MT. The experimental group showed significantly greater improvement of MT than the control group. As for RP, only the experimental group performed the task with less MT when compared with the last block of AP. Additionally, this group significantly decreased MT when compared with the first block. Although, a similar pattern was observed of decreased RT for both groups, in the RP, the experiment group had shorter RT compared with that of the control group.*
Conclusion: *For individuals with chronic stroke, compared with the 1-minute observation alternating with physical practice, the 6-minute duration resulted in greater persistent learning. Moreover, the 6-minute duration greatly enhanced the planning of bimanual cup stacking.*

Keywords: *Action observation, Bimanual task, Dexterity, Mirror neuron system*

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Stroke is the leading cause of death and disability in adults worldwide including Thailand[1,2]. In Thailand, the Ministry of Public Health reported 15,000 deaths from stroke in 2008[2]. After stroke, individuals have significant sensory-motor impairment and disability of the upper and lower extremities on the contralateral side of the lesion. Studies indicated that after 6 months, only 11.6% of them had complete functional recovery of the upper extremities and 38% had partial recovery[3,4]. Comparing among the upper extremity, lower extremity and trunk, the recovery of the upper extremity was slowest during rehabilitation period[5]. In addition to sensory-motor impairment, cognitive deterioration was noted including memory, orientation, and attention. Therefore, the speed and capacity of information processing decrease in stroke cases. That would result in longer reaction time compared with that of nondisabled participants[6-8]. Moreover, individuals with cognitive impairment and slow of perception showed slow recovery. Thus, to regain motor function the information processing capacity requires training. If the effectiveness of stroke rehabilitation is limited, it would lead to long-term disability and great expense of rehabilitation. One study has reported prolonged direct and indirect expenses of rehabilitation programs at approximately 1 million baht each case[9]. Therefore, stroke rehabilitation programs should not focus only on training effectiveness but also cost-effectiveness.

One of several methods to increase training effectiveness and efficiency of motor acquisition and motor learning in nondisabled adults is dyad training[10,11]. Dyad training, performed in pairs, has been reported to enhance motor execution during the

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training day (acquisition phase) and the following day (retention phase)[10,11]. Granados and Wulf found that dyad training was more effective than individual training when nondisabled adults performed a bimanual cup stacking task[11]. We recently demonstrated that dyad training protocol improved learning of bimanual cup stacking better than individual training for individuals with post chronic stroke[12].

The benefit of dyad training is possibly from observing the movements. During movement observation, the observer may recognize the correct movement, detect possible errors in their partner, determine ways to correct the error, facilitate mental rehearsing of the task, and increase the learner's motivation by adding a competitive component to the practice situation[11,13]. Several studies demonstrated the activation of neurons, called "mirror neurons" in the sensorimotor area during observation. These neurons fired both during observation and when performing actual movement[14-17]. Thus, that the effectiveness of dyad training stems partly from activation of the Mirror Neuron System (MNS) is reasonable. Importantly, the study of Stefan and colleagues (2005) showed that observing an action for 6 minutes significantly evoked the primary motor cortex using transcranial magnetic stimulation (TMS) compared with 1-minute duration, similar to that induced by practice[18]. Additionally, Celnik and colleagues (2008) showed that the magnitude of memory formation, measured by TMS, depended upon the types of motor training. When observing thumb movements in the same direction that was physically trained, the "congruent movement" produced a larger motor memory formation than when observing the movement in a direction opposite to that physically trained. This study indicated that the observation of congruent movement combined both physical and enhanced motor training after stroke[19]. The aforementioned evidence raises the possible benefits of dyad training protocol by observing the movements of their partner that might result from activation of the mirror neuron system. However, unclear evidence exists to show that the observation duration in dyad training plays a beneficial effect on motor planning and motor learning. Therefore, the objective of this study was to investigate the effects of observation duration on learning of bimanual cup stacking among individuals with stroke.

Material and Method

Participants

Right-handed individuals with chronic stroke due to a lesion in the territory of the middle or anterior cerebral artery for more than 6 months were recruited by the following inclusion criteria: i) mild to moderate arm motor impairment (the upper extremity Fugl-Myer Motor Assessment >36/66), ii) able to follow simple commands (MoCA score >23), iii) able to sit >30 minutes independently and iv) able to reach, grasp and release a cup. They were divided equally into control and experimental groups by matched pair method relative to their paretic side, age range and level of arm impairment (Fig. 1). A written informed consent form, approved by the Mahidol University Institutional Review Board (MU-IRB, COA No. 2012/060.2903), Mahidol University, was read and signed before enrollment.

Experimental setup and task

The experimental task selected was bimanual cup stacking task. All participants were asked to stack the cup in 2 phases: "up-stacking" (build three cup towers in a 3x6x3 pyramid stacks) and "down-stacking" (putting the 3 pyramid stacks back to their original three towers) as quickly as possible (Fig. 2). After an auditory signal, each participant immediately started the task with their nonparetic hand and alternated hand movements until completing the task. Reaction time (RT) in each trial was measured in milliseconds from onset of the auditory signal until the hand lifted off the

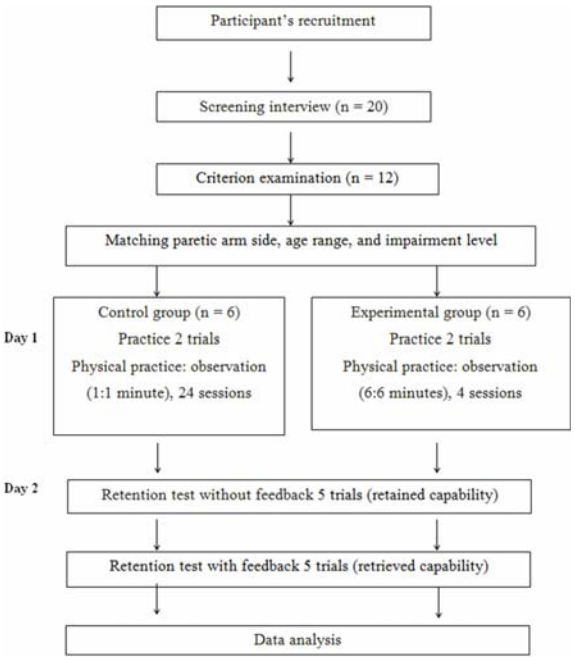

Fig. 1 Experimental protocol and participant allocation.

starting switch (Fig. 2). Movement time (MT) was the time that the nonparetic hand lifted off the start switch until it returned to the switch at the end of the task.

Movement time (MT) of cup stacking in each trial was recorded and used as feedback for participants. Before the practice session, each participant received instructions regarding the task and demonstration of one trial. Then they were asked to perform the task one trial as they preferred and one trial as fast as possible. Before practice began, both groups received the instruction that they should observe their partner and observe the task carefully with the intention to imitate their partner movement and perform the task as quickly as possible. Fig. 1 illustrates the experimental protocol. The testing sessions took place over 2 days. On day 1, the acquisition phase (AP), all participants performed 24 sessions. The control group observed 1 minute alternating with practice 1 minute for 24 sessions. In the experiment group, two participants trained by observing their partner 6 minutes and took turns to practice 6 minutes for 4 sessions. During the practice session, the control group received a summary feedback (FB) about their MT at the end of 6, 12, 18 and 24 minutes of observation duration. Meanwhile, the experimental group received their FB at the end of each block. On day 2, the retention phase (RP), all participants individually performed the first 5 trials without FB (retained capability) followed by another 5 trials with FB (retrieval capability).

Data analysis

The data were averaged every 6 minutes, termed a block. Performance was evaluated in 2 phases: AP and RP. The AP compared the MT and RT in all blocks of the first day by analysis of variance (ANOVA). The RP was analyzed in 2 aspects: 1) retained capability and 2) retrieval capability.

The retained capability was assessed by comparing block 4 day 1 to block 1 day 2. Retrieval capability compared block 4 day 1 to block 2 day 2. Multiple comparisons for repeated measures using Bonferroni correction compared MT and RT among the six blocks in the two groups and among the two groups in each block.

Fig. 2 Experimental setup.

Results

Twelve right-handed participants with stroke with mild impairment of the upper extremities (the average upper extremity Fugl-Myer Motor Assessment >50/66) participated. No differences were found on average, level of arm impairment, age and time after stroke compared between the control and experimental groups. For the control group, the average (SD) age was 64.83 (7.52) years and time after stroke was 47 (56.34) months. For the experimental group, their age was 60.67 (2.81) years and time after stroke was 70 (46.2) months.

Acquisition phase day 1

Both groups showed improvement of task performance by decreased MT across practice sessions. The experiment group completed the task with shorter MT than the control group. The MT of the experimental group gradually decreased and began to reach significant level in block 2. Only the experimental group showed a significantly decreased MT in all blocks compared with the 1st block of the acquisition phase ($p<0.05$) (Table 1). No effects were observed of group or block, or block x group interaction.

For RT, between-group comparisons showed a marked shorter reaction time in the experimental group at block 3 ($p<0.05$) and block 4 ($p = 0.06$) compared with the control group (Table 2). However, no effects were observed in block or group, or block x group interaction (Table 2).

Retention test day 2

Retained capability: For MT, no effects were found of block, group, or block x group interaction. This meant when FB was not given, both groups were able to retain their capability. Although no group difference occurred in MT at the retention test, the experimental group had shorter MT than the control group ($p<0.05$, Table 1).

For RT, a significant effect was observed of group ($p<0.05$), but no effect was seen of block or block x group interaction (Table 2). This meant that both groups were able to retain their reaction time but the experimental group used shorter time to process the information as evidenced by a significantly shorter RT

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

	Blocks	Groups	
		Control (n = 6)	Experimental (n = 6)
Acquisition phase (day 1)	1	64.74 (28.34)	37.44 (26.17)
	2	56.66 (32.65)	34.94 (24.12) [a]
	3	51.95 (34.62)	32.79 (21.24) [a]
	4	50.08 (35.72)	32.36 (20.03) [a]
Retention test (day 2)	1	57.11 (49.59)	31.60 (21.03) [a,b]
	2	54.49 (52.53)	31.25 (22.55) [a,b,c]

[a] significant multiple comparisons among block 1 and other blocks of the acquisition phase and the retention phase at $p< 0.05$
[b] significant multiple comparisons among block 2 and other blocks of the acquisition phase and the retention phase at $p< 0.05$
[c] significant main block effect between block 1 of the acquisition phase and block 2 of the retention test at $p<0.05$

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

	Blocks	Groups	
		Control (n = 6)	Experimental (n = 6)
Acquisition phase (day 1)	1	813.89 (340.96)	553.94 (178.65)
	2	726.38 (292.79)	533.82 (120.33)
	3	730.01 (246.05)	445.83 (134.27)*
	4	694.86 (247.35)	458.54 (122.72)
Retention test (day 2)	1	642.17 (146.25)	415.93 (92.29)*
	2	592.17 (91.70)	403.57 (60.87)*,[a]

[*] significant difference between group comparisons during the acquisition phase and retention phase at $p<0.05$
[a] significant multiple comparisons of block 1 of the acquisition phase and retention phase at $p<0.05$

than the control group at the retention test ($p<0.05$, Table 2).

Retrieval capability

For MT, no effects were observed in blocks between the last block of the acquisition phase and the block with FB in the retention (Table 1). This meant that when participants received FB, they retrieved the learning capability back to the same level as the end of the acquisition phase (Table 1). However, a significant effect was observed in a group ($p<0.05$). Although no block x group interaction was found, the experimental group had a tendency to retrieve better than the control group as evidenced by the shorter MT (Table 1).

For RT, significant effects were observed in block and group ($p<0.05$), but not block x group interaction (Table 2). This meant that when participants received FB, both groups were able to continue to reduce their RT. Moreover, the experimental group retrieved the information better than the control group as evidenced by the shorter RT ($p<0.05$, Table 2).

Discussion

The objective of the present study was to investigate the effects of observation duration in dyad training in learning bimanual cup stacking in individuals with stroke. The main finding of the present study was that both dyad training groups revealed improvement of training across practice sessions and were able to maintain their performance on the following day. Compared with the 1-minute observation alternating with physical practice, the 6-minute duration resulted in greater persisted learning in individuals with chronic stroke. Moreover, the 6-minute duration greatly

enhanced the planning of bimanual cup stacking.

The finding of the present study is in accordance with the previous studies by Shea et al[10] and Granados and Wulf[11] revealing that dyad training can enhance motor learning of a bimanual task. The authors recently showed that the dyad training protocol increased learning capability in individuals with stroke[12]. The current study further demonstrated the differential effects of observation duration in dyad training on motor learning and the planning of the bimanual task. In detail, the experimental and the control groups practiced with different observation durations. Compared with the experimental group who observed the task for 6 minutes, the 1-minute protocol showed poorer performance at block 1. Later, they caught up with the 6-minute protocol at the end of training session. Thus, a trend emerged that the participants in the 6-minute protocol learned a novel task faster than those in the 1-minute protocol did. The findings suggest that the dyad training protocol of 4 sessions alternating between observation and practice periods for 6 minutes more greatly promotes learning effectiveness than 24 sessions of the 1-minute protocol.

The differential effects of different observation duration in dyad training on motor learning may be explained by the study of Stefan et al (2005)[18]. They found neural activities in the primary motor cortex assessed by TMS after observing a repetitive thump movement for the first 2 minutes. A significant change of TMS-evoked motor movement was seen after 5 minutes of action observation suggesting that different observed durations play a role on motor learning. Moreover, Ertel et al (2007)[20] combined 6 minutes of observation with 6 minutes of physical training of observed action, so called "action observation therapy". They showed positive effects of the training on motor learning and improved motor function. The results revealed an increase in neuron activation of several regions involved with motor planning. Therefore, action observation might provide information of an action that facilitates individuals to recognize action and to plan an action before they perform the task.

Taken together, the combination of action observation and physical training of the dyad training protocol is similar to the action observation therapy. The combination of observed action with physical practice in dyad training could increase motor learning through facilitating activities of neurons in sensorimotor areas. One of the candidates is the MNS. These special neurons are activated during both observation and when the executor observes action[21-25]. Thus, the effectiveness of the dyad training protocol that matches both action observation and physical practice may be partly due to the activation the MNS.

There are some limitations in the current study that should be addressed. The participants had mild upper extremity impairment (upper extremity Fugl-Myer Motor Assessment score 56-57 out of 66). The improvement of the task performance may have reached an upper limit of their potential resulting in a similar magnitude of motor improvement measured by overall MT for both observation groups. Therefore, other parameters such as kinematics of the arm and hand are needed to be further investigated to better understand mechanisms underlying the improvement from dyad training protocol.

In summary, compared with 1-minute observation alternating with physical practice, the 6-minute duration resulted in greater persistent learning in individuals with chronic stroke with mild severity. Moreover, the 6-minute duration greatly increased the planning of bimanual cup stacking. However, a larger sample of stroke subjects is still required.

What is already known on this topic?

Dyad training, performing in pairs, was reported to be more effective than individual training when performing a bimanual cup-stacking task in individuals with stroke. However, unclear evidence exists that the observation duration in dyad training play differential improves motor planning and motor learning.

What this study adds?

Compared with 1-minute observation alternating with physical practice, this is the first study to demonstrate that 6 minutes resulted in greater persisted learning for individuals with chronic stroke. Moreover, the 6-minute duration greatly increased the planning of bimanual cup stacking.

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Potential conflicts of interest

None.

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การฝึกเป็นคู่ต่อการเรียนรู้ทักษะเรียงถ้วยด้วยมือสองข้างในผู้ป่วยโรคหลอดเลือดสมอง: ผลของช่วงการสังเกต

จารุกูล ตรีไตรลักษณะ, จินตนา แถบทอง, ภครตี ชัยวัฒน์

วัตถุประสงค์: เพื่อประเมินผลการฝึกเป็นคู่ด้วยเวลาในการสังเกตที่ต่างกันต่อการเรียนรู้ทักษะเรียงถ้วยด้วยมือสองข้างในผู้ป่วยโรคหลอดเลือดสมอง

วัสดุและวิธีการ: ผู้เข้าร่วมวิจัย (กลุ่มทดลองและกลุ่มควบคุม) ฝึกกิจกรรมเป็นคู่ ในวันแรก (ช่วงฝึก) สำหรับกลุ่มวิจัย ผู้ร่วมวิจัยนั่งสังเกตคู่ฝึกโดยระยะเวลาแต่ละรอบเท่ากับ 6 นาที สลับกันสังเกตและฝึกคนละ 4 รอบ ส่วนกลุ่มควบคุมสังเกตและฝึกรอบละ 1 นาที รวม 24 รอบ และในวันถัดมา (ช่วงทดสอบการคงค้าง) ผู้ร่วมวิจัยทำกิจกรรมตามลำพัง ช่วงแรกไม่มีตัวป้อนกลับและต่อมาได้รับตัวป้อนกลับ ตัวแปรตามคือ เวลาในการเรียงถ้วยซึ่งเป็นการประเมินกระบวนการสั่งการการเคลื่อนไหวและเวลาในการตอบสนองซึ่งเป็นการประเมินการวางแผนการเคลื่อนไหว

ผลการศึกษา: ในการฝึกวันแรกทั้งสองกลุ่มใช้เวลาในการเรียงถ้วยลดลง กลุ่มทดลองพัฒนาเวลาที่ใช้ดีกว่า กลุ่มควบคุมอย่างมีนัยสำคัญ ในวันถัดมาเวลาในการเรียงถ้วยลดลงเฉพาะกลุ่มทดลองเท่านั้นเมื่อเทียบกับบล็อค สุดท้ายของวันแรก นอกจากนี้เวลาในกลุ่มทดลองลดลงอย่างมีนัยสำคัญเมื่อเทียบกับบล็อคแรก ถึงแม้ว่าทั้งสองกลุ่ม มีรูปแบบการลดลงของเวลาในการตอบสนองที่คล้ายกันในการทดสอบความคงค้างกลุ่มทดลองใช้เวลาในการตอบสนองน้อยกว่ากลุ่มควบคุม

สรุป: สำหรับผู้ป่วยโรคหลอดเลือดสมองระยะเรื้อรัง เมื่อเปรียบเทียบระหว่างระยะเวลาสังเกตสลับกับการฝึกอย่างละ 1 นาทีและระยะเวลา 6 นาที พบว่าระยะเวลา 6 นาทีส่งผลให้เกิดการคงค้างของการเรียนรู้ได้มากกว่า ยิ่งไปกว่านั้นยังส่งเสริมการวางแผนการเรียงถ้วยได้ดีกว่าด้วย