Original Article

Effect of Combined Mental Tracking Dual-Task During Walking on Gait Speed and Cognitive Performance in Stroke Patients

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Abstract

Subtraction has been commonly used as a part of cognitive dual-task for advanced gait assessment in persons with stroke in clinic. As many patients with stroke were unable to perform subtraction, more practical tasks should be examined for substitution. The main objectives of this study were 1) to compare the feasibility of cognitive tasks in the same mental tracking category as subtraction for substitution purpose; and 2) to examine their effects on gait speed and cognitive performance in stroke. Twenty-nine participants with stroke were asked to perform cognitive tasks, namely, subtraction by 3, spelling backward, arithmetic, and reciting alternate tasks, in sitting and during 10-meter walking. Gait speed and stride lengths were monitored by accelerometers. The correct answers were recorded, and the cognitive dual-task cost was calculated. The feasibility of task was calculated as the percentage of participants who could perform the cognitive task in sitting. The effect of cognitive tasks on gait speed and stride length were compared with normal walk. Our results showed that the feasibility of the subtraction, spelling backward, arithmetic, and reciting alternate tasks were 62.07%, 75.86%, 100%, and 89.66%, respectively. Cognitive dual-task costs were reduced in all cognitive tasks. Gait speed was significantly decreased while performing the subtraction task (P = 0.005), spelling backward task (P = 0.011), and reciting alternate task (P = 0.016), and was not affected during the arithmetic task. Therefore, our results indicate that the reciting alternate and spelling backward task can be used as substitution for subtraction task in dual-task assessment for stroke patients.

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Introduction

A patient's balance ability after stroke is an important component toward attaining autonomy in activities of daily livings. Balance deficit commonly found following stroke is caused by 1) impaired motor function, such as paralysis or loss of muscle movement; 2) abnormal sensory function, such as pain, numbness or other strange sensations; and 3) impaired cognitive function, such as memory loss, emotional problem and changes in behavior and self-care ability.[1-5] Stroke survivors who have decreased balance ability also show high incidence of falls, comparable to healthy elderly.[6] The percentage of fall in persons with stroke is between 23% to 50%, as compared to 32% to 42% in the elderly aged over 70 years.[1,5] The causes of fall in persons with chronic stroke residing in the community are from tripping (36.36%), turning (14%), and loss attention when performing two tasks at the same time during walking (24%).[5,7]

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The performance of two tasks simultaneously is referred to as dual-task. Dual-task can be categorized into 2 groups, motor and cognitive dual-task. The example of motor dual-task is holding an object during walking, whereas talking or calculating during walking are the examples of cognitive dual-task. Previous studies examined changes in performance during manual dual-tasks such as carrying the tray with glasses while walking and buttoning during walking in stroke patients. They found a decrement of gait speed and stride length when performing these motor dual-tasks.[8,9,10] Other studies observed gait speed decrement when performing cognitive dual-tasks, such as counting backward, story remembering and digit span during walking in persons with stroke.[11,12] When comparing the adverse effect of dual-tasks on performance, the cognitive dual-tasks tended to disturb gait speed and balance more than motor dual-tasks did.[10] Therefore, the effect of cognitive dual-task on gait needs to be explored further.

The alteration of gait and cognitive performance when performing cognitive dual-task is described in terms of cognitive-motor interference (CMI).[11] CMI is classified into 9 groups: 1) no interference (no change in both gait and cognitive performances); 2) cognitive-related motor interference (decreased gait performance but no change in cognitive performance); 3) motor-related interference (no change in gait performance but decreased cognitive performance); 4) motor facilitation (improved gait performance but no change in cognitive performance); 5) cognitive facilitation (no change in gait performance but improved cognitive performance); 6) cognitive-priority tradeoff (decreased gait performance but improved cognitive performance); 7) motor-priority tradeoff (improved gait performance but decreased cognitive performance); 8) mutual interference (decrease in both gait and cognitive performance); and 9) mutual facilitation (improve both gait and cognitive performance). Previous studies reported that "cognitive-related motor interference" was the type of CMI frequently observed in patients with stroke.[11,12]

The most common cognitive task used during dual-task paradigm in the practice is counting backward by 3 or 7 digits. Number subtraction is the cognitive task in the mental tracking category where the persons are required to track their answer mentally during counting backward by 3 or 7. Previous studies reported mental tracking category was the most interfering task on gait speed.[11] The mental tracking category consists of many tasks such as subtraction, spelling backward, reciting alternate, and arithmetic tasks. Subtraction by 3 is the most frequently used task to assess the interference of cognitive task during walking in stroke patients.[13] However, subtraction may be too difficult for person with stroke as they cannot subtract number. In these cases, it is unclear which cognitive tasks can be used as a substitute for subtraction task. With several types of tasks in the mental tracking category, there may be a task that is not too difficult for stroke patients to perform. At present, however, there is no information regarding the feasibility of the tasks in the mental tracking category in persons with stroke and the effect of each task in the mental tracking category on cognitive and gait performance in this population. We selected gait speed as the representative of gait performance; previous studies demonstrated that gait speed was sensitive to changed due to cognitive tasks.[10-13] Thus, the purposes of this study were 1) to explore the feasibility of implementing the tasks in the mental tracking category to stroke patients; 2) to compare the effect of adding tasks in the mental tracking category during walking (cognitive dual-task) on gait speed and cognitive performance; and 3) to identify the pattern of cognitive motor interference when performing mental tracking dual-tasks in stroke patients.

Materials and Methods

Participants

Patients with unilateral stroke were recruited from Rehabilitation Centers at multiple hospitals: the Thai Red Cross Society, Police General Hospital, Somdetphrayanasangworn Hospital (SDPY), and Maechan Hospital. Participants were included in the study if they were presented with first unilateral hemispheric stroke, had stable medical conditions, were able to walk more than 10 meters independently with or without using one-point or three-point canes, and had Mini-Mental State Examination (MMSE) Thai version score of at least 24.[14] Patients were excluded when they had neurological disorders other than stroke, hearing loss, blinded or color-blinded, major depression, major peripheral neuropathy or musculo-skeletal problems affecting natural gait, and aphasia. All participants signed an informed consent prior to taking part in the study. This study was approved by Human Ethical Committee, Faculty of Physical Therapy, Srinakharinwirot University, and recruiting hospitals. Sample size calculation was based on data from a previous study, resulting in 24 participants to obtain 80% power. In this study, 31 stroke patients have been recruited. Out of 31 patients recruited, 29 participants passed the inclusion criteria and agreed to participate (Figure 1). Completed cognitive data from 26 participants were analyzed for task feasibility. However, not all participants could complete all tasks in the mental tracking category, leaving only data from 14 persons with stroke for analyzing the effect of mental tracking dual-task on gait speed and cognitive performance.

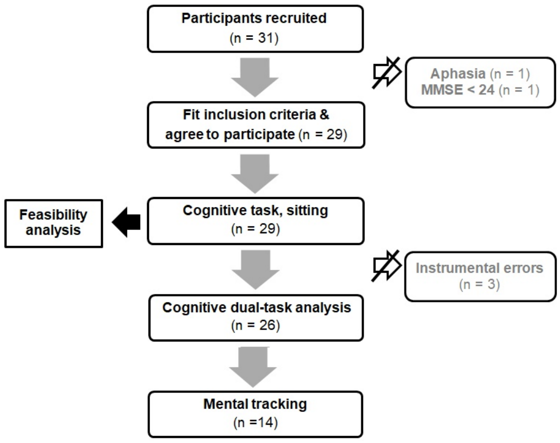

Figure 1 The number of participating stroke patients at each step of the study.

Tasks and procedures

Prior to data collection, general characteristic of the participants, including age, gender, duration of stroke, hemiparetic side, type of stroke, walking aid, education levels, and occupation were acquired from medical record and interview. All participants were required to perform walking, cognitive task in sitting, and cognitive task in walking, respectively. The assessment of cognitive task in sitting was performed for 1 minute, whereas it was performed as long as the person was walking in the walking task. The cognitive tasks used in this study were those in the mental tracking category, i.e., subtraction by 3, spelling backward, arithmetic, and reciting alternate tasks.

In subtraction by 3, the initial number, which was 3 digits long between 120-150, was randomly selected by a physical therapist.[15] For spelling backward, the initial word, containing 4 Thai alphabets, was randomly selected by the physical therapist. After hearing the word, the participants spelled the words backward from the last alphabet to the initial alphabet.[16] In arithmetic task, the physical therapist randomly selected an arithmetic equation, and the participant had to tell if the answer in the equation was correct.[12] For reciting alternate task, the participants were requested to memorize alphabets heard from recorded voice and recall the alphabets backward form the last to the initial.[17]

Accelerometers (Mobility Lab system, APDM, Portland, USA) were used to capture gait speed and stride lengths. Four sensors were placed on the ankles, chest (sternum level) and lumbar region (L5). At the beginning, the participant was asked to walk with a comfortable speed for 10 meters. Next, a type of cognitive task was randomly assigned. The participant was allowed to practice until familiar with the task. Then the test for the cognitive task in sitting (single cognitive task) was performed. The participant sat on a chair with back support while performing the randomly assigned cognitive task for 1 minute. The cognitive correct responses were recorded by another physical therapist. Then the participant performed the cognitive task during a 10-meter walk (dual-task). The instruction during walking was, “Please do both tasks as well as you can.” Walking parameters were recorded with the accelerometers and the cognitive correct responses were recorded by the physical therapist. The other physical therapist walked with the patient for safety precaution. After each test, the participant was allowed to rest for 2 minutes before performing another task, to prevent mental fatigue. Each cognitive task was performed once during sitting and once during walking, until all 4 types of tasks in the mental tracking category were completed.

Data analysis

Task feasibility was calculated as the percentage of participants (from a total of 29) who could perform the cognitive task in sitting. The patients who could perform the task were those who answered cognitive tasks correctly within 3 answers. Gait parameters consisted of gait speed (m/s) and stride length (m) of paretic and non-paretic legs. Gait speed was calculated as the walking distance (10 m) divided by walking duration. The stride length and walking duration were obtained from the accelerometers.

Cognitive performance was represented by cognitive dual-task effect (DTE). To determine DTE, first cognitive correct response rate (CRR), the rate of correct answer from each cognitive task, was calculated using the equation:[18]

$$\text{CRR} = \frac{\text{Number of correct responses}}{\text{time (s)}}$$

Then DTE was calculated as follows:[19]

$$\text{DTE} = \frac{(\text{dual task} - \text{single task})}{\text{single task}} \times 100$$

Repeated measures ANOVA was employed to compare gait parameters among 5 conditions (walking and 4 cognitive dual-tasks), and cognitive performance among 4 dual-tasks during walking. The statistical significance was set at $P < 0.05$. All data were presented as mean ± standard deviation (SD).

Results

Participants

Table 1 shows the characteristics of all participants in this study. The patients with unilateral stroke, either ischemic or hemorrhagic, were 34-77 years old. They had had stroke for 1 to 111 months and had the MMSE Thai version score ranging from 24 to 30. The MMSE score indicated no dementia in all participants.[14] The majority of participants completed primary school and most were employees. Nearly half of the participants walked without walking aid, while the rest used one-point or three-point canes.

Feasibility of mental tracking task in stroke

The feasibility of each mental tracking task, the percentage of participants who could perform the task, was compared in Figure 2. All participants (100%) could perform the arithmetic task, but not all were able to do other tasks in the mental tracking category. Results indicated that the lowest percentage of participants (62.07%) able to perform was in the subtraction task.

Table 1 Basic demographic and gait characteristics (n = 29)

Demographic variables	Stroke subjects
Age (years)	57.17 ± 12.14
Gender (male / female)	21 / 8
Months post stroke	24.97 ± 24.88
Hemiparetic side (left / right)	15 / 14
Type of stroke (ischemic / hemorrhagic)	21 / 8
MMSE Thai score	27 ± 2.10
Walking Aid	
None	14
One-point cane	9
Three-point cane	6
Occupation	
Employee	14
Agriculture	7
Business owner	2
Merchant	4
Housewife	2
Education	
None	1
Primary school	17
Secondary school	8
Bachelor degree	2
Master degree	1
Gait variables	
Gait speed (m/s)	0.27 ± 0.09
Paretic stride length (m)	0.82 ± 0.27
Non-paretic stride length (m)	0.84 ± 0.28

Mean ± SD; MMSE Thai, Mini-Mental State Examination Thai version.

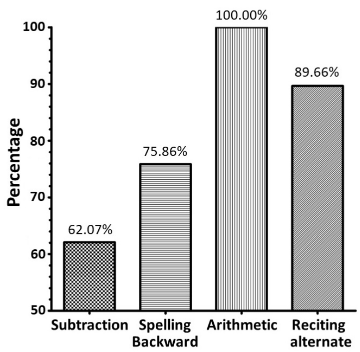

Figure 2 The feasibility of tasks in the mental tracking category.

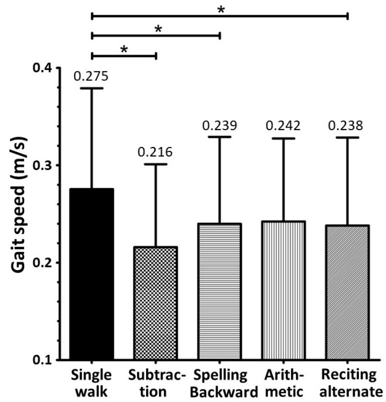

Figure 3 Gait speed during walking under different cognitive tasks. Mean ± SD; *significant difference compared to single walk (*P* < *0.05*).

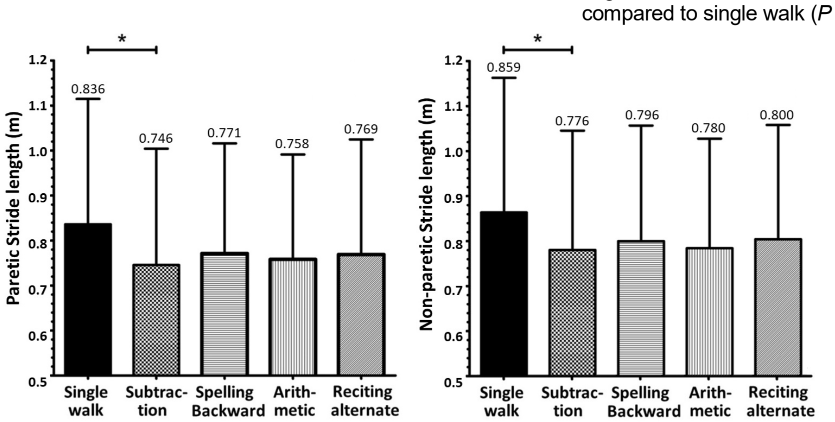

Figure 4 Stride length during walking under different cognitive tasks. ***A***) Paretic; ***B***) non-paretic; mean ± SD; *significant difference, compared to single walk (*P* < *0.05*).

Effect of cognitive dual-task on gait and cognitive performance

Figure 3 shows gait speed (m/s) with and without cognitive dual-task. Compared to walking without cognitive task, gait speed was significantly decreased for all cognitive dual-task, i.e., subtraction (*P* = 0.005), spelling backward (*P* = 0.011) and reciting alternate (*P* = 0.016), but not the arithmetic task. The power of the effect of cognitive dual-task on the gait speed was 0.737. Both paretic stride length (*P* = 0.013) and non-paretic stride length (*P* = 0.042) were significantly decreased during the subtraction dual-task (Figure 4).

Figure 5 presents cognitive dual-task effect calculated in relation to the performance during sitting. The negative percentage change indicated decreased cognitive performance during walking as compared to sitting. Although no significant difference was found between the 4 cognitive tasks, the magnitude of cognitive reduction seemed to be maximum during reciting alternate and minimum during subtraction tasks.

Cognitive-motor interference pattern

Table 2 demonstrates the CMI pattern in persons with stroke when performing mental tracking dual-task. Results demonstrated that "mutual interference" pattern of CMI was predominant no matter which task of mental tracking was selected. Other CMI patterns, such as "cognitive-related motor interference," "cognitive priority trade off," "motor priority trade off," and "mutual facilitation," were occasionally found (7-14%).

Discussion

This is the first study that explored the feasibility of cognitive mental tracking task used in the dual-task paradigm in stroke patients. Our study demonstrated that the arithmetic task was relatively easier than other tasks in the mental tracking category, whereas the subtraction task was the most difficult. The difficulty of subtraction task may be due to the fact that this task requires more complex neural network to process the information than the arithmetic task.[20] Yang et al. (2017) used functional magnetic resonance imaging (fMRI) and dynamic causal modeling (DCM) to identify the brain activity during

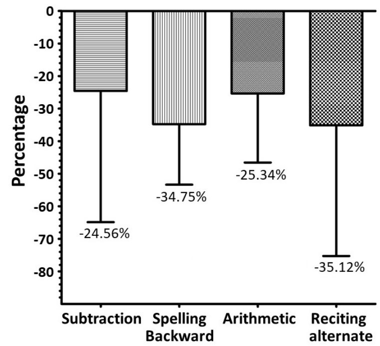

Figure 5 Cognitive Dual-tasks effect (DTE) during walking under different cognitive tasks. Mean ± SD.

Table 2 Cognitive motor interference (CMI) in participants, classified by CMI patterns.

Tasks	Mutual interf.	Cognitive-related motor interf.	Cognitive priority trade off	Motor priority trade off	Motor facilitation	Mutual facilitation	Motor-related cognitive interf.	No interf.	Cognitive facilitation
Subtraction	78.57	7.14	14.29	0.00	0.00	0.00	0.00	0.00	0.00
Spelling backward	92.86	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00
Arithmetic	78.57	7.14	0.00	7.14	0.00	7.14	0.00	0.00	0.00
Reciting alternate	71.43	0.00	7.14	7.14	0.00	14.29	0.00	0.00	0.00

Data are in percentage; interf., interference.

subtraction and arithmetic tasks. Higher neural activity along the dorsal pathways was found when performing subtraction compared to arithmetic task. It was also showed that subtraction task triggered neural activity at bilateral parietal cortex, especially right intraparietal sulcus, while the arithmetic task activated neural network only in the left (dominant) parietal cortex.[20] Our study emphasized the problem of complex cognitive processing in persons suffering from cerebrovascular accident with impaired neurons in the parietal cortex, leading to inability to perform the subtraction task.

In those who were able to perform all the tasks in mental tracking category, we observed a reduction in gait speed during all cognitive mental tracking tasks, except the arithmetic task. The effect was highest during subtraction, as both paretic and non-paretic stride lengths were also affected. These results were not surprising, considering that subtraction requires more neural processing than the arithmetic task. Adding another task, i.e., walking, on top of the cognitive task, would exceed the capacity limit of the central processing which could result in reduced gait speed during cognitive dual-task, as seen during subtraction, spelling backward and reciting alternate dual-tasks. These findings corresponded to previous studies that suggested the decline in gait speed when performing subtraction, spelling backward and reciting alternate dual-tasks,[8,16,17] while the arithmetic dual-task had no influence on gait performance.[12]

In addition to the deterioration on gait, our results indicated that mental tracking task also interfered with cognitive performance as indicated by cognitive dual-task effect (DTE). The exception was seen in the arithmetic task that affected only DTE, not gait performance. The decrease in both motor and cognitive performance was referred to as “mutual interference” pattern which comprised the majority of CMI pattern found in this study. This finding was similar to the study of Plummer *et al.* in 2013 who also found “mutual interference” in patients with stroke when they performed cognitive dual-task.[21] “Mutual interference” can be explained by three theories: attentional capacity sharing theory, bottle neck theory, and multiple resource model. The attentional capacity sharing theory proposes that the brain has limited attentional resource capacities.[22] When performing dual-task, the attentional resource is required more than performing a single task, leading to inadequate attentional resource. As a result, there is deterioration of one or both tasks in the dual-task paradigm. The bottle neck theory explains the mechanism of dual-task interference in terms of a signal processing where the tasks are processed one at a time.[23] Therefore, if two tasks are processed in the same network or neural processor, one task will be delayed until the processor is free from the first task. The multiple resource model emphasizes limited attentional resources stored in a pool of steam to be used in several mental processing. When the mental processing uses the same set of resources during a dual-task, the information processing will be interrupted, thus interference occurs.[24]

Other CMI patterns, such as “cognitive-related motor interference,” “cognitive priority trade off,” and “motor priority trade off,” may involve prioritizing the tasks such that participants paid attention to one task more than another, even though our instruction suggested equal contribution to cognitive and motor tasks.[25] Previous studies reported that the stage of stroke may influence the prioritizing. Those in an acute or subacute stage were more prone to exhibit “mutual interference”[12] while chronic stage revealed “cognitive-related motor interference.”[26] The explanation may be because chronic stroke patients did not need to concentrate on their gait as it became more automatic; attentional resource could then be allocated to the cognitive task.[27] In contrast, patients with stroke in an acute and subacute stage needed to concentrate on both walking and cognitive tasks.[21]

To select appropriate cognitive tasks to assess the influence of cognitive task on gait performance in persons with stroke, both task feasibility and the effect of the cognitive tasks on gait speed need to be taken into account. Our study suggested that reciting alternate or spelling backward task could be used as a substitute task when participants with stroke were unable to perform subtraction task. Arithmetic task was not appropriate for assessing the influence of cognitive dual-task in these patients because it did not affect gait performance as other tasks did, but it may be the first task to be used in the dual-task training due to its feasibility, prior to progressing to a more difficult task.

Limitations. The ability to perform mental tracking cognitive task is related to education levels and occupation. A previous study demonstrated that stroke patients with high education showed no cognitive deficit.[28] Other studies reported that manual workers had high occurrence of cognitive decline after ischemic stroke, but those in the administrative position showed less decrement of cognitive performance than other occupations.[29,30] Results from our study obtained from the participants who were manual workers with relatively low education levels. Although this would represent the majority of stroke patients in Thai community, it would limit the generalization to others with different occupation and education levels.

Conclusion

In conclusion, among mental tracking cognitive tasks, arithmetic task was the easiest, such that when performing with walking, it interfered only with the cognitive performance. In contrast, subtraction task was the most difficult cognitive task that highly interfered with both motor and cognitive performances.

Acknowledgments

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Conflict of Interest

None.

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