ผลของกระบวนการคิดแต่ละประเภทต่อการเดินในผู้ป่วยหลอดเลือดสมอง

TYPES OF COGNITIVE TASK USED IN DUAL-TASK PARADIGM AND ITS EFFECTS ON GAIT IN STROKE

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GRADUATE SCHOOL Srinakharinwirot University

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TYPES OF COGNITIVE TASK USED IN DUAL-TASK PARADIGM AND ITS EFFECTS ON GAIT IN STROKE

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Background: The Timed Up and Go Test (TUG) with serial subtraction was commonly used to assess cognitive dual-task performance while walking for fall prediction. Some people with stroke cannot perform number subtraction, thus, it was unclear on which cognitive tasks could be used to substitute for subtraction task in the TUG test.

Research Question: Which type of cognitive tasks produced the highest detrimental effects during TUG dual-task in stroke patients who were both capable and incapable to complete a subtraction task.

Methods: The participants in this study consisted of twenty-three people who had suffered strokes that were capable of completing subtraction (ST) and nineteen persons who had strokes and were unable perform subtraction (STP). Both groups had a similar age range (thirty-six to eighty-one years) and a stroke onset duration of 0.5 to 252 months. The participants performed TUG without a cognitive task (TUG-single) followed by a cognitive task when seated (cognitive-single). In addition, TUG with a cognitive task (TUG-dual) was performed, with the activity selected from four cognitive tasks, including alternate reciting, auditory working memory, a clock task, and phonologic fluency. The main outcome variables; including TUG duration and cognitive costs, were recorded using an OPAL accelerometer and analyzed using a repeated measure ANOVA.

Results: The TUG duration was significantly longer for all cognitive tasks compared with TUG single (p<0.0001) in the ST group. Whereas, TUG duration was significantly increased only during phonologic fluency task in the STP group (p<0.01). There was a significant difference in cognitive costs between the subtraction task and phonologic fluency task in ST (p<0.01), but no significant differences were identified between tasks in STP. The subtraction task let to the highest decline in both motor and cognitive performances in ST, whereas the phonologic fluency task caused the greatest detrimental effect in STP.

Significance: For stroke patients unable to perform subtraction, phonologic fluency is a suitable method for use in the TUG-cognitive assessment.

Keyword : Timed Up and Go, Cognitive, Stroke, Subtraction

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AMPHA PUMPHO

TABLE OF CONTENTS

Page

ABSTRACT ..... D

ACKNOWLEDGEMENTS ..... F

TABLE OF CONTENTS ..... G

LIST OF TABLES ..... K

LIST OF FIGURES L

CHAPTER 1 INTRODUCTION 1

Background 1

Objective of the Study 4

Significance of the Study 4

Scope of the Study 5

CHAPTER 2 REVIEW OF THE LITERATURE 6

2.1 Postural alteration and fall in survivors with stroke 6

2.2 Gait characteristics in persons with stroke 7

2.2.1 Spatiotemporal deviation in person with stroke 7

2.2.2 Kinetic deviation in stroke 8

2.2.3 Kinematic deviation in stroke 9

2.3 Decline in executive function is associated with increased risk of fall in persons with stroke 11

2.4 Types of cognitive tasks used in dual-task paradigm 12

2.4.1 Working memory 12

2.4.2 Mental tracking 13

2.4.3 Discrimination and decision-making 13

2.4.4 Reaction time 14

2.4.5 Verbal fluency 14

2.5 Mechanism underlying the effect of cognitive dual-task on gait and posture 26

2.6 Assessment of cognitive dual-task during walking 28

2.7 Outcome variables for depicting effect of cognitive dual-task on walking 37

2.7.1 Gait performance 37

2.7.1.1 Gait speed 37

2.7.1.2 Gait variability 37

2.7.2 Cognitive performance 38

CHAPTER 3 METHODOLOGY 46

3.1 Design 46

3.2 Research objective 46

3.3 Pilot study 46

3.3.1 Research objectives of the pilot study 46

3.3.2 Sample size of the pilot study 46

3.3.3 Participants of the pilot study 47

3.3.4 Procedure of the pilot study 48

3.3.5 Data analysis of the pilot study 50

3.4 Main study 51

3.4.1 Sample size of the main study 51

3.4.2 Participants of the main study 52

3.4.3 Measurement tools 52

3.4.5 Procedures of the main study 53
3.4.6 Study variables 54
3.4.6.1 Motor performances: 54
3.4.6.2 Cognitive performance 54
3.4.6 Statistical analysis 54
CHAPTER 4 FINDINGS 56
4.1 Results of Pilot study 56
4.1.1 Feasibility of cognitive tasks in stroke 57
4.1.2 Effects of cognitive dual-task on gait and cognitive performances 58
4.1.2.1 Mental tracking tasks 58
4.1.2.2 Working memory tasks 58
4.1.2.3 Discrimination and decision-making tasks 58
4.1.2.4 Verbal fluency tasks 58
4.2 Summary of task selection 62
4.3 Results of the main study 64
4.3.1 Effects of cognitive tasks when combined with TUG (TUG-dual) on motor performances 66
4.3.2 Effects of cognitive tasks when combined with TUG (TUG-dual) on cognitive performances 68
CHAPTER 5 CONCLUSION AND DISCUSSION 72
Clinical application 74
Study limitation 74
Conclusion 75
REFERENCES 76

VITA 97

LIST OF TABLES

Page

TABLE 1 Summary of task procedure from previous studies that investigated effects of dual-task on gait 15

TABLE 2 Clinical Tests of Dual-task performance with walking and a secondary cognitive 29

TABLE 3 Summary of previous studies that investigated effects of dual-task on gait in participants with stroke 33

TABLE 4 Reliability of dual-task mobility assessment in people with stroke 40

TABLE 5 Reliability of dual-task mobility assessment by using GAITRite walkway system in people with stroke 42

TABLE 6 Validity of dual-task mobility assessment in people with stroke 43

TABLE 7 The cognitive task procedure of pilot study 48

TABLE 8 The demographic characteristics of participants in the pilot study 56

TABLE 9 Selected cognitive tasks in each type of cognitive task 63

TABLE 10 Demographic characteristic of participants 65

LIST OF FIGURES

Page

FIGURE 1 Feasibility of cognitive tasks in the pilot study. 57

FIGURE 2 Gait speed under dual-task conditions compared with single walk. 59

FIGURE 3 Paretic stride length under dual-task conditions compared with single task. 60

FIGURE 4 Non-paretic stride length under dual-task conditions compared with single walk in the pilot study. 61

FIGURE 5 Cognitive Dual-Task Effect (DTE). 62

FIGURE 6 Flow chart shows the number of participants in each group. 64

FIGURE 7 Average total TUG and subcomponent of TUG duration (with 95%CI) 67

FIGURE 8 Group average (with 95%CI) of cognitive cost (%DTE) 68

FIGURE 9 Cognitive cost of different cognitive tasks from individual subject with stroke 70

CHAPTER 1
INTRODUCTION

Background

People with stroke have greater risk of falling than similar aged individuals.[1] The risk of falling was more than twice as high for patients with stroke, when compared with age- and gender-matched controls (relative risk = 2.2; 95% CI, 1.1 to 4.3).[2] The activities that falls most frequently occurred are walking and transferring.[3] In addition, some more complex walking activities such as obstacle crossing and turning are impaired in people with stroke even in those who are able to walk without physical assistance.[4, 5]

Recent research found that cognition, mobility and functional performance are major factors responsible for falls, and might contribute to fall risk and fall related injury in patients with stroke.[6] Decline in attention, psychomotor processing, problem solving, and awareness of self and surroundings, as known as executive function, evidently influence on postural control, gait, and falls.[7] Measurement of executive function provides essential information on the prediction of falls.[8] Decrements in attention and executive function possibly have impact on postural control and gait performance under conditions where the individual also performs an accompanying task of varying cognitive load (i.e., dual-task).[7] The dual-task methodology requires an individual to perform a task that is being evaluated in terms of its attentional demand (primary task), while simultaneously performing an alternative task (secondary task).[9] During the past 2 decades, dual-task methodology has been developed and used for assessing cognitive motor interference (CMI) while walking in various population.[10] Cognitive motor interference refers to the phenomenon in which simultaneous performance of cognitive task and a motor task interferes with the performance of one or both tasks.[11] In previous dual-task studies, CMI was evidenced as changes in performance when an individual simultaneously performed a cognitive demanding task during mobility.[12] Effects of CMI on gait include decreased speed, decreased cadence, decreased stride length, increased stride time, and increased stride time variability.[12] Such impaired dual-task performance has been associated with increased risk of falls in elderly and patients with clinical balance impairment.[13-16]

The clinical measures that are commonly used to assess dual-task performance with cognitive task during walking include the "stop walking while talking" (SWWT), the Walking While Talking Test (WWT), the Multiple Tasks Test (MTT), and the Timed Up and Go cognitive (TUG cognitive).[17] For the SWWT, the examiner starts the conversation with the subject during walking. The observed response is positive if subject stops walking when talking.[17] The SWWT is simple, fast, free of charge and does not require any testing equipment. This test could be possibly used as a predictor of falls in elderly (83% positive predictive value, 76% negative predictive value, and 95% specificity).[18] However, SWWT has the limitations in application such as low sensitivity (48%) and insensitive to subtle changes that may occurs (i.e., slowed walking, slowed talking, changes in complexity of conversation).[17] The WWT can be classified into simple and complex WWT. To perform this test, the subject will be asked to recite the letters of alphabet aloud while walking (simple WWT) or reciting alternate letters of alphabet while walking (complex WWT).[19] The WWT demonstrated good correlation between the assessments done by the clinician and an independent neuropsychology assistant (r = 0.602), high specificity (89% for simple WWT and 96% for complex WWT), and valid to identify older individuals at high risk for falls (OR=7.02 for simple WWT and 13.7 for complex WWT).[19] However, the WWT also has limitations such as low sensitivity for identifying falls risk (46% for simple WWT and 39% for complex WWT), cognitive task difficulty varies, or no assessment of single task cognitive performance.[17, 19]

In the Multiple Tasks Test (MTT), subjects will be asked to stand up from a chair, walk undisturbed along a predefined course, turn 180° and sit down again. Subjects will be asked to repeat this series of movement seven times which an extra component will be added to the earlier trial. The example of extra components are answering a continuous series of brief answer, avoiding the obstacles on the floor, carrying an empty tray, carrying loaded tray with two hardboiled eggs in cups and one loosely rolling egg, and wearing indoor slippery shoes.[20] However, there are some drawbacks in the application of the

MTT, such as no report of reliability of scoring, cognitive task difficulty varies, and some of the dual tasks listed seem to be too easy.[17] In the TUG cognitive, subjects will be asked to perform TUG (standing up from a chair, walk 3m as quickly and safely as possible, walk back, and sit down) with the addition of cognitive task (subtract by 3s from a random number between 20 and 100).[21] The TUG cognitive is useful for evaluation of walking balance. Performing TUG cognitive have a detrimental effect on functional mobility, which additional secondary task increased the time taken to complete the TUG by 22% to 25%.[21] The completion time of TUG cognitive has 80% sensitivity and 93% specificity for identifying community-dwelling older adults who are prone to falls.[21] However, the TUG cognitive also has the limitations. The limitations of TUG cognitive include cognitive task difficulties varies based on education or math ability, and sensitivity of TUG cognitive to predict falls in older adults is lower than the TUG alone.[17, 21]

Among these four clinical tests for assessing dual-task performance, TUG cognitive seems to be widely used for clinical assessment. In fact, the TUG cognitive has been included in the Balance Evaluation Systems Test (BESTest) and mini-Balance Evaluation Systems Test (Mini-BESTest). These clinical assessments are suitable for assessing balance in people with stroke. The BESTest is reliable (excellent intrarater reliability and interrater reliability; ICC =.99), valid (highly correlated with the BBS; *r*=.96), sensitive and specific in assessing balance in people with subacute stroke across all levels of functional disability.[22] Likewise, the Mini-BESTest is reliable with excellent internal consistency (Cronbach alpha =.89-.94), intrarater reliability, (ICC [3,1] =.97), and interrater reliability (ICC [2,1] = .96) and valid for evaluating balance in people with chronic stroke.[23]

However, there are some limitations for performing TUG-cognitive with serial subtraction, some persons with stroke have subtraction problem due to neuronal damage in the central nervous system that is responsible for arithmetic performance.[24, 25] Lesion sites were associated with different selective impairments in the numerical domain.[24, 26] It has been reported that quantitative number processing possibly involved bilateral inferior parietal areas which impairment was presented with subtraction deficits, whereas impairment of left subcortical network was associated with addition/multiplication deficits.[24] In those with subtraction problems, it is unclear which cognitive tasks can be used to substitute serial subtraction when assessing TUG-cognitive.

It has been evidenced that various types of cognitive tasks affect gait performance and walking speed differently.[27, 28] Cognitive task can be classified into five types including reaction time, discrimination and decision-making, mental tracking, working memory tasks, and verbal fluency.[12] The extent on types of cognitive tasks affecting dual task performance is still conflicting. Study by Hall *et al*. (2011) reported that alternate reciting letters and verbal fluency task had the greatest impact on gait performance (30% slowing of gait), while the counting backward by 3's had a modest effect (18% slowing), and reciting the alphabet had minimal impact (4% slowing) in community-dwelling older adults.[27] In contrast, results of study by Montero-Odasso *et al.* (2012) showed that subtraction serial 7s from 100 had a greater detrimental effect on gait performance than naming animal task in older adults.[28] Nevertheless, such information in the person with stroke has not been documented. As a result, the application of cognitive dual-task paradigm in the stroke rehabilitation is limited.

Objective of the Study

The objective of this study was to determine the type of cognitive task that when combined with TUG would lead to the largest detrimental effects on motor and cognitive performances in persons with stroke who had subtraction problem. Data from persons with stroke who did not have subtraction problem was also collected as reference.

We hypothesize that adding the cognitive task in the same category with the serial subtraction would result in the largest decrease in both motor and cognitive performances of persons with stroke who had subtraction problem.

Significance of the Study

Apart from the traditional use of arithmetic task, this study provided the repertoire of other cognitive tasks that can be used in conjunction with the motor task when assessing the cognitive-motor balance ability in patients with stroke. The results could be applied in the clinical practice as they will enable the clinicians to customize the cognitive tasks for assessment and treatment based on individual limitation.

Scope of the Study

This study focused on cognitive involvement on balance and gait, especially the capacity of the brain to process both executive and motor functions simultaneously. The study targeted the persons with stroke who were able to walk independently in the community.

CHAPTER 2
REVIEW OF THE LITERATURE

2.1 Postural alteration and fall in survivors with stroke

Postural control consists of two main functional goals, including postural orientation and postural equilibrium.[29] Postural orientation is related to the active alignment of the trunk and head with respect to the gravity, support surfaces, the visual surround and internal references. In contrast, postural equilibrium involves the coordination of movement strategies to stabilize the center of body mass during either self-initiated or externally triggered disturbances of stability.[29] Important resources required for postural stability and orientation include 1) biomechanical constraints (degree of freedom, strength, limits of stability), 2) movement strategies (reactive, anticipatory, voluntary), 3) sensory strategies (sensory integration, sensory reweighting), 4) orientation in space (perception, gravity, surfaces, vision, verticality), 5) control of dynamics (gait, proactive), and 6) cognitive processing (attention, learning).[29] Common deficits found in stroke such as motor disorders, sensory impairment, weight-bearing asymmetry, smaller surface of stability, increased sway, perceptual deficits and altered spatial cognition could contribute to postural control deficits in this group of patients.[30]

Poor postural control can lead to falls in people with stroke.[31] Previous studies have explored risk factors for falls in people with stroke. The most consistent identified factors for risk of fall are balance impairment[31-34], dependent in activities of daily living[31-33], hemineglect[33, 35, 36], and depression.[2, 37] Falls are a common adverse event at all stages after stroke, occurring in the acute, rehabilitative, and chronic phases.[1] Study by Teasell *et al*. (2002) reported that 37% of people with stroke experienced at least one fall, and 19% experienced at least two falls during hospitalization. Even at the later stages of stroke, risk of falling in these people also higher than similarly aged individuals.[38] Mackintosh *et al.* (2013) found that 36% of people with more than one-year poststroke reported falling in the previous twelve months, compared with 24% of age- and gender-matched controls.[38] Thirty-two percent of falls in stroke rehabilitation are resulted from intrinsic mechanism (mobility systems failure, impaired balance, cognitive impairment, or impaired consciousness), 11% from extrinsic mechanisms (slip-perturbed stance, trip-perturbed swing, or displaced center of gravity), 25% occurred in nonbipedal position (while sitting or lying), 31% remained unclassified.[2, 31-38] The activities that the majority of persons with stroke fell are walking[2, 32, 38] or transferring[38]. In addition, the complex walking tasks such as crossing obstacle and turning are impaired in people with stroke even in those who are able to walk without physical assistance.[4, 5] Postural instability and miscalculation of step lengths before and after the obstacle may contribute to difficulty negotiating obstacles in people with stroke.[39] Turning is also a risk activity in which falls in individual with stroke usually occur.[37] The ability to turn poststroke is compromised such that it requires greater number of steps and longer time to complete turns. Turning ability has been found to be related to the degree of gait asymmetry and low level of functional ambulation.[40]

2.2 Gait characteristics in persons with stroke

2.2.1 Spatiotemporal deviation in person with stroke

The temporal (time-dependent) and spatial (distance-dependent) factors have been used to quantify human gait.[41] The spatio-temporal asymmetry including the step length, swing time, stance time, and have significant negative association with gait velocity in persons with stroke.[42] In chronic stroke, temporal asymmetry in hemiplegic gait is commonly presented as a prolonged paretic swing time and a prolonged non-paretic stance time.[43, 44] The asymmetric between paretic and non-paretic sides commonly reported are a longer proportion of time spent in stance phase on the non-paretic side and a longer proportion of time spent in the double support phase on the paretic side.[45-47] Reduced gait speed in people with stroke as compared with healthy age-matched individual has been consistently reported in the previous studies.[48-50] Decrease in gait speed in this population is associated with shorter stride length and longer cycle duration.[51, 52] The pattern of spatial asymmetry is often characterized by a shorter step length of the non-paretic limb which often resulted from the shorten non-paretic swing phase.[53]

2.2.2 Kinetic deviation in stroke

Kinetics are involved the general term given to the forces that cause the movement.[54] The variables that are included in kinetic analyses are the ground reaction forces, joint moment, joint powers, and mechanical energies.[55]

Ground reaction forces

Ground reaction force (GRF) is the force exerted by the body onto the floor surface which is commonly measured by a force transducer embedded in the walking surface.[54] The vertical and anterior-posterior components of ground reaction forces have been described in chronic stroke. Decreased vertical GRF has been reported on the paretic limb relative to the non-paretic limb.[44] In addition, the anterior-posterior GRF shows a higher braking than propulsive impulse on paretic limb.[56] Study by Bowden et al. (2006) reported that the anterior-posterior GRF was significant correlated with both walking speed and hemiparesis severity in chronic stroke. The percentage of total propulsion generated by the paretic limb was 16%, 36%, and 49% for chronic stroke with high, moderate, and low severity, respectively.[56] Walking speed was strongly positively correlated to paretic propulsive impulse and to non-paretic braking impulse.[56] The paretic propulsion is strongly positively associated with plantarflexor activity, but also negatively associated with leg flexor activity, especially in the severe hemiparesis.[57] The activity of flexor muscles during pre-swing seems to counteract plantarflexor activity in individual with severe hemiparesis contributing to a decreased paretic propulsive impulse.[57] Also, inappropriate non- paretic (soleus, medial gastrocnemius, semimebranosus) and paretic (eg, tibialis anterior) muscle activity can influence increased paretic braking in early stance and reduced paretic propulsion in pre-swing, respectively.[57]

Joint moment

The joint moment of force or torque is the net result of the muscular, ligamentous, and friction forces that act to influence joint rotation.[54] The joint moments are usually described into positive for extensor or plantarflexor moments because they attempt to push the body upwards away from the ground, and flexor moments as being negative because they tend to collapse the limb.[55] In healthy persons, the knee moments display a negative flexor moment during early stance, followed by a positive extensor moment throughout the remainding of stance phase. In contrast, the individuals with stroke exhibit a positive extensor moment throughout the gait cycle in the paretic lower limb.[55] Previous research reported that most moments and power bursts are decreased in amplitude in individuals with stroke, and also are smaller on the paretic side than non-paretic side and smaller in both limbs compared with healthy controls.[43, 58, 59]

Joint powers

Power is the rate at which work is done. The mechanical power that generated at joints is calculated as the product of moment force and the angular velocity, omega (ω):[60]

$$P \text{ (watts)} = M \text{ (newton-meters)} \times \omega \text{ (radians per second)}$$

In individuals with chronic stroke, inter-limb asymmetry has been reported during walking.[61] The non-paretic limb produced significantly more positive net mechanical power than the paretic limb during all phases of a stride and over a complete stride.[61] The average net mechanical power on paretic limb was less positive during pre-swing and more negative during loading response than non-paretic limb; and negative over a complete stride on paretic limb while positive on non-paretic limb.[61] The paretic limb decelerates the COM with less push-off at pre-swing and more braking at loading response, while the non-paretic limb accelerates the COM with more push-off at pre-swing.[62]

2.2.3 Kinematic deviation in stroke

Kinematic analyses are involved a detailed description of human movement without regard of the actual forces that cause the movement. The kinematic variables include linear and angular displacements, velocities, and acceleration.[54]

Joint kinematics

Joint kinematics are the variables that describe the spatial movement between segments, such as joint angular motion measured by degree.[41] Joint kinematics of individuals with chronic stroke present the differences from normal participants in both stance phase and swing phase, and also exhibit large inter-individual variability.[55] In the sagittal plane, common kinematic deviations of the paretic lower limb in the people with stroke include a more plantarflexed ankle position at initial contact, occasional knee hyperextension at weight acceptance, and also less knee flexion and a decreased dorsiflexion during swing.[63, 64] In the horizontal plane, it has been reported that hip and ankle of paretic limb demonstrated abnormally large external rotation throughout the gait cycle.[65] While in the frontal plane, the paretic hip and paretic ankle exhibit abnormally large abduction and inversion, respectively.[65] In addition, in the frontal plane, increased pelvic hiking during swing phase has been reported.[65]

Joint kinematics during stance phase in stroke

During stance phase, range of motion of hip in the sagittal plane exhibits a greater variation of atypical joint motions among the individuals with stroke than does swing phase.[55] At initial contact, there has been reported that these people may have either reduced or increased hip flexion more than normal.[55, 64, 66] During a stance phase, the hip normally extends from about 20˚-25˚ of flexion at weight acceptance to 10˚ of extension at toe-off.[60] However, in individuals with stroke, a decrease in hip extension is commonly reported and this may be caused by adaptive shortening of hip extensor or excessive hip flexor muscle activity, or an overactive plantar flexor muscles which limits ankle dorsiflexion and consequently hip extension in the late-stance phase.[41] The knee patterns during stance phase that are commonly reported are 1) increased knee flexion during the stance phase (particular at initial contact), 2) decreased knee flexion during the early-stance phase, followed by knee hyperextension in the late-stance phase and delayed movement into knee flexion for preparing of swing phase, and 3) excessive knee hyperextension throughout most of the stance phase.[55] Moreover, a decreased plantar flexion at toe-off is commonly found. Decreased in plantar flexion at toe-off may be due to inability to contract the plantar flexors concentrically with enough tension or a decrease in the length of the plantar flexor muscles which is likely to reduce the ability of plantar flexor muscles to produce enough force and lead to decrease plantar flexion.[67]

Joint kinematics during swing phase in stroke

During swing phase, the hip joint flexes from about 10˚ of extension at toe-off to 20˚ of flexion at mid swing.[60] A decrease in hip flexion is commonly found in people with stroke which may be caused by inability to appropriately activate hip flexor muscles or an overactive hip extensor muscles.[41] In general, during the peak of swing phase, flexion of the knee is usually between 60˚-70˚ occurred before mid-swing and nearly extended fully before initial contact.[60] In the individuals with stroke, two common knee patterns reported during swing phase are 1) a decrease in knee flexion during swing phase, and stiff knee gait characteristic and 2) a decrease in knee extension before heel strike.[41] The over activity of rectus femoris muscle and inadequate push-off or weak knee flexor muscles may attribute to decrease in knee flexion during swing phase.[68, 69] In addition, decreased dorsiflexion of the ankle during swing phase is another kinematic disturbance in individuals with stroke. Decrease dorsiflexion at swing phase and also at heel strike may be the result of over-activity of plantar flexor muscles, inability to generate sufficient dorsiflexor muscle moment, or shortening of plantar flexor muscles.[58, 68]

Overall, the kinematic changes of hip, knee, and ankle in the sagittal plane during swing phase in individuals with stroke are characterized by decreased hip flexion, decreased knee flexion, and decreased ankle dorsiflexion or continuous plantar flexion. The resulting increase in leg length can lead to reduced floor clearance during swing phase, characterizing by toe dragging or compensatory circumduction of the leg, or elevation of the pelvis on the side of the swing leg.[41]

2.3 Decline in executive function is associated with increased risk of fall in persons with stroke

Executive function refers to a variety of cognitive process that integrates the information from the anterior and posterior brain regions to modulate and produce behavior, and extending to sequences of logical reasoning.[70, 71] Executive function have four major components, including volition, planning, purposive action, and effective performance (action monitoring).[71]

Executive function probably plays the important role in fall risk poststroke.[14] Impaired executive functions are possibly resulted in impaired gait performance with decreased speed and greater gait variability.[72] Previous study found that impairments of cognitive processing-speed, working memory and executive functions are frequent in elderly stroke patients without dementia.[73] Recent research also found that cognition, mobility and functional performance are major factors responsible for falls, and might contribute to fall risk and fall related injury in patients with stroke.[6] Decline in attention, psychomotor processing, problem solving, and awareness of self and surroundings, also known as executive function, evidently influence on postural control, gait, and falls.[7] Decrements in attention and executive function have impact on postural control and gait performance under conditions where the individual also performs an accompanying task of varying cognitive load (i.e., dual-task).[7] Measurement of executive function and its involvement in postural control provides essential information on the prediction of falls.[8]

Dual-task methodology has been developed and used for assessing cognitive motor interference (CMI) while walking in various population including stroke.[10] Cognitive motor interference refers to the phenomenon in which simultaneous performance of a cognitive task and a motor task interferes with the performance of one or both tasks.[11] In previous dual-task studies, CMI was evidenced by changes in performance when an individual simultaneously performed a cognitive demanding task during mobility.[12] Several studies found that CMI adversely affected on balance, gait velocity, and gait parameters in patients with stroke.[74-77] Evidently, impaired dual-task performance has been associated with increased risk of falls in people with stroke.[15]

2.4 Types of cognitive tasks used in dual-task paradigm

Various cognitive dual-task paradigms have been developed for evaluating the effect of cognitive task on balance and mobility performance. However, they are varied in the level of difficulty and attention demand. The cognitive tasks can be classified into five types based on the classification system by Al-Yahya *et al.* (2011), including working memory, mental tracking, reaction time, discrimination and decision-making, and verbal fluency.[12]

2.4.1 Working memory

Working memory refers to a system that related to the temporary storage and manipulation of the information necessary for complex cognitive tasks, such as language comprehension, learning, and reasoning.[78, 79] Working memory tasks involve the executive attention-control mechanism that is recruited for combat interference. This ability seems to be mediated by portions of prefrontal cortex.[80] The simplest working memory test is Digit span reverse, which also known as Digit span backward.[71]

The digit span tests are the most commonly used cognitive test for measuring span of immediate verbal recall.[71] The digit span tests in the Wechsler batteries (intelligence and memory scales) comprise two different tests; Digit span forward and Digit span backward, both are assumed to possibly tap overlapping systems of phonological processing and working memory.[81] In the digit span forward, subjects repeat digits in the same order as presented, whereas in the digit span backward, subjects repeat digits in reverse order.[71] Functional neuroimaging study revealed that both of these tasks rely upon a largely overlapping functional neural system associated with working memory, most notably right dorsolateral prefrontal cortex (DLPFC) and bilateral inferior parietal lobule (IPL) as well as the anterior cingulate and medial occipital cortex.[81]

2.4.2 Mental tracking

The mental tracking tasks refer to the tasks that require holding information while performing a mental process. These tasks can be complicated by instructing the subjects to track two or more stimuli or associated ideas simultaneously, alternatively, or sequentially.[71] The example of mental tracking tasks are serial number subtraction and alphabet backward that are usually used for examining attention and information processing speed.[82] The activities of prefrontal cortex are associated with general-purpose functional activities such as working memory. The prefrontal cortex also has important role in monitoring or manipulating information as required in calculation tasks.[83] In addition, the cingulate gyri, the insula, and the cerebellum are found to be responsible for number and calculation tasks.[83]

2.4.3 Discrimination and decision-making

The discrimination and decision-making tasks refer to the tasks that require information for encoding and analyzing and then producing a response. The cognitive tests in this category are usually used for examining attention and response inhibition such as the Stroop paradigm.[84] In traditional Stroop paradigm, participants are asked to name, as rapidly as possible, the color of the ink in which a word is written. The Stroop effect is found when taking longer time to name the word instead of telling the color.[85] The results from neurophysiological study has shown that the areas of prefrontal cortex mediates the optimal and adaptive decision-making that is necessary for ability to make choice for individual needs and goals.[86]

2.4.4 Reaction time

Many cognitive operations need sufficient information processing speed for relevant operation to be executed within the limited time.[82] Tests of response speed measuring processing speed directly are useful for understanding the nature of the associated attention deficits.[87] Prolonged reaction time is associated with the impairment of an alertness system which mainly involves the frontal regions of the brain.[88]

2.4.5 Verbal fluency

Verbal fluency tasks have been widely used for assessing language and executive control processes in human brain.[71] Verbal fluency test evaluates the spontaneous production of words under restricted search conditions (verbal association fluency). This ability relies on the coordinated of several brain areas, particularly in the frontal and temporal lobes of the left hemisphere.[71, 89] To perform verbal fluency task, depending on the type of fluency task, subjects are asked to retrieve words that start with a specific letter (e.g., F,A,S: phonologic fluency or letter fluency) or words that belong to a semantic category (e.g., animals, clothing) which typically over a 1-min period.[90] These two tasks are processed through different pathways and different brain region activation. Letter fluency requires selecting and retrieving information based on spelling (orthography) which is associated with enhanced responses in the left premotor/inferior frontal gyrus.[91] In contrast, category fluency places more demand on conceptual knowledge stores, enhanced activity in the left fusiform and left middle frontal gyrus.[91]

Previous studies have been evaluated the effects of dual-task on dual-task performance and gait parameters during walking in various population. Those studies applied different cognitive task types with various tasks and variation of procedures. The cognitive task procedures in these studies have been described in Table 1.

TABLE 1 Summary of task procedure from previous studies that investigated effects of dual-task on gait

Task	Cognitive task procedure	References
Mental tracking		
Counting backward by 1	Participants were asked to counting backward out loud (from fifty).	Allali *et al*. (2007)[92], Allali *et al*. (2008), Beauchet *et al*. (2003), Beauchet *et al.* (2005a)[93], Beauchet *et al.* (2005b)[94], Beauchet *et al.* (2008)[95]
	Question and answer dual-task situation (Q&A): Question and answer required continuous answers from the beginning throughout the walkway. The cognitive questions included common tests from a clinical mental status examination: continuous subtraction.	Catena *et al*. (2007)[96]
	Participants were asked to counting backward by one from one hundred.	Montero-Oddasso *et al*. (2009)[97]
Serial subtraction by 3	Participants walked while reciting out loud serial subtraction of 3, starting from a random three-digit number.	Hausdorff *et al*. (2008)[98], Brown *et al*. (2009)[99]
	Participants counted backwards by 3s.	Brauer and Morris (2010)[100], Dennis *et al*. (2009)[76], Priest *et al*. (2008)[101], Srygley *et al*. (2009)[102]
	Participants were asked to count backwards in 3s from a number between 20 and 100 randomly selected by the examiner.	Galletly and Brauer (2005)[103]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	Participants were asked to subtract repeatedly the number by three starting from 200 down.	Hartmann *et al*. (2009)[104]
	Participants were asked to count backward aloud by 3s from a starting number, which was determined by selecting a card with a randomly generated number from 125 to 250 written on it.	O'Shea *et al*. (2002)[105]
Serial subtraction by 7	Participants walked while reciting out loud serial subtraction of 7, starting from a random three-digit number.	Hausdorff *et al*. (2008)[98]
	Participants were asked to continuously subtract by 7.	Parker *et al*. (2005)[106], Catena *et al*. (2009)[107]
	Participants were asked to continuously subtract by 7, starting from 100.	Reelick *et al*. (2009)[108]
	Participants were asked to count backward by seven from a random number between 291 and 299.	Al-Yahya *et al*. (2009)[109]
	Participants were asked to quickly and accurately subtract backward by seven from a randomly given number.	Chong *et al*. (2009)[110], Paul *et al*. (2009)[111]
	Participants were asked to serially subtract 7s from a 3-digit number (eg, 200, 193, 186).	Hausdorff *et al*. (2003)[112], Hausdorff *et al*. (2008)[98], Laessoe *et al*. (2008)[113], Srygley *et al*. (2009)[102]
	Participants were asked to perform serial 7 subtractions (eg, 500, 493, 496).	Plotnik *et al*. (2009)[114]
	Participants were asked to recite out loud serial subtractions of seven, starting from 500.	Springer *et al*. (2006)[14], Yogev-Seligmann *et al*. (2005)[115]

Table 1 (Continued)

Task	Cognitive task procedure	References
	Participants were asked to subtract by 7 from 100.	van Iersel *et al*. (2007)[116], van Iersel *et al*. (2008)[117]
Spelling backward	The participants were asked to spelling a common five-letter word in reverse.	Catena *et al*. (2007)[96], Catena *et al*. (2009)[107]
	Participants were asked to spell 5-letter words in reverse.	Hollman *et al*. (2007)[118], Parker *et al*. (2005)[106], Parker *et al*. (2006)[119]
Reciting in reveres	The participants were asked to reciting the months of the year in reverse.	Catena *et al*. (2007)[96], Catena *et al*. (2009)[107], Parker *et al*. (2005)[106], Parker *et al*.
	Participants were asked to say the days of the week backwards.	Kelly *et al*. (2008)[120]
Arithmetic task	Simple sums (e.g., "5+6=11") were presented every 5 sec. Subjects responded as quickly as accurately as possible either "yes" or "no" to indicate whether each sum was correct or not. Responses and response latency from start of each sum were recorded.	Haggard *et al*. (2000)[121]
Phoneme monitoring	Participants listened to a story (via headphones) while walking (knowing that they would be questioned about it contents) and counted the number of times two pre-specified words appeared in the text at random intervals.	Hausdoff *et al*. (2008)[98], Srygley *et al*. (2009)[102]
Alternate reciting	Simple test: Participants were asked to recite consecutive letters of the alphabet aloud (i.e., a, b, c, …)	Liu-Ambrose *et al*. (2009)[122], Verghese *et al*. (2002)[19]
	Complex test: Participants were asked to recite	

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	alternate letters of the alphabet (i.e., a, c, e, …)	
Reciting alternate letters	Participants were asked to walk while reciting alternate letters of the alphabet (skipping the letter in between). The initial letter was randomly varied between "A" (A-C-E) and "B" (B-D-F) between trials.	Verghese *et al.* (2007)[123]
Working memory		
Auditory working memory (digit span with increased difficulty)	Digit span task: Participants were asked to present with a digit sequence, memorize it, and then repeat the digits at the conclusion of the motor task. The cognitive complexity of the secondary task was manipulated using 3 blocks of random, non-repeating sequences of digits (3, 5, and 7 digits in length). Articulation was manipulated in 2 blocks, by either having participants continually rehearsed the digits aloud, or continually rehearsed the digits silently during perform the gait task.	Armieri *et al*. (2009)[124]
Auditory working memory	Participants listened to sequences of digits, played aloud on a CD player, and were required to repeat each sequence in order.	Hamilton *et al.* (2009)[125]
	Repeating forward and backward a series of digits. The digits were randomly chosen and delivered through two loud speakers from a computer when the subject was ready to start walking. The reaction time was measured in seconds from the offset of the last digit to the onset of his/her vocal responded	Cherng *et al*. (2007)[126], Cherng *et al*. (2009)[127]
	Participants were asked to count tones played on a tape recorder, the number of which was reported to the tester.	Lord *et al*. (2010)[128]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	'1-back' task: Participants listened and responded to auditory tapes originally developed for the Paced Auditory Serial Addition test (PASAT). Each subject was instructed to respond to each number presented by stating the previously presented number until told to stop.	Schrodt *et al.* (2004)[129]
	Simple task: Participants listened to a text (with headphones) while walking. After completing the walk, they were asked to answer 10 multiple-choice questions regarding to the content of the text. Complex task: Phoneme monitoring task, participants were asked to count how many times two pre-specified words appeared in the text.	Springer *et al*. (2006)[14], Yogev-Seligman *et al*. (2005)[115]
Memorization	Shopping list task: The task required committing a 7-item shopping list to memory as it was played over a stereo system; the number of items correctly recalled was measured. Six different shopping lists (matched for word length, difficulty and familiarity) were recorded over duration of 5, 10, 15 and 20 sec.	Hyndman *et al.* (2006)[15]
	Participants were instructed to use the method of loci as a technique to encode and retrieve lists of words. The memory items were drawn from a digitized pool of 1,100 concrete nouns. Words were presented at a standard rate of 10 s per word, or more quickly when difficulty was manipulated.	Li *et al*. (2001)[130]
	Participants were asked to recall a series of random numbers.	Huang *et al*. (2003)[131]
Auditory working memory (n-back)	The digits were presented at the start of the walk and recalled at the end walking trial, therefore participants had to remember the digit length with	McCulloch *et al.* (2009)[17]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	the appropriate delay in order for that length to be used in dual-task condition.	
Auditory working memory (digit span)	Easy level: Participants were asked to perform a forward digit rehearsal task. Hard level: Participants were asked to perform a backward digit rehearsal task.	Hung *et al*. (2007)[132]
Reaction Time		
Auditory reaction time	The trials of push-button and visual-spatial reaction test performed while seated and walking. When seated, the push-button and visual-spatial reaction-time tests included 10 auditory tones and 5 auditory 'time-of-day' prompts, respectively. The number of tones and prompts given during the walking tests varied according to the subjects' walking time and random delivery of prompts.	Brown *et al*. (2005)[133]
	Participants were required to respond to an auditory cue as quickly as possible while continue walking, by loudly saying the word "top". The articulation of the hard consonant "T" provided a definitive signal for the calculation of RT.	Faulkner *et al*. (2006)[134]
	The cognitive task was to respond as rapidly as possible to an auditory stimulus (1 KHz, 50 ms duration) with a vocal response ('top').	Lajoie *et al*. (1999)[135]
	Participants were asked to vocalize the letter "b" as rapidly as possible in response to the presentation of the 1,500 Hz tone. Voice response time was recorded for each trial.	Wright and Kemp (1992)[9]
Electrical stimulation reaction time	The RT task consisted of biting a pressure transducer placed in the mouth in response to an unpredictable electrical stimulation (single stimulus, duration: 10 ms) applied by an electrode on the	Regnaux *et al*. (2006)[136]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	back of the neck. Stimuli were manually triggered by an examiner at a frequency ranging from 2,000 to 5,000 ms.	
Visual reaction time	Immediately the stimulus was presented, participants pressed a hand-held response button attached to a computer via a light flexible cable. The stimulus was a red letter “R” presented on a computer monitor positioned 2 m. In each condition with stimulus presentation at 10 s, 18 s, 24 s, 38 s, 45 s, 52 s of each minute for 15 min.	Sparrow *et al*. (2008)[137]
Discrimination and Decision Making		
Auditory	Participants reported if an auditory tone was high or low in pitch.	Brauer and Morris (2010)[100]
Visio-spatial	Participants reported whether the spatial pattern of nine dots in one grid was the same or different from another grid. The monochrome visuo-spatial task was presented via a projector onto the wall at the end of the walkway.	Brauer and Morris (2010)[100]
Audio-discrimination	The color classification task: participants listened to a pre-recorded audiotape and answering ‘yes’ when they heard the word ‘red’ and ‘no’ when they heard the word ‘blue’. The audiotape presented the words ‘red’ and ‘blue’ in random order at 3-s intervals.	Canning *et al*. (2006)[77]
	Participants were asked to identify environmental sounds adapted from sound effect compact discs in the Teleconference Studio at UNC-CH. The auditory identification task included a total of 15 sounds.	Huang *et al.* (2003)[131]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	Participants were asked to respond numbers spoken by the researcher every 10 sec by stating “yes” if the number was even and “no” for odd numbers.	Lord *et al*. (2006)[138]
	The auditory clock task: Participants heard a time (e.g., “two-oh-seven”) and were asked to say “yes” if both hands were in a particular half of the clock and “no” if they were not.	Plummer-D'Amato *et al*. (2008)[75]
Visio-spatial decision making	Participants were listening for ‘time-of-day’ prompts and determining whether the two hands of a clock were on the same or different sides of the clock face. Participants were instructed to visualize the time and say aloud “same” or “different” as quickly as possible. To illustrate the two sides of the clock face, participants were shown a clock with a vertical line down its center through the 12 and 6.	Faulkner *et al*. (2006)[134]
	Participants heard speech segments describing times of the day (for example, “10 past 3”, “25 to 7”), presented every 5 seconds. Participants responded as quickly and as accurately as possible whether the hour and minute hands would be on the same side or on different sides of the clock face, for each time given.	Haggard *et al*. (2000)[121], Dennis *et al*. (2009)[76]
	Participants were asked to identify pictures of common objects or toys adapted from the Photo Cue Cards and picture-vocabulary book. The pictures were saved on a laptop computer and projected on a 20-inch color video monitor at the far end of the walkway	Huang *et al*. (2003)[131]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
Stroop test	During the Stroop test, images consisting of the name of one of four colors, printed in the text of a different color, were projected onto the wall. The height of the letter was 15 cm. The image changed at a frequency of one Hz. Participants were instructed to verbally identify the color of the text and to ignore the word itself.	Grabiner and Troy (2005)[139]
	The Stroop test consisted of 3 conditions: 1) a baseline condition, consisting of squares that were displayed in one of four colors (yellow, blue, red, green), 2) an incongruent condition, consisting of color words that were always shown in an incongruent font, 3) a movement Stroop condition, consisting of movement-related words that were always in one of the four adopted font colors. The stroop items were shown on a computer. As soon as participant had verbally labeled all 9 items on a slide the experimenter pressed key, which triggered the appearance of the next slide.	Lamoth *et al*. (2008)[140]
	The auditory task was a modified version of the Stroop test in which the words “man” or “woman” were pronounced by either a man or woman through the earphones requiring subjects to name the speaker’s sex and not the word heard.	McFadyen *et al*. (2009a)[141]
	Participants wore headphones that delivered the simultaneous auditory Stroop task consisting of a high or low pitch voice saying the words “high” or “low”.	McFadyen et al. (2009b)[142], Siu *et al*. (2008)[143]
	Subjects were required to indicate the pitch of the voice and to ignore the word said.	Siu *et al*. (2009)[144]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
Electrical stimulation (weak, strong)	A recognition RT. Stimuli of different strength (weak, strong) were individually determined for each subject. Participants were instructed to bite the pressure transducer placed in the month as rapidly as possible only when a weak stimulus was presented.	Regnaux *et al*. (2006)[136]
Verbal fluency		
Articulation (upward counting)	Participants were asked to count from 1 upward by ones or counting forward.	Allali *et al*. (2007)[92], Camicioli *et al*. (2006)[145]
Word generation (categorical + letter)	Participants were asked to name animals with names starting with a specific letter given to him/her at the beginning of the test.	Bandinelli *et al*. (2006)[146], Deshpande *et al*. (2009)[147]
Word generation (categorical)	Participants were asked to enumerate as many animal names as possible.	Beauchet *et al*. (2005)[93], Montero-Odasso *et al*. (2009)[97], Reelick *et al*. (2009)[108], van Iersel *et al*. (2008)[117], Dubost *et al*. (2008)[148]
	Participants were asked to recite different male names out loud while walking.	Camicioli *et al*. (1997)[149]
	Participants were given a category (“thing to eat”, thing to drink”, “things in the house” or “things in the street) and asked to generate as many exemplars of the category as possible until they heard to stop (after 1 minute).	Haggard *et al*. (2000)[121]
Word association	Participants were asked to give a verbal response on hearing the auditory verbal stimulus. Participants responded by saying 'yes' when they	Bowen *et al*. (2001)[74]

TABLE 1 (Continued)

Task	Cognitive task procedure	References
	heard the word 'red' and 'no' when they heard the word 'blue'. No words other than 'red' and 'blue' were used.	
	Participants were asked to say as many words as possible beginning with certain letters, termed the controlled oral word association test.	Brauer and Morris (2010)[100]
	Participants were first asked to remember a pair of associated words (e.g., “dog”, “bone”). They were then presented with 40 words, occurring every 1.5 sec. The target pair occurred 6 times within the list. The participants were asked to respond “yes” only when the target pair was heard in the correct order.	Haggard *et al.* (2000)[121]
Conversation	Speech samples were elicited from the participants using a set of questions which encouraging to talk for at least 2 min.	de Hoon et al. (2003)[150], Plummer-D'Amato et al. (2008)[75], Rochester et al. (2004)[151]
Word generation (phonemic)	Controlled Oral Word Association Test: Participant were asked to list as the many different words that begin with a specific letter, with 'F' and 'S' used for each trial.	Galletly and Brauer (2005)[103]
	Participant were asked to recite words starting with letters "K" and "O".	van Iersel et al. (2007)[116]
	Participants were asked to recall as many words as possible beginning with a predefined letter during 1 minute.	Yogev-Seligmann et al. (2010)[152]
Reciting letters	Participants were asked to recite the letters of the alphabet aloud.	Verghese et al. (2002)[19]

2.5 Mechanism underlying the effect of cognitive dual-task on gait and posture

In the previous reviews, it has been established that cognitive dual task influences the performance of gait and posture. To unravel the mechanism underlying such effects, several theories have been developed to explain the difficulties in simultaneous performance of dual-task.[153] The most well-known theories are listed in the following sections, including the capacity sharing theory, the bottleneck (task switching) theory, and the cross talk theory.[154]

Capacity sharing

The capacity sharing proposed that the processing capacity (or mental resources) is shared among tasks, therefore there will be less capacity for each individual task when performing more than one task at any given moment time[154]. For example, the attention resources are limited in capacity when performing two attention demanding tasks and as a result it will cause deterioration of at least one of the task.[10]

Bottleneck

The bottleneck theory proposed that when two tasks need to be processed at the same time, one or more tasks will be delayed or otherwise impaired.[154] The processing time of the second task will be delayed until the processor is available after processing the first task.[10] This theory reflects a structural limitation inherent in the cognitive architecture.[155]

Cross talk

This theory claimed that when performing two tasks which involve similar inputs concurrently, two tasks may use the same neuronal population, leading to cross talk of the process.[154] However, cross talk is not frequently occurred due to the dual-task interference.[154]

From the above mention theories, three potential models including 1) the cross domain competition model, 2) the U-shaped nonlinear interaction model, and 3) the task prioritization model have been proposed to explain the effect of cognitive dual task on postural performance.

Model 1: The cross domain competition model

This model proposed that postural control and cognitive activity compete for attention resources so that postural activity performance in dual task conditions would be altered compared to the single postural-task performance.[156] As a result, balance performance should be less efficient in the dual task conditions due to attention resource sharing.[157] Similarly, negative effects on posture of this attention resource competition are greatest in the most difficult cognitive task.[158]

Model 2: The U-shaped nonlinear interaction model

This concept postulates that balance performance can be either improved or diminished depending on whether the cognitive demand of the secondary task is low or high.[156] Vuillerme *et al.* (2000) reported a decrease in postural sway when performing simultaneous reaction time tasks consisting of verbal responses to visual or auditory stimuli.[159] Also, the results of study by Deviterne *et al.* (2005) showed that when added cognitive load through rotatory-auditory stimulation, the quality of postural control was improved in older adults.[160] These studies supported that balance improvement in dual task conditions can be observed with low-demanding secondary-cognitive tasks. Improvement in postural performance by low level difficulty of cognitive dual task activities is possibly due to a shift of the focus of attention away from the postural domain without resource competition.[161] On the other hand, at higher levels of cognitive task difficulty, the detrimental effects are found when resource competition actually sets in.[161] However, the beneficial effects of cognitive task are reduced with aging, while the detrimental effects are increased due to the cross-domain competition and reduced attention capacity in the elderly.[156]

Model 3: The task prioritization model

The prioritization of postural control over secondary task performance can be altered in older adult under conditions of postural threat.[162] Many factors are associated with the allocation of attention during the performance of concurrent tasks, including the nature of both the cognitive and postural task, the goal of the subject, and the instructions.[163] In conditions that pose highly threat of injury, postural control would be the first priority for attention resource.[163] Meanwhile, in conditions that stability is not potential injurious, a person may prioritize a secondary task over the postural control task.[163]

2.6 Assessment of cognitive dual-task during walking

The clinical measures that are commonly used to assess dual-task performance with cognitive task during walking include the "stop walking while talking" (SWWT), the Walking While Talking Test (WWT), the Multiple Test (MTT), and the Timed Up and Go cognitive (TUG cognitive).[17] Although these existing clinical measures have the ability to assess dual-task performance during walking, their own limitations, tasks difficulty, education or literacy are important issues for consideration. For the SWWT, the examiner starts the conversation with the subject during walking. The observed response is positive if subject stops walking when talking.[17] The SWWT is simple, fast, free of charge, and does not require any testing equipment. This test could be possibly used as a predictor of falls in elderly (83% positive predictive value, 76% negative predictive value, and 95% specificity).[18] However, SWWT has the limitations in application such as low sensitivity (48%) and insensitive to subtle changes that may occurs (i.e., slowed walking, slowed talking, changes in complexity of conversation).[17]

The WWT can be classified into simple and complex WWT. To perform this test, the subject will be asked to recite the letters of alphabet aloud while walking (simple WWT) or reciting alternate letters of alphabet while walking (complex WWT).[19] The WWT demonstrated good correlation between the assessments done by the clinician and an independent neuropsychology assistant ($r = 0.602$), high specificity (89% for simple WWT and 96% for complex WWT), and valid to identify older individuals at high risk for falls (OR=7.02 for simple WWT and 13.7 for complex WWT).[19] However, the WWT also has limitations such as low sensitivity for identifying falls risk (46% for simple WWT and 39% for complex WWT), cognitive task difficulty varies, or no assessment of single task cognitive performance.[17],[19]

In the Multiple Tasks Test (MTT), subjects will be asked to stand up from a chair, walk undisturbed along a predefined course, turn 180° and sit down again. Subjects will be asked to repeat this series of movement seven times which an extra component will be added to the earlier trial. The example of extra components are answering a continuous series of brief answer, avoiding the obstacles on the floor, carrying an empty tray, carrying loaded tray with two hardboiled eggs in cups and one loosely rolling egg, and wearing indoor slippery shoes.[20] However, there are some drawbacks in the application of the MTT, such as no report of reliability of scoring, cognitive task difficulty varies, and some of the dual tasks listed seem to be too easy.[17]

In the TUG cognitive, subjects will be asked to perform TUG (standing up from a chair, walk 3m as quickly and safely as possible, walk back, and sit down) with the addition of cognitive task (subtract by 3s from a random number between 20 and 100).[21] The TUG cognitive is useful for evaluation of walking balance. Performing TUG cognitive have a detrimental effect on functional mobility, which additional secondary task increased the time taken to complete the TUG by 22% to 25%.[21] The completion time of TUG cognitive has 80% sensitivity and 93% specificity for identifying community-dwelling older adults who are prone to falls.[21] However, the TUG cognitive also has the limitations. The limitations of TUG cognitive include cognitive task difficulties varies based on education or math ability, and sensitivity of TUG cognitive to predict falls in older adults is lower than the TUG alone.[17],[21] The details of these clinical tests, psychometric properties, and limitations are described in Table 2.

TABLE 2 Clinical Tests of Dual-task performance with walking and a secondary cognitive

Test	Walking task	Cognitive task	Measurement	Psychometric properties	Limitations for older adults
“Stop walking when talking” test (SWWTT)[18]	Walking at self-selected speed with or without aids	Conversation is initiated by an examiner	The response will be recorded as positive if persons stops walking when talking	Positive predictive value = 83%[18], negative predictive value = 76%[18], specificity =	Low sensitivity[18], insensitive to subtle changes that may occurs: slowed walking, slowed

TABLE 2 (Continued)

Test	Walking task	Cognitive task	Measurement	Psychometric properties	Limitations for older adults
				95%[18], sensitivity = 48%[18]	talking, changes in complexity of conversation[17]
Timed Up and Go cognitive (TUG cognitive)[21]	Stand up from a chair, walk 3 m as quickly as safely as possible, turn around, walk back, and sit down	Counting backward by 3s from a random selected number between 20 and 100	Times for walking in single and dual-task condition	TUG cognitive completion time to predict falls: sensitivity = 80%[21], specificity= 93%[21], cutoff = 15 s[21] TUG cognitive completion time to prefrail individuals: AUC (95%CI) = 0.60 (0.46, 0.74)[164], sensitivity = 29%[164], specificity = 93%[164], age-adjusted OR (95%CI) = 2.8 (0.5, 15.4) (NS)[164]	TUG cognitive does not provide more sensitive indicator of likelihood for falls than TUG alone[21], cognitive task difficulties varies based on education and math ability[17]
Walking While Talking Test (WWT)[19]	Walking at self-selected speed,	WWT-simple: recite alphabet	Times for walking in single and	Walking time to predict falls: WWT-simple: sensitivity =	Low sensitivity for identifying falls risk[19], cognitive task

TABLE 2 (Continued)

Test	Walking task	Cognitive task	Measurement	Psychometric properties	Limitations for older adults
	walk 20 feet, turn, and return (40 feet total)	WWT-complex: recite alternate letters of alphabet	both dual-task conditions	46.1%[19], specificity = 89.4%[19], PPV = 54.5%[19], OR = 7.02[19]; WWT-complex: sensitivity = 38.5%[19], specificity = 95.6%[19], PPV = 71.4%[19], OR = 13.7[19]	difficulty varies[17]
Multiple Tasks Test (MTT)[20]	Stand up from a chair, walk at self-selected speed, turn 180˚, sitting down, with cumulative addition of avoid obstacles, carry an empty tray, carry tray with 2 hardboiled	Response a continuous series of brief questions	Observe for obvious slowing (hesitation) or stop in multiple task conditions, comparing to single task walking and baseline performance	Correlation between the Berg Balance Scale (BBS) and the Multiple Tasks Test (MTT) ranged between -0.765 and -0.79[165]	Subjective judgment of changes in dual-task condition based on dual-task condition, reliability of scoring is not reported, cognitive task difficulty varies[17]

TABLE 2 (continued)

Test	Walking task	Cognitive task	Measurement	Psychometric properties	Limitations for older adults
	eggs in cups and 1 loosely rolling egg, using slippery soles, squat and tapping a floor, wear sunglasses				

Among these four clinical tests for assessing dual-task performance, TUG cognitive seems to be widely used for clinical assessment. In fact, the TUG cognitive has been included in the Balance Evaluation Systems Test (BESTest) and mini-Balance Evaluation Systems Test (Mini-BESTest). These clinical assessments are suitable for assessing balance in people with stroke. The BESTest is reliable (excellent intrarater reliability and interrater reliability; ICC =.99), valid (highly correlated with the BBS; *r*=.96), sensitive and specific in assessing balance in people with subacute stroke across all levels of functional disability.[22] Likewise, the Mini-BESTest is reliable with excellent internal consistency (Cronbach alpha =.89-.94), intrarater reliability, (ICC [3,1] =.97), and interrater reliability (ICC [2,1] = .96) and valid for evaluating balance in people with chronic stroke.[23] However, there are some limitations for performing TUG cognitive in patients with stroke, as some patients with stroke cannot subtract number correctly due to poor ability to perform arithmetic task. In these cases, it is unclear on which cognitive tasks can be used as a substitute for inability to perform arithmetic task.

During the past two decades, different dual-task assessment tests have been developed for assessing balance and mobility performance in various populations including stroke. Previous studies have evaluated the effects of dual-task on gait in participants with stroke.[15, 74-77, 121, 136, 138, 166, 167] The details of these studies and their results were described in Table 3. Most studies revealed the decrement of gait occurred while performing cognitive dual-task in this population. However, some studies reported no effects of cognitive dual-task on gait. Study by Lord *et al*. (2006) reported a significant effect of environment (clinic, suburban street, and shopping mall), but no effect of cognitive dual-task (audio-discrimination) on gait in chronic stroke.[138] Another study by Regnaux *et al*. (2006) reported that the walking parameters were not affected by the dual-task condition (preformed electrical stimulation reaction time task while walking on treadmill) in subjects with stroke.[136] In addition, several studies revealed that type of mobility and cognitive task used is highly affected on dual-task mobility performance. Study by Dennis *et al*. (2009) suggested that nature of the interference might related to the type of cognitive task and the magnitude of interference is related to the walking intensity.[76] This study reported that the subjects with stroke slowed down their speed during walking whilst concurrently serial subtraction by 3s task (prioritized successfully completion of cognitive task), but not appeared during the clock face task. Moreover, the trade-off to cognitive task performance occurred during fast walking, with significantly more errors being recorded.[76] Study by Patel *at al*. (2014) also concluded that cognitive-motor interference pattern in chronic stroke differed significantly with type of cognitive task.[167] The results of this study showed the highest motor cost for serial subtraction task in chronic stroke, whereas the young group was highest for visuomotor reaction time task. The cognitive cost was highest for visuomotor reaction time task and lowest for Stroop test task in both groups, but significantly greater in chronic stroke.[167]

TABLE 3 Summary of previous studies that investigated effects of dual-task on gait in participants with stroke

Study	Participants	Walking task	Cognitive task	Effects on gait
Haggard *et al*. (2000)[121]	Neurological patie nts N = 50 (33 from neurological rehabilitation unit, 11 from stroke rehabilitation ward, 6 from young disabled unit), age = 50.18 ± 16.47 years, time since onset = 1.36 ± 2.56 years Healthy control: N = 10, age = 45.3 ± 17.75 years	Walked for 1 min at self-selected speed	Verbal fluency: word generation task (categorical), word association (verbal paired associate monitoring task) Mental tracking: arithmetic task (simple sums e.g. 5+6=11) Discrimination and decision making: visio-spatial decision making	Increased stride duration
Bowen *et al.* (2001)[74]	Stroke: N = 11, age = 72 ± 9 years, time since onset = 120 ± 48 days	Walked 8 m at self-selected speed	Verbal fluency: word association	Decreased speed, increased double-support time
Cockburn *et al.* (2003)[166]	Stroke: N = 10, age = 57.9 ± 9.75 years, time since onset = 5.6 ± 3.8 months	Walked for 1 min at self-selected speed	Verbal fluency: word generation (categorical)	Increased stride time
Regnaux *et al*. (2005)	Stroke: N = 18, age = 52.4 (29 – 74) years, time since onset = 13.6 months Healthy control: N = 10, age = range 25 – 55 years	Walked at self-selected speed on treadmill	Reaction time: electrical stimulation reaction time	Longer RT during walking compared to sitting and standing, no gait

TABLE 3 (Continued)

Study	Participants	Walking task	Cognitive task	Effects on gait
				modification across the stimulation for stroke and control subjects
Lord *et al*. (2006)[138]	Stroke: N = 27, age = 61 ± 11.6 years, time since onset = 45.8 ± 34.2 months	Walked for 6 min at self-selected speed	Discrimination and decision making: audio-discrimination	Gait speed, step frequency, and step length were not significant altered
Hyndman *et al*. (2006)[15]	Stroke: N = 36, age = 66.5 ± 11.8 years, time since onset = 6.3 ± 11.6 years Healthy control: N = 24, age = 62.3 ± 11.6 years	Walked 5 m at self-selected speed	Working memory: remembering a shopping list	Decreased speed, decreased stride length
Canning *et al*. (2006)[77]	Stroke: N = 20, age = 66 ± 10, time since onset = 3.9 ± 19 months Community dwelling, N = 20, age = 64 ± 8 years Healthy young: N = 20, age = 20 ± 2 years	Walked 10 m at self-selected speed	Discrimination and decision making: audio-discrimination	Stroke subjects walked slower, took shorter strides and fewer steps/min than elder controls
Plummer-D'Amato *et al*. (2008)[75]	Stroke: N = 13, age = 60.5 ± 15.3 years,	Walked for 3 min at self-selected speed	Working memory: auditory 1-back	Decreased gait speed (slower speed in speech

TABLE 3 (Continued)

Study	Participants	Walking task	Cognitive task	Effects on gait
	time since onset = 8.7 ± 4.8 months		Discrimination and decision making: audio-discrimination (clock task) Verbal fluency: conversation (speech task)	task than the 1-back and clock task, and slower in the clock task than the 1-back), decreased cadence, decreased stride length
Dennis *et al*. (2009)[76]	Stroke: N = 21, age = 61 ± 12 years, time since onset = 25 (7-50 months Healthy control: N = 10, age = 60 ± 6 years	Walked at self-selected speed for 1 min, walked at fast speed for 1 min	Mental tracking: serial subtractions by 3 Discrimination and decision making: visio-spatial decision making (the clock face task)	Slowed speed during serial 3s task, but not during the clock face task
Patel *et al*. (2014)[167]	Stroke: N = 10, age = 56.8 ± 5.95, time since onset = 4.6 ± 2.58 years Healthy control: N = 15, age = 25.6 ± 5.23 years	Walked 3 m at self-selected speed	Mental tracking: serial subtractions by 1 Reaction time: visuomotor reaction time task Discrimination and decision making: Stroop test	Decreased gait speed, highest motor costs for serial subtraction task in stroke and highest cognitive costs for visuomotor reaction time task

From results of previous studies as described in the Table 3, the overall dual-task related changes in spatio-temporal gait parameters include decreased speed, decreased cadence, decreased stride length, increased stride time, and increased double support time in people with stroke. It can be seen from previous studies that different cognitive tasks have been employed to examine the effect of cognitive task on walking in persons with stroke. Although the mental tracking tasks seem to have higher motor costs than the decision making and reaction time tasks, none of the previous studies compared the effect of all types of cognitive tasks on gait. As a result, the answer to which cognitive task could be used to substitute when the persons with stroke cannot perform serial number subtraction remains unknown.

2.7 Outcome variables for depicting effect of cognitive dual-task on walking

2.7.1 Gait performance

Cognitive motor interference while walking can disturb gait performance, resulting in alteration of spatio-temporal gait parameters including decreased speed, decreased cadence, decrease stride length, increased stride time, and increased stride time variability in various population.[12] Similarity, decreased walking speed, increased stride time, decreased stride length, decreased cadence, and increased double support time have also been found in stroke population.[15, 74-77, 121, 166, 167]

2.7.1.1 Gait speed

Gait speed is one of the useful outcome measures that can reflect health and physical function.[168] Slower gait speed is associated with higher risk of falls in the older adults.[169] Study by Holtzer *et al*. (2006) revealed that gait speed is associated with the cognitive function and its relationship varied as a function of task condition.[170] Slowing in gait speed while performing dual-task may possibly predict falls.[95, 171]

2.7.1.2 Gait variability

Previous researches have been investigated the nature of the relationship among the gait velocity, the average stride length, and the variability of these measures and falls. Study by Maki (1997) reported that shorter stride length, slower velocity, and prolonged double support were associated with fear of fall but not to the risk of falling, while measures of variability predict future falls in community-dwelling older adults.[172] This study stated that subjects with a fear of falling walked more slowly, but fall risk was independent of gait speed and modulated by gait variability.[172]

Gait variability is a quantifiable feature of walking that is altered either in terms of magnitude or dynamics in clinically relevant syndromes, such as falling, frailty, and neurological diseases (e.g., Parkinson's, Huntington's, and Alzheimer's disease).[173-177] Stride-to-stride variability, as measured by the coefficient of variation (CV), is a measure of the reproducibility of the limb-coordination movements from one stride to the next during walking.[177] Previous research found increased stride-to-stride variability (standard deviation and coefficient) of stride time, swing time, and percent stance time of gait in elderly fallers, suggesting that gait variability may be useful in assessing fall risk in the elderly.[178]

Low stride variability reflects autonomic process that requires minimal attention and is also related to efficient gait control and gait safety.[179] In contrast, high stride time variability (STV) is an indicator of gait instability and related to risk of falling.[172, 180] STV is a measure of temporal stride variability related to the control of the rhythmic stepping mechanism.[181] STV can be calculated by determining the standard deviation and the coefficient of variation of the stride time.[172, 180]

In dual-task studies, Dubost *et al.* (2008) investigated the role of attention-demanding task on dual-task related changes in stride time and stride length variability in healthy young adults. The results of this study showed that stride time increased significantly under dual-task condition independently of dual-task related decrease in stride velocity, while stride length variability did not change under dual-task.[148] Another study by Kressig *et al*. (2008) determined the relationship between STV and falls occurring during hospital stay while dual-task walking conditions. This study found that STV during walking was significantly associated with the occurrence of the first fall event.[182] These results suggested that the degree of STV in dual-task walking conditions distinguished fallers from non-fallers in older inpatients.[182]

2.7.2 Cognitive performance

To assess cognitive performance, the outcome variables are varied according to nature of cognitive task. For shopping list task in the working memory task domain, number of items recalled from a shopping list is the dependent variable used to assess cognitive task performance.[15] The common outcome measures in previous studies for assessing cognitive performance in stroke were included:

- the number of correct response and response latency of word generation (eg. Naming of thing to eat) in the verbal fluency task domain[121, 166]

- the number of correct response of simple arithmetic (eg. 5+6)[121] or counting backward by 1[167] or counting backward by 3 task in the mental tracking task domain[76]

- the response latency in the reaction time task domain[136, 167]

- the number of target pairs correctly detected in a verbal paired associated monitoring task in the verbal fluency task domain[121]

- the correct response and response latency for indicating whether the hour and minute hands on a clock would be in the same half area or not in the discrimination and decision-making task domain[75, 76, 121]

- the correct response in a auditory 1-back task in the working memory task domain[75], linguistic measures of speech in the verbal fluency domain[75]

- the number of correct response in a Stroop test in the discrimination and decision making task domain.[167]

For indicating the influence of additional of cognitive task on cognitive performance, the dual task effect (DTE) can be calculated for each outcome measured (eg. response accuracy, response latency).[183] A decrement under dual-task conditions (i.e. dual-task cost) is presented in negative value, while an improvement under dual-task conditions (i.e. dual-task benefit) is presented in positive value.[183]

Previous studies have examined effects of dual-task in stroke, however the psychometric properties of these outcome variables are essential to be considered for further applying the assessment tools or interventions. The reliability, validity, and ability to assess balance or distinguish fallers of the dual-task assessment with variety of cognitive and mobility tasks are important issues for consideration and need to be concerned. The reliability and validity of dual-task mobility assessments in stroke have been described in Table 4 – 6. Study by Yang *et al*. (2016) reported that walking time (by using a stop watch) in various dual-task assessments demonstrated good to excellent reliability ($ICC_{(2,1)}$ = 0.70-0.93); relative minimal detectable change at 95% confidence level ($MDC_{95\%}$) = 29-45%.[184] Study by Cho *et al*. (2015) also reported that walking velocity and spatio-temporal gait parameters (by using GAITRite walkway system) in dual-task assessment have good to excellent reliability ($ICC_{(2,1)}$ = 0.69-0.90).[185] Meanwhile, the reliability for cognitive (correct response rate) was more varied ($ICC_{(2,1)}$ = 0.58-0.81) with higher $MDC_{95\%}$ ($MDC_{95\%}$ = 58.6-80.9%).[184] The dual-task walking demonstrated good concurrent validity, where the walking time and correct cognitive response rate obtained in dual-task walking tests were moderately to strongly correlated with those of dual-task TUG test.[184] However, results from Yang *et al.* (2016) showed that none of dual-task mobility assessments could significant discriminate fallers from non-fallers in stroke. Their study contradicted to previous study where TUG was able to discriminate fallers from non-fallers with high sensitivity and specificity in community-dwelling older adults.[21, 184]

TABLE 4 Reliability of dual-task mobility assessment in people with stroke

Dual-task mobility assessment	Test-retest reliability for walking time (by using a stop watch) (N=46)[184]				Test-retest reliability for the cognitive (correct response rate: number of words or digits per second) and manual task (N=46)[184]			
	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)
Comfortable speed with verbal fluency	0.83*	0.69-0.90	1.8(11.4)	5.1(31.5)	0.66*	0.46-0.80	0.10(21.2)	0.27 (58.6)
Comfortable speed with serial 3 subtraction	0.78*	0.62-0.88	2.3(14.3)	6.4(39.7)	0.62*	0.40-0.77	0.10(25.9)	0.29 (71.8)
Comfortable speed with manual task	0.80*	0.63-0.89	2.4(15.1)	6.6(41.8)	-	-	-	-
Maximal speed with	0.81*	0.68-0.89	1.9(13.6)	5.4(37.7)	0.64*	0.44-0.78	0.13(23.2)	0.36 (64.4)

TABLE 4 (Continued)

Dual-task mobility assessment	Test-retest reliability for walking time (by using a stop watch) (N=46)[184]				Test-retest reliability for the cognitive (correct response rate: number of words or digits per second) and manual task (N=46)[184]			
	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)
verbal fluency								
Maximal speed with serial subtraction	0.85*	0.75-0.92	1.7(11.9)	4.6(33.1)	0.72*	0.55-0.84	0.11(24.4)	0.30(67.7)
Maximal speed with manual task	0.88*	0.79-0.93	1.7(12.5)	4.8(34.5)	-	-	-	-
Backward walking with verbal fluency	0.87*	0.76-0.93	10.1(22.2)	27.9(61.4)	0.73*	0.56-0.84	0.07(24.1)	0.18(66.7)
Backward walking with serial 3 subtraction	0.93*	0.86-0.97	6.9(15.2)	19.0(42.3)	0.81*	0.69-0.89	0.07(21.5)	0.20(59.5)
Backward walking with manual task	-	-	-	-	-	-	-	-
Obstacle course with verbal fluency	0.88*	0.78-0.93	2.1(12.0)	5.8(33.2)	0.58*	0.33-0.75	0.10(25.9)	0.28(71.7)

TABLE 4 (Continued)

Dual-task mobility assessment	Test-retest reliability for walking time (by using a stop watch) (N=46)[184]				Test-retest reliability for the cognitive (correct response rate: number of words or digits per second) and manual task (N=46)[184]			
	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)	$ICC_{(2,1)}$	95%CI for $ICC_{(2,1)}$	SEM(SEM%)	MDC(MDC_{95}%)
Obstacle course with serial 3 subtraction	0.70*	0.52-0.82	3.9(21.5)	10.8(59.6)	0.74*	0.58-.085	0.09(24.2)	0.25(66.9)
Obstacle course with manual task	0.81*	0.64-0.89	3.0(16.1)	8.3(44.6)	-	-	-	-
TUG with verbal fluency	0.88*	0.80-0.93	1.9(10.3)	5.3(28.6)	0.75*	0.59-0.86	0.08(22.0)	0.22(60.9)
TUG with serial 3 subtraction	0.76*	0.60-0.86	2.7(14.7)	7.4(40.7)	0.59*	0.37-0.75	0.10(29.2)	0.27(80.9)
TUG with manual task	0.86*	0.75-0.92	2.2(10.5)	6.0(29.2)	-	-	-	-

*: reliability coefficient was statistically significant ($p < 0.01$), CI: confidence interval; $ICC_{(2,1)}$: intraclass correlation coefficient (model 2 from 1); MDC_{95}: minimal detectable change at the 95% confidence level; MDC_{95}%: percentage minimal detectable change at the 95% confidence level; SEM: standard error of measurement; SEM%: percentage standard error of measurement; TUG: timed up-and-go test

TABLE 5 Reliability of dual-task mobility assessment by using GAITRite walkway system in people with stroke

Dual task mobility assessment	Test-retest for spatio-temporal gait parameters (by using GAITRite walkway system) (N = 43)[185]											
	Velocity		Cadence		P-step length		NP-step length		P-stride length		NP-stride length	
	$ICC_{2,1}$	95%CI	$ICC_{2,1}$	95%CI	$ICC_{2,1}$	95%CI	$ICC_{2,1}$	95%CI	$ICC_{2,1}$	95% CI	$ICC_{2,1}$	95% CI
Comfortable speed with CB	0.87	0.78-0.93	0.69	0.49-0.81	0.90	0.82-0.94	0.88	0.79-0.93	0.87	0.77-0.92	0.79	0.65-0.88

CB = Counting backward, CI: confidence interval; $ICC_{(2,1)}$: intraclass correlation coefficient (model 2 from 1); P-step length: paretic-step length; NP-step length: non-paretic step length; P-stride length: paretic-stride length; NP-stride length: non-paretic-stride length

TABLE 6 Validity of dual-task mobility assessment in people with stroke

Dual task mobility assessment	Know-groups validity: using walking time to discriminate fallers VS. non-fallers[184]					
	AUC(95%CI)	Cut-off(s)	Sensitivity (%)(95%CI)	Specificity (%)(95%CI)	Positive likelihood ratio (95%CI)	Negative likelihood ratio(95%CI)
Comfortable speed with verbal fluency	0.54(0.39-0.69)	14.7	60.0 (38.7-78.1)	48.5 (37.1-60.2)	1.17 (0.76-1.79)	0.82 (0.46-1.49)
Comfortable speed with serial 3 subtraction	0.59(0.44-0.74)	16.8	55.0 (34.2-74.2)	64.7 (52.8-75.0)	1.56 (0.94-2.60)	0.70 (0.42-1.16)
Comfortable speed with manual task	0.55 (0.40-0.70)	14.9	65.0 (43.3-81.9)	52.9 (41.2-64.3)	1.38 (0.92-2.08)	0.66 (0.35-1.25)
Maximal speed with	0.61 (0.47-0.76)	12.7	70.0 (48.1-85.5)	52.9 (41.2-64.3)	1.49 (1.02-2.18)	0.57 (0.28-1.15)

TABLE 6 (Continued)

Dual task mobility assessment	Know-groups validity: using walking time to discriminate fallers VS. non-fallers[184]					
	AUC(95%CI)	Cut-off(s)	Sensitivity(%)(95%CI)	Specificity(%)(95%CI)	Positive likelihood ratio (95%CI)	Negative likelihood ratio(95%CI)
verbal fluency						
Maximal speed with serial 3 subtraction	0.63(0.49-0.77)	14.0	65.0(43.3-81.9)	61.8(49.9-72.4)	1.70(1.09-2.64)	0.57(0.30-1.06)
Maximal speed with manual task	0.57(0.42-0.71)	11.5	70.0(48.1-85.5)	44.1(33.0-55.9)	1.25(0.88-1.79)	0.68(0.33-1.40)
Backward walking with verbal fluency	0.57(0.43-0.72)	35.0	65.0(43.3-81.9)	48.5(37.1-60.2)	1.26(0.85-1.88)	0.72(0.38-1.38)
Backward walking with serial 3 subtraction	0.58(0.44-0.72)	37.0	70.0(48.1-85.5)	44.1(33.0-55.9)	1.25(0.88-1.79)	0.68(0.33-1.40)
Obstacle course with verbal fluency	0.55(0.40-0.70)	33.6	20.0(8.1-41.6)	95.6(87.8-98.5)	4.53(1.11-18.6)	0.84(0.67-1.05)
Obstacle course with serial 3 subtraction	0.51(0.36-0.66)	32.5	20.0(8.1-41.6)	97.1(89.9-99.2)	6.8(1.34-34.45)	0.82(0.66-1.03)

TABLE 6 (Continued)

Dual task mobility assessment	Know-groups validity: using walking time to discriminate fallers VS. non-fallers[184]					
	AUC(95%CI)	Cut-off(s)	Sensitivity(%)(95%CI)	Specificity(%)(95%CI)	Positive likelihood ratio (95%CI)	Negative likelihood ratio(95%CI)
Obstacle course with manual task	0.53(0.38-0.68)	33.2	30.0(14.6-51.9)	89.7(80.2-94.9)	2.91(1.11-7.69)	0.78(0.58-1.05)
TUG with verbal fluency	0.55(0.41-0.69)	15.1	75.0(53.1-88.8)	35.3(25.0-47.2)	1.16(0.85-1.58)	0.71(0.31-1.62)
TUG with serial 3 subtraction	0.60(0.46-0.73)	15.6	80.0(58.4-91.9)	36.8(26.3-48.6)	1.27(0.95-1.68)	0.54(0.22-1.38)
TUG with manual task	0.55(0.40-0.69)	15.5	85.0(64.0-94.8)	22.1(13.9-33.3)	1.09(0.87-1.36)	0.68(0.22-2.12)

Although previous studies have determined the effects of dual- task assessment and their psychometric properties, some types of cognitive tasks (especially discrimination and decision-making, working memory, and reaction time) have not been studied yet. Therefore, there is a need for determining which dual-task assessment would have ability to provide sufficient challenge, on both mobility and cognitive tasks, to elicit dual-task costs in a way that can be observed by a clinician. The most suitable type and condition of the cognitive task that provides optimal dual-task costs should be identified for assessing dual-task mobility performance in people with stroke.

CHAPTER 3
METHODOLOGY

3.1 Design

The design of this study was a repeated measures design.

3.2 Research objective

The objective of this study was to determine the type of cognitive task that led to highest detrimental effects during TUG-dual in persons with stroke who had subtraction problem and those who did not.

Before determining the effects of cognitive tasks during TUG-dual in persons with stroke, we carried out the pilot study for selecting one of various cognitive tasks in each type that led to the highest deteriorating effect of gait and cognitive performance and also high feasibility in clinic. Results from pilot study were then used as the cognitive tasks to be explored in the main study.

3.3 Pilot study

3.3.1 Research objectives of the pilot study

1. To explore the feasibility of implementing the cognitive tasks in four type of cognitive task (mental tracking, working memory, discrimination and decision-making, and verbal fluency) during walking in persons with stroke.

2. To compare the effects of adding cognitive tasks (various tasks in each type of cognitive task) during walking on gait performances and cognitive performance.

3.3.2 Sample size of the pilot study

The sample size calculation for the repeated measure ANOVA was calculated by using the following formula:[186, 187]

$$N \approx 4 \sum_{i=1}^{k} \sum_{j=1}^{k} \rho_{ij} \, S_i S_j \left(Z_{1-\alpha/2} + Z_{1-\beta} \right)^2 / (k\Delta^2)$$

with N = the number of sample size

S_i = the standard deviation of the outcome from time point i

S_j = the standard deviation of the time point j

ρ_{ij} = the correlation of the outcome at time points i and j

Δ = the difference of mean of the outcome from time point i and j

k = the number of repeated measurements

Z = the constant number which is according to the error probability (α) and power (β)

The minimum number of subjects required in pilot study was 21, for a two-side test at α = 0.05, β = 0.2 and k = 4, with selected values of S_i = 0.373, S_j = 0.379, ρ_{ij} = 0.68, Δ = 0.081 obtained from study by Plummer-D' Amato et al. (2008).[75] The dropout rate was calculated at 10% of sample size, so the total number of subjects that required for pilot study was 24 persons.

3.3.3 Participants of the pilot study

Participants with stoke were recruited from the Police General Hospital, Rehabilitation Center of The Thai Red Cross Society, Maechan Hospital, and Somdej Phrayan Sangwon Hospital, based on these inclusion criteria; diagnosis of cerebrovascular accident with medical stable, able to walk independently at least 10 meters with or without walking aids, and able to perform simple calculation and spelling. The participants were excluded if they had: 1) brainstem or cerebellar lesion, 2) cerebral aneurysm, 3) color blindness, 4) hearing loss, 5) aphasia, 6) severe visual impairment, 7) major depression (as score on 2Q $\geq$ 1 and scored on 9Q questionnaire as $\geq$ 19, 8) orthopedic condition or pain affecting natural gait, 10) other neurological disorders that sufficiently disturb balance, 10) inadequate language comprehension, unable to understand the instruction, or 11) cognitive deficit (as measured by the Mini-Mental State Exam Thai version (MMSE Thai 2002) $\leq$ 22). Ethical approval was granted by the institutional Review Board of Srinakharinwirot University. All participants signed the written informed consent prior to participate in the study.

3.3.4 Procedure of the pilot study

Although there are 5 types of cognitive task, the reaction time task was not explored in this study due to the feasibility of using this type in the clinical setting. As a result, four types of cognitive tasks were examined. Based on the results, one of various conditions in each cognitive type that had the strongest effect on gait and cognitive performances and high feasibility was selected as the conditions to be explored in the main study.

All participants were required to perform walking for 10 meters, cognitive task in sitting (cognitive-single), and cognitive task while walking (cognitive-dual), respectively. The assessment of cognitive performance in sitting was performed for one minute. The order of cognitive task was randomly assigned. After the test, the participant was allowed to rest to prevent mental fatigue for 2 minutes before performing another task until they completed all tasks. The cognitive task procedures were described in Table 7.

TABLE 7 The cognitive task procedure of pilot study

Type of cognitive task	Task condition	Procedure	Note
Mental tracking	1) Subtraction by 3	Participants were asked to reciting out loud serial subtraction of 3, starting from a random three-digit number.	Only one cognitive task that has highly effects on gait and cognitive performances and also high feasibility in each cognitive task type was selected for further investigation in the main study
	2) Spelling backward	Participants were asked to spell 4-letter words in reverse.	
	3) Arithmetic task	Simple sums (e.g., “5+6=11”) were presented every 5 sec. Participants were asked to response as quickly as accurately as possible either “yes” or “no” to indicate whether each sum was correct or not.	
	4) Alternate reciting	Participants were asked to recite	

TABLE 7 (Continued)

Type of cognitive task	Task condition	Procedure	Note
		consecutive letters of the alphabet aloud.	
Working memory	1) Shopping list task	The participants were asked to memorize a 7-item shopping list as it is played over a stereo system.	
	2) Easy auditory working memory	Participants were asked to recall a series of random numbers.	
	3) Hard auditory working memory	The participants were asked to listen to sequences of digits, as it is played over a stereo system. Then, they were asked to repeat each sequence in reverse.	
Discrimination and decision making	1) Color classification	The participants listen to a pre-recorded audiotape and answering 'yes' when they heard the word 'red' and 'no' when they heard the word 'blue'. The audiotape presents the words 'red' and 'blue' in random order at 3-s intervals.	
	2) Clock task	The participants listen for 'time-of-day' prompts and determine whether the two hands of a clock are on the same or different sides of the clock face. Participants were instructed to visualize the time and say aloud "same" or "different" as quickly as possible.	
	3) Stroop test	Images consisting of the name of one of four colors, printed in the text	

TABLE 7 (Continued)

Type of cognitive task	Task condition	Procedure	Note
		of a different color, were projected in front of the participants. Participants were instructed to verbally identify the color of the text and to ignore the word itself.	
Verbal fluency	1) Word generation (categorial + alphabet fluency)	Participants were asked to name animals with names starting with a specific letter given to him/her at the beginning of the test.	
	2) Semantic fluency (categorical fluency)	The participants were asked to enumerate as many animal names as possible.	
	3) Phonologic fluency (alphabet fluency)	Participants were asked to say as many words as possible beginning with certain letters	

3.3.5 Data analysis of the pilot study

For the feasibility of task, the number of participants who could perform the cognitive task in sitting were calculated as the percentage of all participants. The criteria for identifying the feasibility of task was those who were able to perform task with more than 3 correct answers. Gait performances including gait speed and stride length of paretic and non-paretic legs were analyzed. Gait speed was calculated from the distance of walking (10 meters) divided by duration of walking (second). Duration of walking and stride length were obtained by using the accelerometer system (APDM Mobility Lab System).

For the cognitive performance, the cognitive correct response rate (CRR) was calculated. The correct response rate (CRR) was used for measuring the performance level of cognitive task, and it can be calculated as:

CRR = number of correct responses ÷ time

where the "CRR" represents the total correct words or digits generated during the trials, and "time" is the time (in seconds) taken to complete the task.[184]

The dual-task effect (DTE) was used to determine the influence of addition of the cognitive task. As a relative measure of change, the DTE was calculated for each outcome measure. The decrement cognitive performance under dual-task conditions (cognitive costs) is represented in negative value, while the improvement cognitive performance under dual-task condition is presented in positive value (cognitive benefits).[183] These DTE was measured using the following formula:[183]

$$\frac{(\text{CRR dual task} - \text{CRR single task}) \times 100\%}{\text{CRR single task}}$$

All statistical analyses were conducted using the SPSS statistics software version 25. Repeated-measured analyses of variance (ANOVA) was used to analyze the main effect of cognitive type on motor and cognitive performance. The level of significant was set at 0.05 and the Bonferroni test was used for post hoc analyses.

3.4 Main study

3.4.1 Sample size of the main study

The sample size calculation for the repeated measure ANOVA was calculated by using G*power version 3.1. The minimum number of subjects required in ST group was 22 persons, for selected values of the error probability (α) was set at 0.05, power (β) was estimated at 0.8, number of repeated measurements was set at 6 time points, and the effect size specification as in Cohen (1988) was 0.79. For the STP group, the minimum number of subjects required was 21 persons, for selected values of the error probability (α) was set at 0.05, power (β) was estimated at 0.8, number of repeated measurements was set at 5 time points, and the effect size specification as in Cohen (1988) was 0.79.

3.4.2 Participants of the main study

Participants with stoke were recruited from the Police General Hospital, Rehabilitation Center of The Thai Red Cross Society, Maechan Hospital, and Somdej Phrayan Sangwon Hospital based on these inclusion criteria; diagnosis of cerebrovascular accident with medical stable and able to walk independently at least 6 meters with or without walking aids. The participants were excluded if they had: 1) brainstem or cerebellar lesion, 2) cerebral aneurysm, 3) color blindness, 4) hearing loss, 5) aphasia, 6) severe visual impairment, 7) major depression (as score on 2Q $\geq$ 1 and scored on 9Q questionnaire as $\geq$ 19, 8) orthopedic condition or pain affecting natural gait, 10) other neurological disorders that sufficiently disturb balance, 10) inadequate language comprehension, unable to understand the instruction, or 11) cognitive deficit (as measured by the Mini-Mental State Exam Thai version (MMSE Thai 2002) $\leq$ 22. Participants were then classified into 2 groups based on the ability to perform subtraction by 3's (5 times); able to subtract (ST) and subtraction problem (STP). The criteria for identifying the STP group were those unable to perform serial subtract or had only one correct answer (out of five). Ethical approval was granted by the institutional Review Board of Srinakharinwirot University. All participants signed the written informed consent prior to participate in the study.

3.4.3 Measurement tools

Baseline information including age, gender, height, hemiplegic side, time since stroke, and education level were collected in all participants using the questionnaire. Motor and walking performance of participants with stroke were determined using the Fug-Meyer Assessment motor subscale (FM-motor) and stride velocity, respectively. Responses on the cognitive tasks were recorded using digital recorders. Two raters checked the correct answers and any repetition was scored once.

For assessing motor performance during TUG-single and TUG-dual, the APDM's mobility Lab™ (APDM Inc) was used to collect and store data. By using a gyroscope (± 400°/s range) and accelerometer (± 5g range) captured angular and acceleration at the sampling rate of 200 Hz, the gait cycles and related events are detected and estimated. [188] Four portable 3D inertial sensors were placed on the participant at mid-thoracic, 5th lumbar vertebrae, and left and right ankles. In the TUG protocol, the subjects were instructed to stand up from a chair, walk 3 meters with self-selected speed, turn 180°, then walk back and sit down.

3.4.5 Procedures of the main study

Participants received the standardized verbal instruction regarding the cognitive task procedure and was allowed to practice while sitting on the chair. To avoid the learning effects, the contents of the cognitive task performed during tests were not similar to those when practice (e.g. different digit numbers, different letters, etc.). After a practice trial, participants performed TUG without cognitive task (TUG-single) followed by cognitive task when seated (cognitive-single) and TUG with cognitive task (TUG-dual) of a randomly selected cognitive task, including alternate reciting, auditory working memory, clock task, and phonologic fluency, until all tasks were performed. The participants in the ST group were asked to perform one additional task of serial subtraction.

The order of these four cognitive tasks (A: Mental tracking, B: Working memory, C: Discrimination and decision-making, D: Verbal fluency) was randomized. The block randomization technique was used for ensure the equally of task allocation. Possible task allocations within each block were (1) ABCD, (2) ABDC, (3) ACDB, (4) ACBD, (5) ADBC, (6) ADCB, (7) BACD, (8) BADC, (9) BCDA, (10) BCAD, (11) BDAC, (12) BDCA, (13) CABD, (14) CADB, (15) CBDA, (16) CBAD, (17) CDAB, (18) CDBA, (19) DABC, (20) DACB, (21) DBAC, (22) DBCA, (23) DCAB, and (24) DCBA.

The instruction for performing TUG with additional of cognitive task as “please perform both tasks as well as possible” was given to the participants for all TUG-dual assessments. However, there is no instruction to prioritize either gait or cognitive task. The rater 1 was observed whether the participant stops walking during the trial. The rater 2 was recorded the participant’s answers, which the number of total answers and correct answers was counted.

3.4.6 Study variables

3.4.6.1 Motor performances:

Total TUG duration, sit-to-stand duration, straight walk duration, turn duration, turn-to-sit duration, and gait speed were calculated from APDM's mobility Lab software.

Information of turn was determined by measuring the change in angle of the body. The algorithm integrated the angular velocity about the roll axis of the sternum monitor to calculate the angle change of the body and detected turn. The angle change from 0 to 180 degrees is considered the act of turn, and if the angle change from 180 to 360 degrees is considered the turn-to-sit.[(189)]

The APDM's mobility Lab record each trial based on the configuration on the TUG plug-in. The TUG plug-in calculate the spatio-temporal parameters from the angular velocity of the pitch axis of the gyroscope of the shanks.[(190)] By using this signal from shanks, gait cycles and related events are detected and temporal parameters of gait are estimated. The TUG algorithm gather the data and search for the initial contact and terminal contact of the feet.[(188, 190)] The swing phase of the gait cycle was determined by a positive shank angular velocity reaching the highest values at around the mid-swing. Prior the mid-swing location, a negative angular velocity peak can be observed which associated with the terminal contact. The first negative peak that located after the mid-swing was selected as the initial contact.[(188)]

3.4.6.2 Cognitive performance

The correct response rate (CRR) and the cognitive DTE were used to determine cognitive performance and were calculated using the similar formula as in the pilot study.

3.4.6 Statistical analysis

All statistical analyses were conducted using the SPSS statistics software version 25. An independent t-test was used for comparing age, onset of stroke, scores of FM-motor, and gait speed. For comparing education level, a Mann-Whitney U test was used. Repeated-measured analyses of variance (ANOVA) was used to analyze the main effect of cognitive type on motor and cognitive performance. The level of significant was set at 0.05 and the Bonferroni test was used for post hoc analyses.

CHAPTER 4
FINDINGS

4.1 Results of Pilot study

Twentynine persons with stroke were recruited from the hospitals and rehabilitation centers based on the inclusion and exclusion criteria. The participants had ischemic or hemorrhagic stroke and their stroke onsets were varied from 1 to 111 months. Their ages were ranged from 34 to 77 years old and most of them had education at elementary level. Their demographic characteristics were described in Table 8.

TABLE 8 The demographic characteristics of participants in the pilot study

Demographic Variables	N = 29
Age (years)	57.17 ± 12.14
Gender (male/female)	21/8
Hemiparetic side (left/right)	15/14
Time since stroke (months)	24.97 ± 24.88
MMSE score	27 ± 2.10
Walking aid	
None	14
One point cane	9
Three point cane	6
Education level	
None	1
Elementary	17
High school	8
Degree	3
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

Note: The data are present as mean ± SD or number.

4.1.1 Feasibility of cognitive tasks in stroke

The complexity and difficulty of cognitive tasks used were varied. Participants cannot finish or perform some of the cognitive tasks due to their difficulty and complexity. The percentage of participants who completed the tasks in each type of cognitive task ((A) Mental tracking tasks, (B) Working memory tasks, (C) Discrimination and decision-making tasks, (D) Verbal fluency tasks) were compared to determine the feasibility of cognitive tasks (Figure 1). The tasks that received highest feasibility were arithmetic (MT), Easy working memory (WM), Stroop test (DM) and Phonologic fluency (VF).

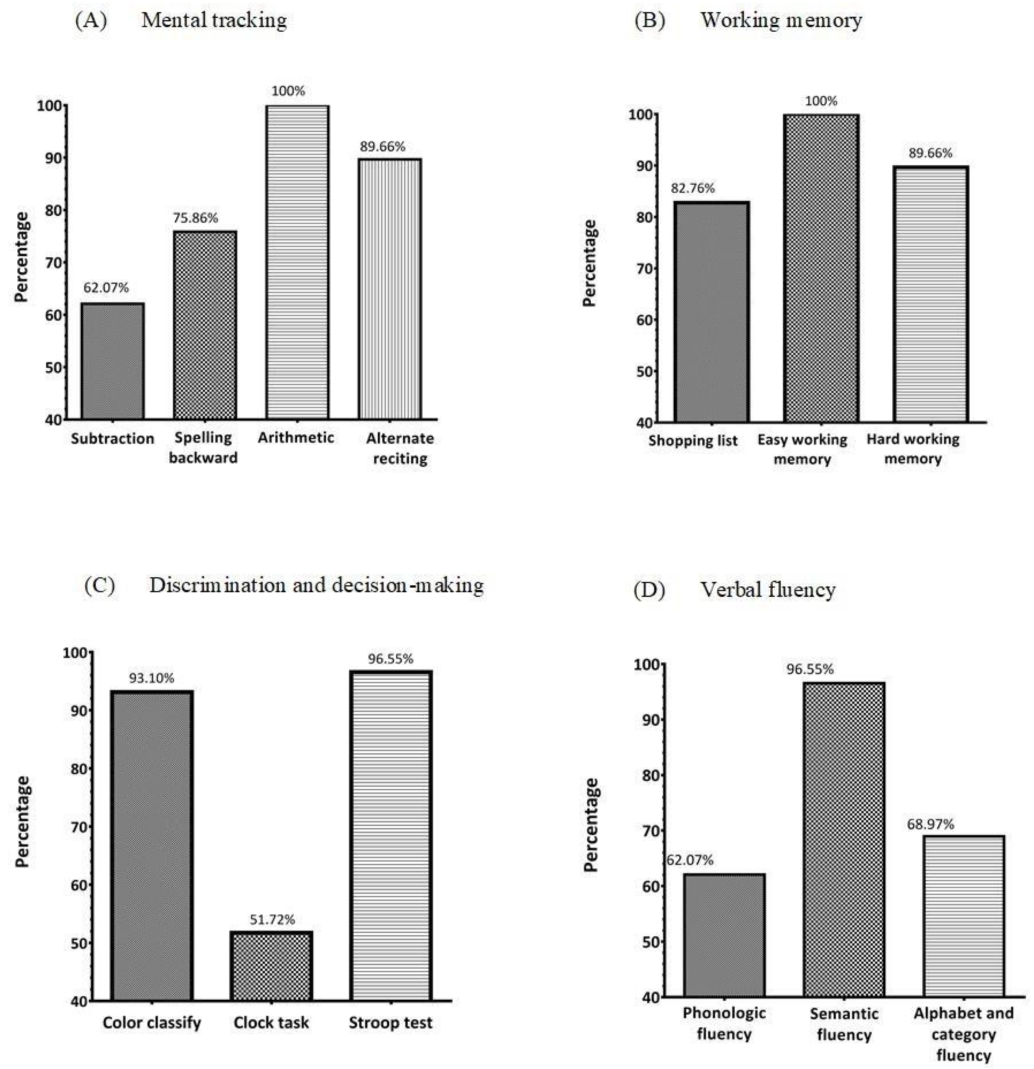

FIGURE 1 Feasibility of cognitive tasks in the pilot study.

4.1.2 Effects of cognitive dual-task on gait and cognitive performances

The effects of cognitive task on gait speed, paretic and non-paretic stride length, and cognitive performance were determined (Figure 2-5).

4.1.2.1 Mental tracking tasks

Results showed that most of mental tracking tasks caused decrease in gait speed, except the arithmetic task (Figure 2). The gait speed was lowest under subtraction (0.216) and alternate reciting task (0.238) (Figure 2). However, when considering the paretic and non-paretic stride length, subtraction was the only task that caused decrease in paretic and non-paretic stride length (Figure 3-4). For the effect on cognitive performance, negative value of DTE was highest in alternate reciting task (-35.12%) and lowest in subtraction task (-24.56%) (Figure 5). Therefore, based on deteriorative effects on gait and cognitive performances, subtraction and alternate reciting task were selected.

4.1.2.2 Working memory tasks

All working memory tasks caused detrimental effects on gait speed (Figure 2). For determining the effect on cognitive performance, the auditory working memory task (hard level: -28.43%; easy level: -28.17%) possibly caused higher deteriorating effects than the shopping task (-7.11%) (Figure 5). However, considering the feasibility to use the task, all of participants can perform the auditory working memory task (easy level). Therefore, the auditory working memory (easy level) was selected.

4.1.2.3 Discrimination and decision-making tasks

The gait speed, paretic and non-paretic stride length under color classify task, clock task, and Stroop test were not statistical different compared with single walk (Figure 2-4). However, the gait speed tended to be lowest for the clock task (Figure 2). For the cognitive performance, the color classify (-37.85%) and clock task (-31.23%) possibly caused more deteriorating effects than Stroop test (-23.32%). Therefore, the clock task was selected.

4.1.2.4 Verbal fluency tasks

The gait speed, paretic and non-paretic stride length were statistical different compared with single walk only under phonologic fluency task (Figure 2-4). In addition, the phonologic fluency task caused higher deteriorative effects on cognitive performance (-11.83%) than other tasks (Figure 5). Therefore, the phonologic fluency was selected.

Therefore, based on results of pilot study as mention above, the selection tasks were included: 1) mental tracking: subtraction and alternate reciting task, 2) working memory: auditory working memory (easy level), 3) discrimination and decision making: clock task, 4) verbal fluency: phonologic fluency task (Table 9).

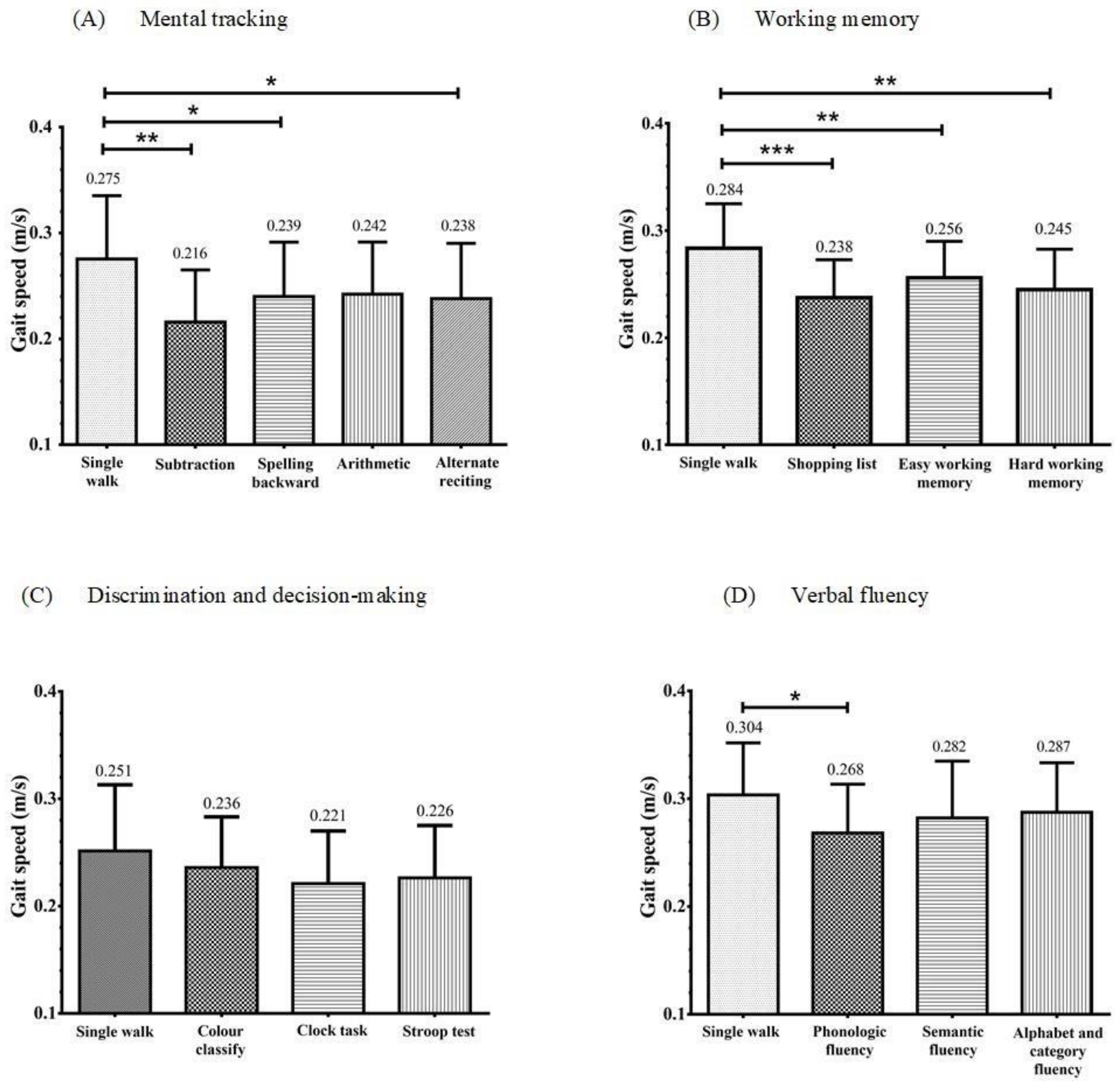

FIGURE 2 Gait speed under dual-task conditions compared with single walk.

(Figure 2: Average gait speed (with 95% CI) of (A) Mental tracking tasks, (B) Working memory tasks, (C) Discrimination and decision-making tasks, (D) Verbal fluency tasks. (* depicts significant difference at p<0.05. ** depicts significant difference at p<0.01. *** depicts significant difference at p<0.0001))

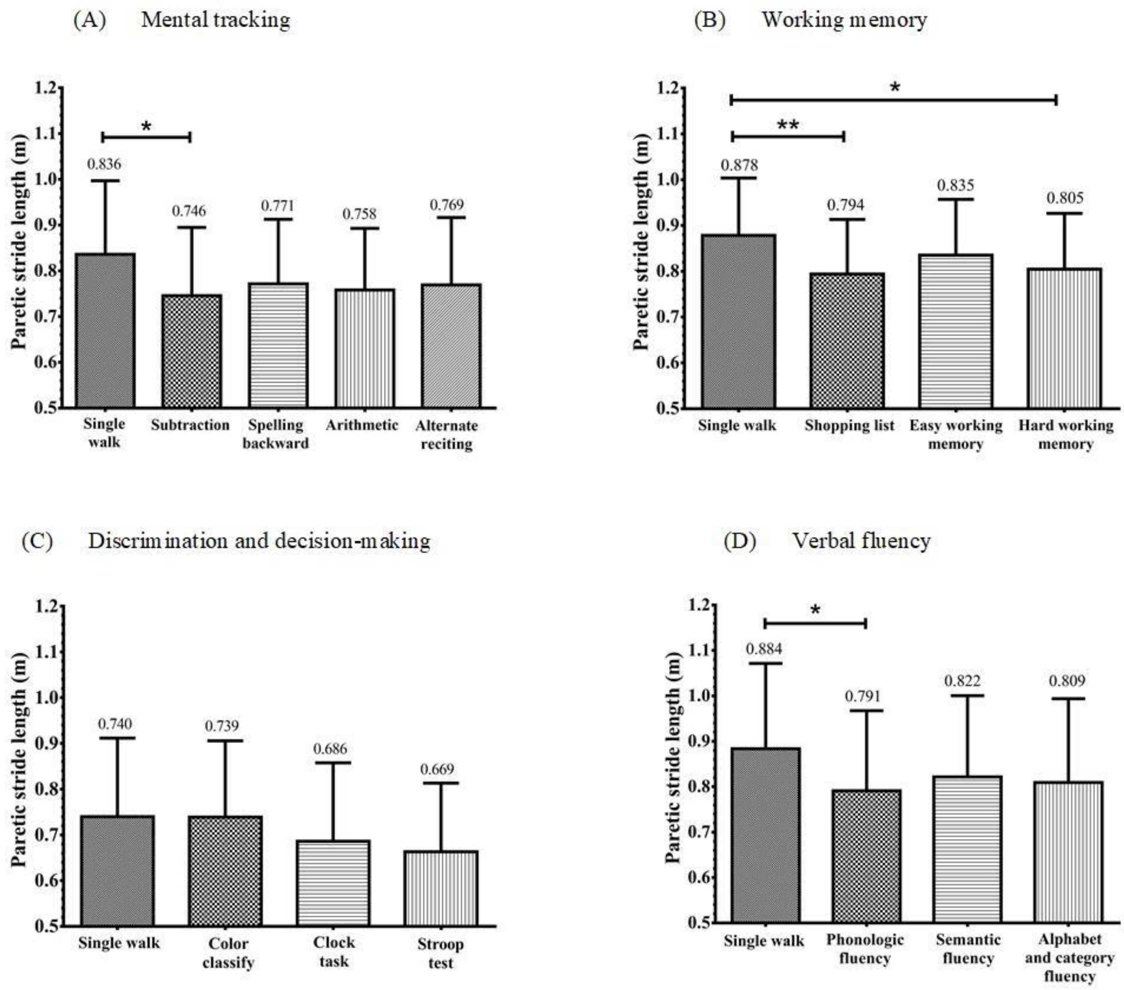

FIGURE 3 Paretic stride length under dual-task conditions compared with single task.

(Figure 3: Average paretic stride length (with 95% CI) of (A) Mental tracking tasks, (B) Working memory tasks, (C) Discrimination and decision-making tasks, (D) Verbal fluency tasks. (* depicts significant difference at p<0.05. ** depicts significant difference at p<0.01))

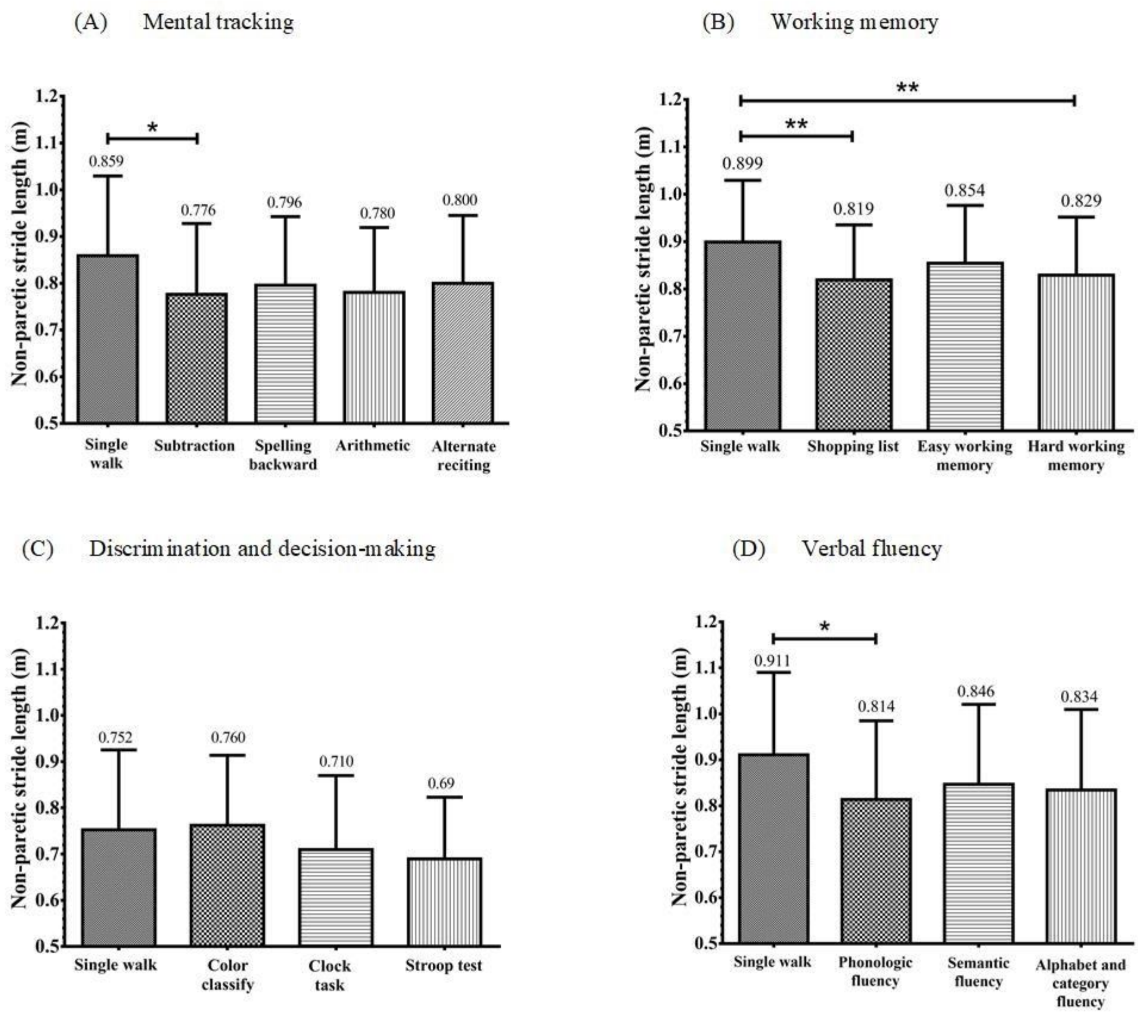

FIGURE 4 Non-paretic stride length under dual-task conditions compared with single walk in the pilot study.

(Figure 4: Average non-paretic stride length (with 95% CI) of (A) Mental tracking tasks, (B) Working memory tasks, (C) Discrimination and decision-making tasks, (D) Verbal fluency tasks. (* depicts significant difference at $p<0.05$. ** depicts significant difference at $p<0.01$))

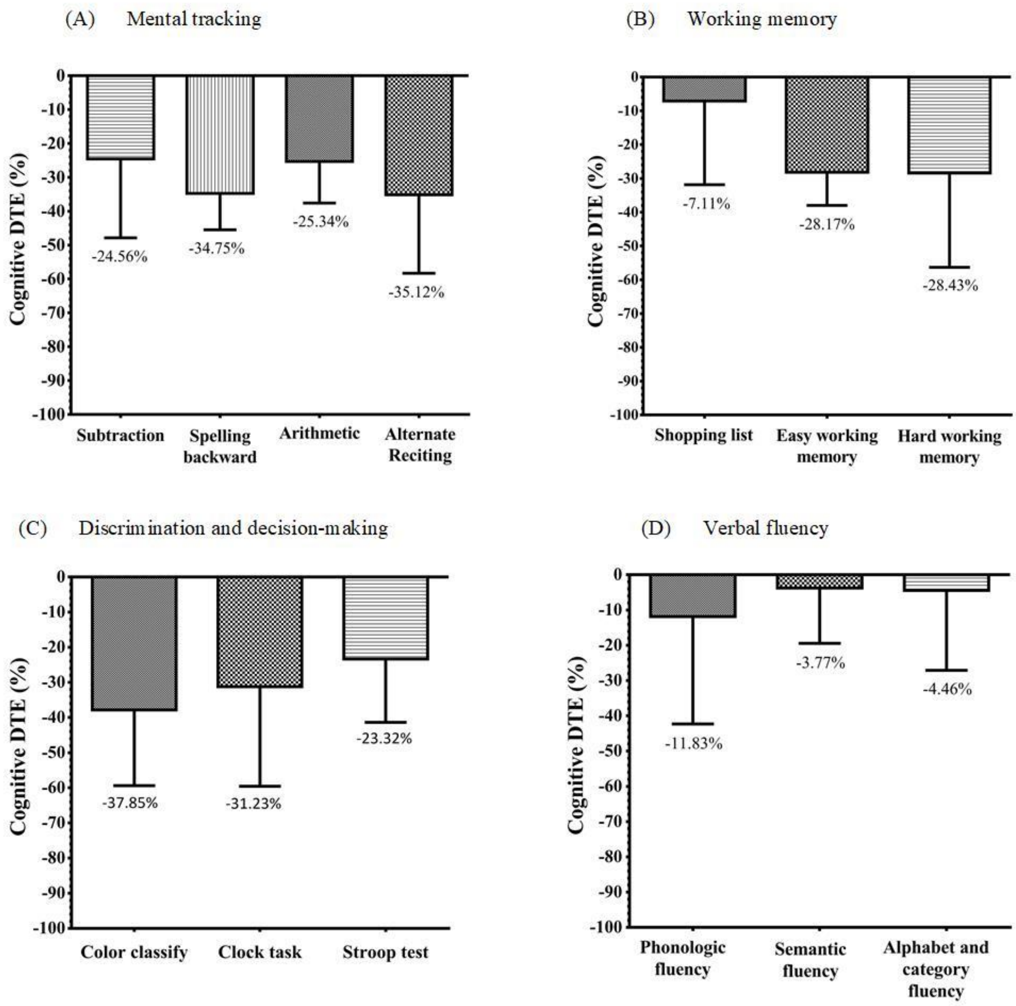

FIGURE 5 Cognitive Dual-Task Effect (DTE).

(Figure 5: Average percentage of cognitive DTE (with 95% CI) of (A) Mental tracking tasks, (B) Working memory tasks, (C) Discrimination and decision-making tasks, (D) Verbal fluency tasks).

4.2 Summary of task selection

To summarize, the task that led to most deteriorating effect on gait and cognitive performances in each cognitive category were described in Table 9.

TABLE 9 Selected cognitive tasks in each type of cognitive task

No	Category	Tasks condition	Selected task	Instruction
1	Mental tracking (MT)	- Subtraction by 3 - Spelling backward - Alternate reciting - Arithmetic task	Subtraction by 3	Reciting out loud serial subtraction of 3, starting from a random three digits number
			Alternate reciting	Reciting consecutive letters of the alphabet aloud
2	Working memory (WM)	- Easy auditory working memory - Hard auditory working memory - Shopping list task	Easy auditory working memory	Recalling a series of random numbers
3	Discrimination and decision making (DM)	- Color classify task - Clock task - Stroop test	Clock task	Listening for 'time-of-day' prompt and say aloud "same" or "different" by determine whether the two hands of a clock are on the same or different sides of the clock face
4	Verbal fluency (VF)	Phonologic fluency (alphabet fluency)	Phonologic fluency	Recalling words with a specific letter given to

TABLE 9 (continued)

No	Category	Tasks condition	Selected task	Instruction
		Semantic fluency (category fluency) Word generation (alphabet and category fluency)		him/her at the beginning of the test

4.3 Results of the main study

From 50 participants, 24 persons were classified into ST group and 26 were classified into STP group. One participant in group ST and four participants in group STP were excluded from the analyses because of the invalid data. Resulting in 23 in STP and 22 in ST group (Figure 6). Also, the baseline characteristics (including age, stroke onset, gait speed, FM-motor scores, and education) between these two groups were compared (Table 10). The participants in both groups were not different in age, onset, hemiparetic side, the use of walking aid, lower limb function and walking speed. However, the education level of group ST was significantly higher than group STP ($p < 0.05$) (Table 10).

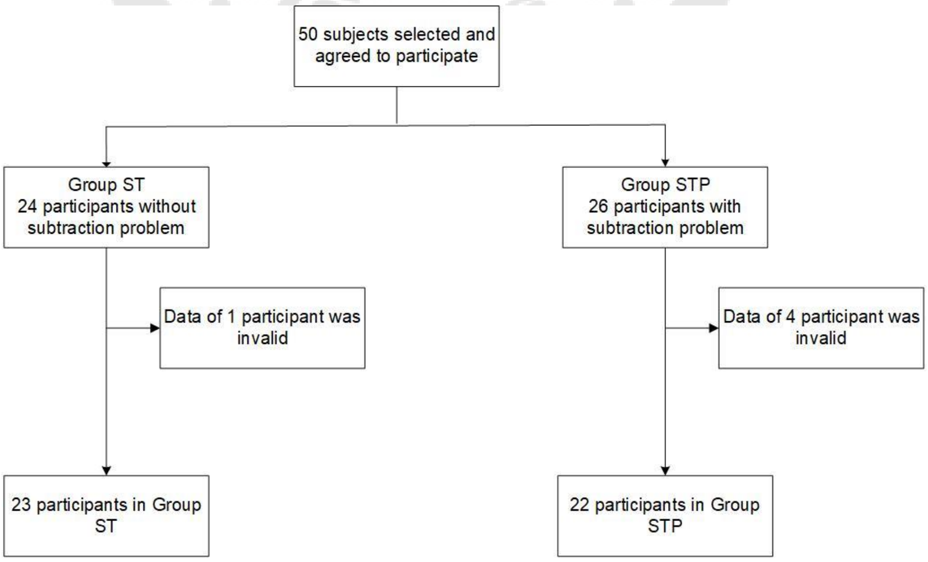

FIGURE 6 Flow chart shows the number of participants in each group.

TABLE 10 Demographic characteristic of participants

Demographic variables	ST (N = 23)	STP (N = 22)	P value
Age (years)	59.52 ± 10.47	62.77 ± 6.94	0.23
Gender (male/female)	13/10	11/11	
Hemiparetic side (left/right)	9/14	13/9	
Time since stroke (months)	44.13 ± 62.29	42.07 ± 39.81	0.89
Recurrent stroke (yes/no)	2/21	3/19	
FM-motor (total 34 scores)	30.35 ± 4.91	28 ± 4.31	0.09
Walking aid			
None	22	19	
One point cane	1	2	
Three points cane	-	1	
Education level			0.04*
Elementary	13	19	
High school	9	2	
Degree	1	1	
Gait speed (m/s)	0.75 ± 0.23	0.67 ± 0.25	0.3

Note: The data was present as mean ± SD or number.

However, three participants in group STP were not capable to perform all of the tasks. One of them was not capable to perform alternate reciting task, another one for clock task, and the last one for alternate reciting and the clock task. Therefore, the data of 23 participants in STP and 19 participants in ST was analyzed with the repeated measured ANOVA to determine the effects of cognitive tasks on their TUG and cognitive performances.

4.3.1 Effects of cognitive tasks when combined with TUG (TUG-dual) on motor performances

Figure 6 shows total TUG duration from both groups during TUG-single and TUG-dual. In ST, total TUG duration was significantly longer during all TUG-dual as compared to TUG single ($p < 0.0001$). In contrast, total TUG duration in STP significantly increased only during phonologic fluency task ($p < 0.01$). Figure 6 also shows duration spent in four components of TUG. No significant difference in duration was found during the sit-to-stand component between TUG-single and all TUG-dual in both groups. Straight walk duration and turning duration were significant longer between TUG-single and all TUG-dual in the ST ($p < 0.01$ and $p < 0.0001$, respectively). While in the STP, straight walking duration and turning duration were significant longer only between TUG single and TUG-phonologic fluency ($p < 0.05$). Turn-to-sit duration was different from TUG-single during TUG-subtraction ($p < 0.05$), TUG-alternate reciting ($p < 0.05$), and TUG-clock task ($p < 0.01$) in the ST. While, in the STP, no significant difference between tasks was found in turn-to-sit duration.

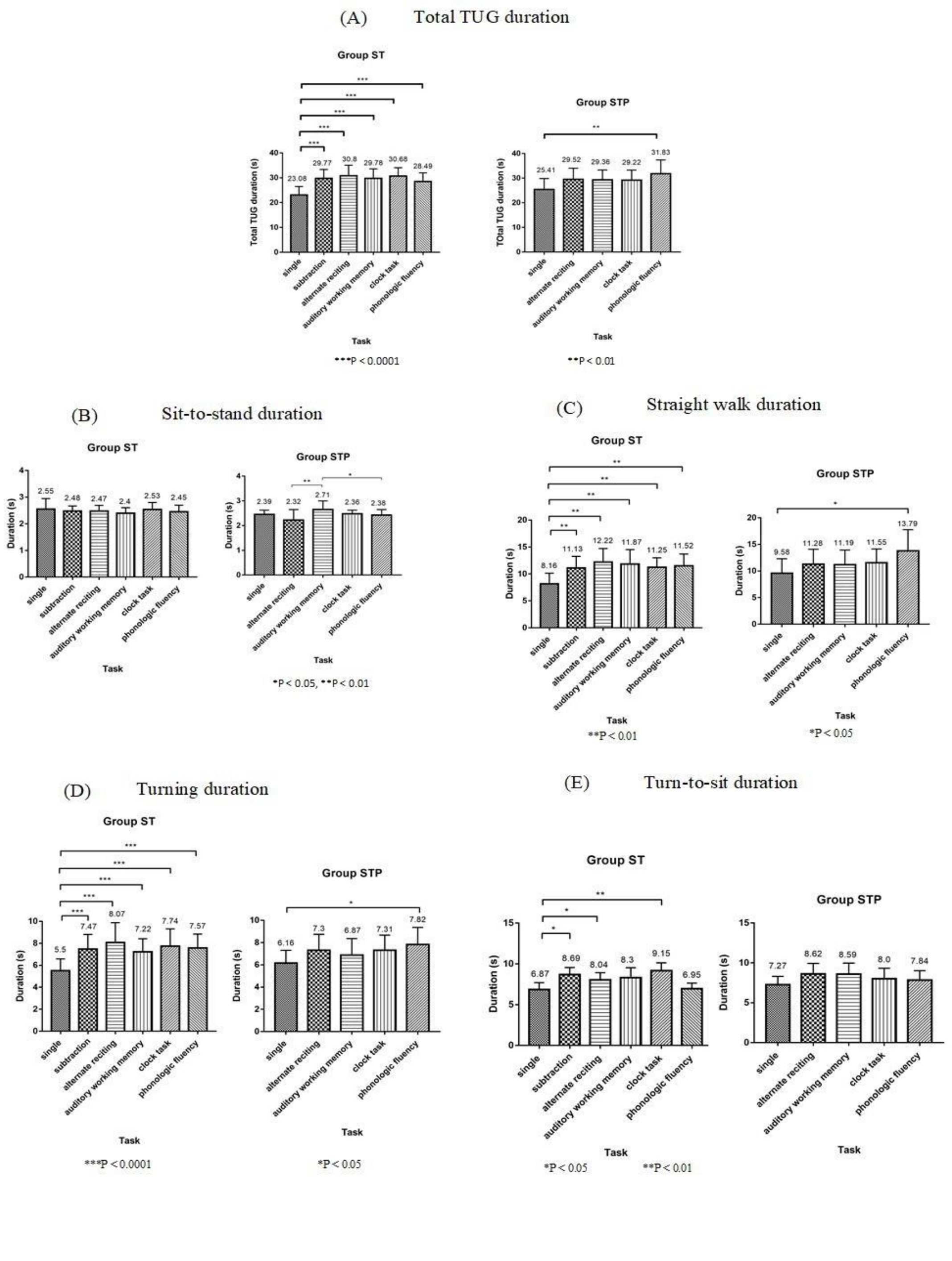

FIGURE 7 Average total TUG and subcomponent of TUG duration (with 95%CI)

(Figure 7: Average of (A) Total TUG duration (B) Sit-to-stand duration, (C) Straight walk duration, (D) Turning duration, (E) Turn-to-sit duration, comparing between cognitive tasks in persons with stroke who were able to subtract (ST) and those with subtraction problem

(STP). (* depicts significant difference at p<0.05. ** depicts significant difference at p<0.01. *** depicts significant difference at p<0.0001))

4.3.2 Effects of cognitive tasks when combined with TUG (TUG-dual) on cognitive performances

For the cognitive cost, the group average revealed the highest detrimental effect on cognitive performance was found in the serial subtraction task in group ST and in phonologic fluency task in group STP (Figure 8). There was also significant difference between subtraction task and phonologic fluency task in the ST ($p < 0.01$), but no significant different was found between tasks in STP (Figure 8).

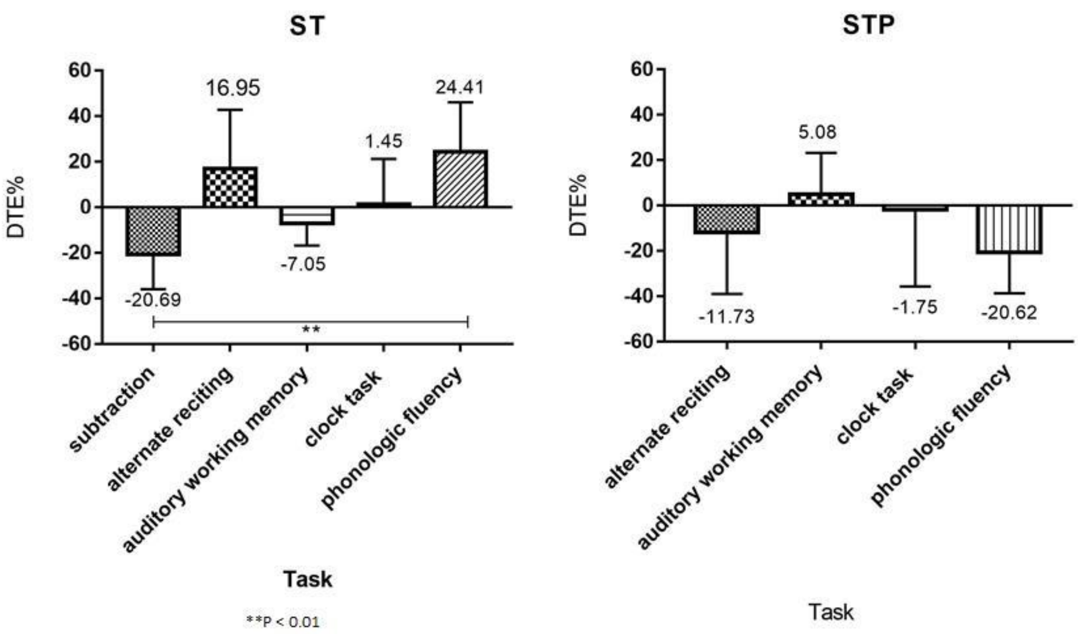

FIGURE 8 Group average (with 95%CI) of cognitive cost (%DTE)

(Figure 8: Group average (with 95% CI) of cognitive cost (%DTE), comparing between different cognitive tasks in able to subtract (ST) group and subtraction problem (STP) group. Positive value means improve in cognitive performance (cognitive benefits), negative value means decline in cognitive performance (cognitive costs). ** depicts significant difference at p<0.01.)

There were there different cognitive patterns (decline: as negative value of DTE%; no change: as zero value of DTE%, and improvement of cognitive performance: as positive value of DTE%, as compared to cognitive function during sitting) found in an individual in group ST (N= 23) and group STP (N = 19) (Figure 9).

Most participants (65.22%) in group ST showed decreased cognitive performance during TUG-dual in the subtraction task, as compared to cognitive-single. In contrast, the majority of participants in group STP (57.89%) demonstrated a decline in cognitive performance during the phonologic fluency task (Figure 9).

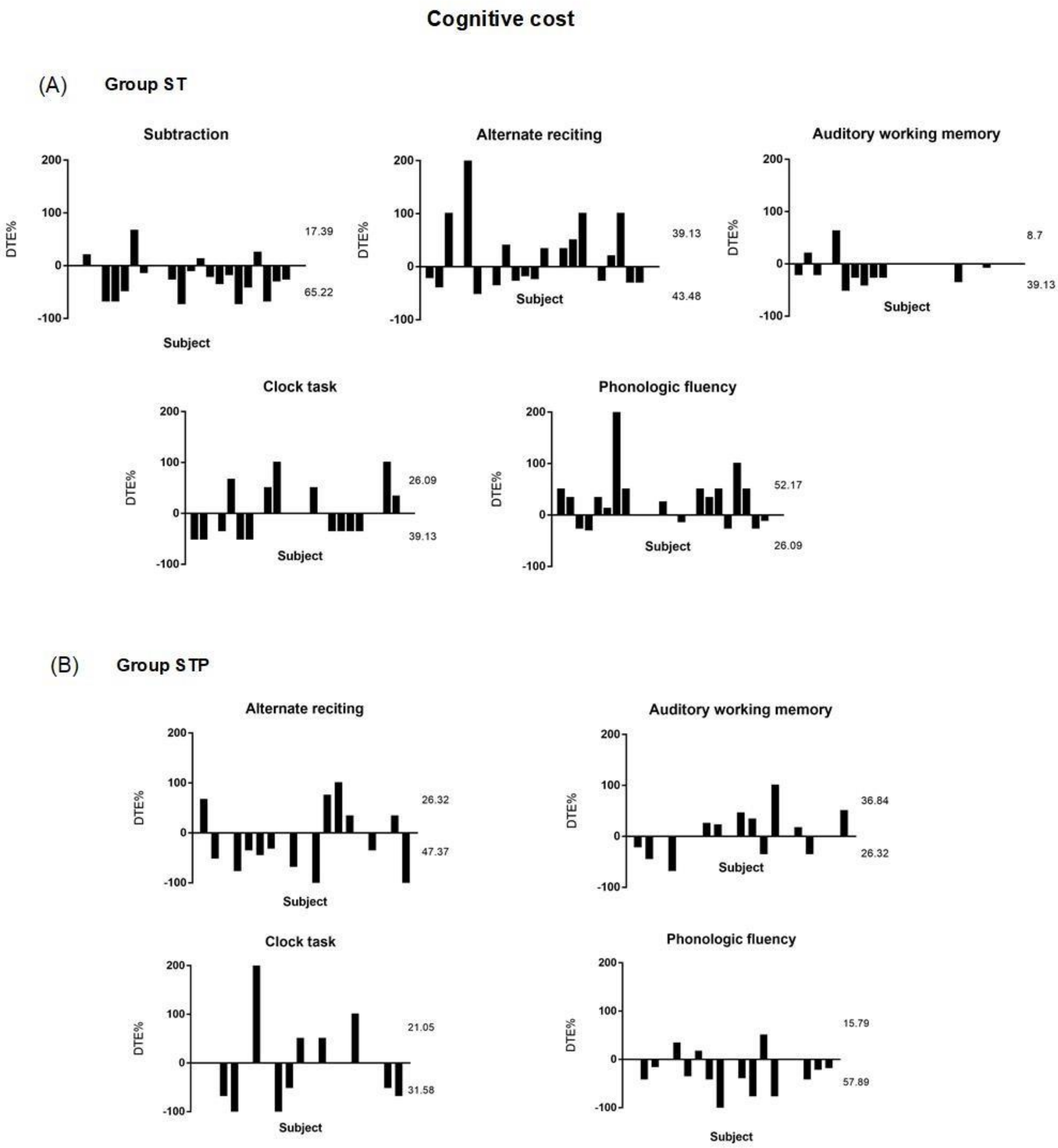

FIGURE 9 Cognitive cost of different cognitive tasks from individual subject with stroke

(Figure 9: Cognitive cost of different cognitive tasks from individual subject with stroke in: (A) able to subtract (ST group; N = 23) and (B) subtraction problem (STP group; N = 19). Positive value means dual-task benefits, negative value means dual-task costs, and zero value means no effect. The upper number represents percentage of participants with improve in cognitive performance (cognitive benefits), and lower number represents percentage of participants with decline in cognitive performance (cognitive costs).

CHAPTER 5
CONCLUSION AND DISCUSSION

This study is the first study to identify the type of cognitive task that led to the highest detrimental effect during TUG-dual in persons with stroke who had subtraction problem. Results did not support our hypothesis that similar type of cognitive task would interfere with the cognitive-motor performance in both groups of persons with stroke. Instead we found that type of cognitive task played different role in interfering with the cognitive-motor performance during walking in persons with stroke who did not have subtraction problem and those who did.

In persons with stroke who can perform number subtraction, “subtraction task” demonstrated higher detrimental effects on cognitive-motor performance during cognitive-dual test than other cognitive tasks. Study by Patel and Bhatt (2014) also reported the higher negative cognitive cost for subtraction than the Stroop task (discrimination and decision-making)(167), suggesting that type and complexity of the task are important in dual-task interference.(191) We demonstrated in this study that subtraction task was considered to be more complex than phonologic fluency, as it resulted in higher cognitive cost. The difficulty of subtraction task may be due to the fact that this task required higher neural activity than phonologic fluency task. The subtraction task triggered neural activity at bilateral inferior parietal network.(24, 192) Whereas, phonologic fluency activated neural network only in the left inferior frontal cortex and supplementary motor area.(193-195) In addition, the subtraction task essentially depends on working memory and is more directly related to executive function than verbal fluency task.(196)

Other cognitive tasks used in this study showed less detrimental effects than subtraction task on motor and cognitive performance in persons with stroke who can perform subtraction. Auditory working memory task caused deteriorate effects on motor and cognitive performances with less magnitude than subtraction task. In contrast, the alternate reciting letter and clock task resulted in deteriorate effects on TUG performance, but the effects on cognitive performance were still inconclusive, as we found nearly equal number of participants with negative effects and positive effects on cognitive performance. These findings were in agreement with previous studies who reported low effects of clock task and alternate reciting letter on dual-task gait performance. Study by Dennis et al. (2009) reported no change in gait speed in individuals with stroke during performed clock task.[15] Another study by Liu-Ambrose et al. (2009) found that alternate reciting letter task did not interfere with gait performance in elderly.[122]

In persons with stroke who cannot subtract, phonologic fluency is found to be greater demanding attentional resources for planning and information process compared to other cognitive tasks. Total TUG duration was significant longer only for phonologic fluency task which caused by the increase in turning duration and straight walk duration. The control of turning requires cognitive resources and more cognitively demanding than walking in a straight line.[197-199] It has been suggested that cognitive and sensory information processing during turning are greater than straight walking.[200] Previous study also supported that verbal fluency can cause decrement in dual-task performance in neurological patients including stroke.[121]

Therefore, this study suggested that the extent of cognitive motor interference (CMI) differed between group with subtraction problem and those without, especially during component of turning and straight walk duration. Reduction in both motor and cognitive performance were found when adding all cognitive tasks compared with TUG-single in stroke who can subtract, whereas the cognitive-motor performance only significantly reduced in the STP group when adding phonologic fluency task. The impairment of inferior parietal areas was associated with subtraction deficit.[18] The inferior parietal areas, including the angular gyrus, the supramarginal gyrus, and the intraparietal sulcus are suggested to be involved in subtraction as well as language and semantic processing, spatial attention and orienting, mathematical cognition, temporal processing, visuo-spatial attention, visual short-term memory, and basic number processing.[201] Thus, not only mathematical function, but these activation areas also involve in attention, memory and spatial orienting.

Our Findings showed less deteriorate effects while performed other cognitive tasks (alternate reciting task, auditory working memory task, and clock task) as compared to phonologic fluency task in the subtraction-problem group. This may be due the fact that only phonologic fluency triggers more neural activities in the supplementary motor area as compared to other cognitive tasks. For the alternate reciting task, the neural activities in left intraparietal sulcus, bilateral superior temporal gyrus, and inferior frontal gyrus are activated.(202) Working memory task is related to an executive attention control mechanism and this ability is mediated by portions of prefrontal cortex.(80) For the clock task, the activation of inferior frontal gyrus and anterior insula bilaterally, left supramarginal gyrus, and putamen were noted.(203) The supplementary motor area plays the important role in postural control, contributing to the timing and amplitude of the anticipatory postural adjustment of human gait initiation.(204) Therefore, the competitive cognitive demand for retrieving specific words within lexical memory and gait control probably caused greater deteriorate effects on TUG-dual during perform phonologic fluency task.

Clinical application

Apart from the traditional use of arithmetic task such as number subtraction, this study provided the alternative of using phonologic verbal fluency in conjunction with the TUG when assessing the cognitive-motor ability in individuals with stroke who have difficulties in subtraction. This can be applied in the clinical practice as it will enable the clinicians to customize the cognitive tasks for assessment based on individual limitation.

Study limitation

This study has some limitations. Firstly, different education background could lead to different scores in evaluation of cognitive function in stroke.(205) Also, the measure of phonologic fluency is differentially sensitive to age and education.(206) Results from this study obtained from the participants that mostly have a primary education level. So, the generalization of results is limited. Secondly, gait pattern, cognitive abilities, motor and functional outcomes after stroke correlated with brain lesion site and location.(194, 207, 208) The lesion assessment based on CT or MRI images was not taken in all participants. Further longitudinal study is required to further explore the relationship between the performances under TUG-verbal fluency and falls in stroke with subtraction problem.

Conclusion

In conclusion, type of cognitive task played different role in interfering with the cognitive-motor performance during walking in persons with stroke who did not have subtraction problem and those who did. When combined with the TUG, the mental tracking task caused largest reduction in cognitive-motor performance in persons with stroke who can perform subtraction. Apart from subtraction task, alternate reciting, auditory working memory, clock task, and phonologic fluency showed less detrimental effects on motor and cognitive performances in these population.

In contrast, phonologic fluency led to the largest detrimental effects on dual-task performances in stroke without subtraction problem. Total TUG duration was significant longer only for phonologic fluency task which caused by the increase in turning duration and straight walk duration. Although the alternate reciting task is classified in the same category of mental tracking as subtraction task, its deterioration effect was less than the phonologic fluency task.

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