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Relationships Between Cognitive Function and Gait-Related Dual-Task Interference After Stroke

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Abstract

Previous studies have reported that decreased cognitive ability has been consistently associated with significant declines in performance of one or both tasks under a dual-task walking condition. This study examined the relationship between specific cognitive abilities and the dual-task costs (DTCs) of spatio-temporal gait parameters in stroke patients. The spatio-temporal gait parameters were measured among 30 stroke patients while walking with and without a cognitive task (Stroop Word-Color Task) at the study participant's preferred walking speed. Cognitive abilities were measured using Computerized Neuropsychological Testing. Pearson's correlation coefficients (r) were calculated to quantify the associations between the neuropsychological measures and the DTCs in the spatio-temporal gait parameters. Moderate to strong correlations were found between the Auditory Continuous Performance test (ACPT) and the DTCs of the Single Support Time of Non-paretic (r=.37), the Trail Making A (TMA) test and the DTCs of Velocity (r=.71), TMA test and the DTCs of the Step Length of Paretic (r=.37), TMA test and the DTCs of the Step Length Non-paretic (r=.36), the Trail Making B (TMB) test and the DTCs of Velocity (r=.70), the Stroop Word-Color test and the DTCs of Velocity (r=-.40), Visual-span Backward (V-span B) test and the DTCs of Velocity (r=-.41), V-span B test and the DTCs of the Double Support Time of Non-paretic (r=.38), Digit-span Forward test and the DTCs of the Step Time of Non-paretic (r=-.39), and Digit-span Backward test and the DTCs of the Single Support Time of Paretic (r=.36). Especially TMA test and TMB test were found to be more strongly correlated to the DTCs of gait velocity than the other correlations. Understanding these cognitive features will provide guidance for identifying dual- task walking ability.

Key Words: Cognitive function; Dual-task; Gait; Stroke.

Introduction

Many daily activities in human life require a person to complete several tasks concurrently. These dual-task conditions result in deterioration in the performance of one or both tasks. Dual-task refers to the simultaneous performance of two tasks. It has been used to examine the effect of a secondary task on gait, balance, and cognitive performance in clinical populations in order to understand the role of attention on the maintenance of postural stability and walking. After a stroke, cognitive capacity may be reduced, resulting in slower gait velocity (Bowen et al, 2001; Hyndman et al, 2006; Plummer-D'Amato et al, 2008), reduced cadence (Kemper et al, 2006; Plummer-D'Amato et al, 2008), shorter stride length (Hyndman et al, 2006; Plummer-D'Amato et al, 2008), increased stride duration (Plummer-D'Amato et

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al, 2008), longer double limb support phases (Plummer-D'Amato et al, 2010), and difficulty maintaining balance under dual-task conditions (Bowen et al, 2001). These changes may result from cognitive or motor deficits (Woollacott and Shumway-Cook, 2002).

Decreased cognitive ability has been consistently associated with significant declines in physical performance and greater dependency on basic daily activities (Ble et al, 2005; Malmstrom et al, 2005). In a previous study with older adults, the ability to walk while engaging in simple cognitive tasks could be explained by participant characteristics and motor factors, while more complex cognitive tasks could be explained by the subject's cognitive factors in addition to participant characteristics and motor factors (Hall et al, 2011). However, cognitive abilities that affect dual-task walking are more impaired after a stroke. Furthermore, additional impairments of the motor system may result in an increased demand for limited attention resources. As a result, even when performing simple cognitive tasks both cognitive and motor factors affect the dual-task capacity (Coppin et al, 2006).

The cognitive contribution to gait control is supported by experimental evidence offered by the dual-task paradigm. Many research studies using this paradigm have been conducted to identify the relationship between cognition and gait in patients with Alzheimer's disease or mild cognitive impairment, and in older adults (Takehiko et al, 2014). Few studies have been conducted on stroke patients; however, studying the relationship between cognitive ability and dual-task gait interference is essential for identifying the capacity to perform gait-related dual-task exercises.

The purpose of this study was to examine the relative impact that cognitive ability and functional mobility, related to gait, have on spatio-temporal gait parameters while performing cognitive dual-task walking in individuals with a stroke.

Methods

Subjects

Thirty hemiparetic subjects, 16 men and 14 women (mean age: 54.9±12.1 years; mean time since onset of stroke: 4.9±2.8 months), participated in this study. Table 1 shows the subjects' characteristics. Inclusion criteria were as follows: an ability to walk 10 m independently without an assistive device, a score of at least 25 on the mini-mental state examination Korea version, a stable medical condition to allow participation in the testing protocol, and the ability to understand the instructions for the test procedures. Exclusion criteria included orthopedic conditions that affected walking, vision or hearing impairments, severe aphasia or dysarthria, and the inability to follow instructions. The study was ap-

Table 1. General and clinical characteristics of the subjects (N=30)

	Mean±SD[a]	Range
Gender (male/female)	16/14	
Age (year)	54.9±12.1	32～77
Onset time (month)	4.9±2.8	1～12
Diagnosis (infarction/hemorrhage)	20/10	
Affected side (left/right)	21/9	
MMSE-K[b]	29.3±1.8	25～30
TUG[c] (sec)	18.9±9.5	8～52
2 min walk test (m)	76.8±38.4	22～205

[a]mean±standard deviation, [b]mini mental state examination Korea version, [c]timed up and go test.

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proved by the Institutional Review Board at Seoul Rehabilitation Hospital (Approved by IRB 2012-yeon-01).

Experimental protocol

The test of cognitive ability was conducted by a skilled occupational therapist in the occupational therapy room and the dual-task walking test was conducted by skilled examiners in the physical therapy room. The tests were managed individually, and participants completed the tests in hour-long sessions on separate days. During the dual-task walking test, we used the Stroop Word-Color test (SWCT) as a cognitive task. While engaging in the SWCT, the participants were presented with the name of a color (green, blue, yellow, and red) printed in a color that did not match the color's name (e.g., the word red might be printed in blue); and the word was flashed on a screen in front of the walking pathway. The horizontal and vertical size of the text was 15 ㎝.

The study participants were instructed to walk at their self-selected speed. They were tested under one dual-task condition and one single-task conditions (walking without a concurrent task). The trial order was randomized to compensate for the effects of practice and fatigue. All gait tasks were performed at the participants' preferred speed. Each task condition was performed once.

Outcome measurements

Spatio-temporal gait parameters

The spatio-temporal gait parameters were measured using the GAITRite® walkway system (CIR Systems, Sparta, NJ, USA). The GAITRite® system contains six sensor pads encapsulated in a rolled-up carpet with an active area that is 3.66 m long and .61 m wide. The computer computed the raw data from the walkway into temporal and spatial gait parameters. The GAITRite® system has an inter-rater reliability of .95 and an intra-rater reliability of .90 for mild-to-moderately neurologically impaired subjects (Bilney et al, 2003; McDonough et al, 2001). The GAITRite® walkway was placed in the middle of the 10 m hallway to eliminate the effect of acceleration or deceleration. The following spatio-temporal parameters were recorded: Gait velocity, Step Time of Paretic (STP), Step Time of Non-paretic (STN), Single Support Time of Paretic (SSTP), Single Support Time of Non-paretic (SSTN), Double Support Time of Paretic (DSTP), Double Support Time of Non-paretic (DSTN), Step Length of Paretic (SLP), and Step Length of Non-paretic (SLN). The dual-task costs (DTCs) of the gait parameters were calculated by dividing the difference between the single- and dual-task performance by the single-task performance, expressed as a percentage (McDowd, 1986). Positive values indicate a decrease in performance under dual-task conditions.

Timed up and go test (TUG)

The TUG is widely used to assess mobility, which consists of balance, transfers, walking, and turning while walking. Subjects are asked to stand from a sitting position, walk forward 3 m, turn around, walk back to the chair, and sit down at a comfortable walking speed. The tester records the time of performance. The TUG has been shown to be a valid assessment of functional mobility and is strongly reliable when applied to subjects with stroke (Ng and Hui, 2005).

2 min walk test

The 2 min walk test is a shortened version of the original 12 min walk test and was developed to assess walking endurance in patients with pulmonary disease (Butland et al, 1982). This test measures the distance (in meters) that an individual is able to walk at comfortable speed for 2 min. Starting from a standing position, subjects walked continuously around two pylons placed 20 m apart for 2 min. The distance covered was measured to the nearest 10th of a meter using a walk wheel.

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Neuropsychologic test

The cognitive function of all the study participants was assessed using Computerized Neuropsychological Testing (CNT) (Maxmedica, Seoul, Korea). The CNT consisted of the Visual Continuous Performance test (VCPT), the Auditory Continuous Performance test (ACPT), the Trail Making A (TMA) test, the Trail Making B (TMB) test, SWCT, the Visual Span (V-span) test, and the Digit Span (D-span) test. Each of these tests is described below.

Visual continuous performance test (VCPT)

In this test, several numbers are shown on a screen and the examiner gives prior instructions to the participants about which button to press when the suggested numbers were presented. The examiner measures the participants' reaction time. VCPT measures a person's sustained and selective attention (Kasai et al, 2002).

Auditory continuous performance test (ACPT)

In this test, numbers are announced over a loud speaker, and the examiner gives the participants prior instructions about which button to press when they hear those numbers. The examiner measures the participants' reaction time. ACPT measures a person's sustained and selective attention (Kasai et al, 2002).

Trail making A (TMA), Trail making B (TMB) test

In a Trail Making test, participants connect the dots of 25 successive targets on a computer screen. This test has two parts: TMA and TMB. TMA consists of numbers (1, 2, 3, etc.) and the participants are instructed to connect those numbers in sequential order; TMB consists of numbers and letters and the participants are instructed to alternate the numbers and letters (1, A, 2, B, etc.) in sequential order. The examiner measures the total time it takes the participants to complete the tests. TMA is used primarily to examine cognitive processing speed and TMB is used to examine executive functioning (Tombaugh, 2004).

Stroop word-color test (SWCT)

In this test, participants are presented with the name of a color (green, blue, yellow, and red) that is printed in a color that does not match the color's name (e.g., the word red might be printed in blue) and the participant must identify the real name of the color as soon as possible. This test is used to measure total time. SWCT is considered to measure selective attention, cognitive flexibility, and processing speed, and it is used as a tool in the evaluation of executive functions (Balzano et al, 2006).

Visual span (V-span) test

In this test, nine circles are flashed on the screen in a series of positions. After the participants remember the order, they click a mouse along the forward sequence of the positions then they click a mouse along the backward sequence of the positions (V-span B). The score is based on the total number of positions that the participant remembered correctly. The V-span is used to measure working memory (Tanabe and Osaka, 2009).

Digit span (D-span) test

In this test, participants hear a series of digits announced over computer speakers, and they immediately repeat the digits in the forward (D-span F) and backward (D-span B) direction.

The score is based on the total number of digits that the participant remembered correctly. The D-span is used to measure the storage capacity of working memory (Tanabe and Osaka, 2009).

Statistical analysis

We used the Kolmogorov-Smirnov test to examine the normality of the neuropsychological measures, functional mobility measures, and the DTCs of the

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spatio-temporal gait parameters. For all the data, the normally distributed Pearson's correlation coefficients (r) were calculated to quantify the bivariate associations between the neuropsychological measures and the DTCs of the spatio-temporal gait parameters. Additionally, we calculated the association between the functional mobility measures and the DTCs for the spatio-temporal gait parameters. Regressions were not performed because of the small sample size. All analyses were performed using SPSS ver. 18.0 software (SPSS Inc. Chicago, IL, USA). Significance level was set at $p<.05$.

Results

The Kolmogorov-Smirnov test results show that all of the neuropsychological measures, functional mobility measures and the DTCs of the spatio-temporal gait parameters are normally distributed. The results of the neuropsychological testing are summarized in Table 2.

The participants show decreased velocity, STP, STN, SSTP, SSTN, SLP and SLN under the dual-task conditions in comparison to the single-task conditions, while the participants show increased DSTP and DSTN under the dual-task walking condition (Table 3).

Table 4 presents weak to strong correlations between the DTCs of the spatio-temporal gait parameters and the neuropsychological testing measures. Significant correlation were found between ACPT and the DTCs of SSTN (r=.37), TMA and the DTCs of Velocity (r=.71), TMA and the DTCs of SLP (r=.37), TMA and the DTCs of SLN (r=.36), TMB and the DTCs of Velocity (r=.70), SWCT and the DTCs of Velocity (r=-.40), V-span B and the DTCs of Velocity (r=-.41), V-span B and the DTCs of DSTN (r=.38), D-span F and the DTCs of STN (r=-.39), and D-span B and the DTCs of SSTP (r=.36). Weak correlation was found between the DTCs of the spatio-temporal gait parameters and the functional mobility measurements.

Discussion

To our knowledge, no prior studies have included such a wide range of cognitive measures and gait parameters in stroke patients. In this study, the cog

Table 2. Descriptive data of the neuropsychological measures (N=30)

	Mean±SD[a]	Range
V-CPT[b] (sec)	.47±.07	.32∼.69
A-CPT[c] (sec)	.63±.06	.46∼.78
TMA[d] (sec)	51.93±23.30	17.00∼114.00
TMB[e] (sec)	121.60±80.64	30.00∼305.00
SWCT[f] (sec)	52.11±26.10	
V-span[g]		
V-span F[h]	5.49±.93	3.20∼7.10
V-span B[i]	4.60±1.31	2.20∼7.10
D-span[j]		
D-span F[k]	5.77±1.36	3.10∼8.20
D-span B[l]	4.38±1.34	2.30∼7.20

[a]mean±standard deviation, [b]visual continuous performance test, [c]auditory continuous performance test, [d]trail marking A, [e]trail marking B, [f]Stroop word-color test, [g]visual span, [h]visual span forward, [i]visual span backward, [j]digit span, [k]digit span forward, [l]digit span backward.

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Table 3. DTCs (%) on spatio-temporal gait parameters (N=30)

	Mean±SD[a]	Range
Velocity	18.64±12.12	2.18～52.04
STP[b]	105.44±13.65	134.92～79.70
STN[c]	107.28±25.63	188.10～67.32
SSTP[d]	58.25±19.84	100.51～7.50
SSTN[e]	57.59±16.18	85.73～1.51
DSTP[f]	-75.49±24.61	-146.57～-14.09
DSTN[g]	-73.91±28.78	-164.79～-17.72
SLP[h]	45.86±19.53	89.50～7.56
SLN[i]	12.14±12.59	54.54～38.71

[a]mean±standard deviation, [b]step time of paretic, [c]step time of non-paretic, [d]single support time of paretic, [e]single support time of non-paretic, [f]double support time of paretic, [g]double support time of non-paretic, [h]step length of paretic, [i]step length of non-paretic.

Table 4. Correlations between DTCs on spatio-temporal gait parameters and neuropsychological and functional mobility measures

DTCs[a] in gait parameters measures	Neuropsychological and functional mobility measures										
	V-CPT[b]	A-CPT[c]	TMA[d]	TMB[e]	SWCT[f]	V-span F[g]	V-span B[h]	D-span F[i]	D-span B[j]	TUG[k]	2 min walk test
Velocity	-.03	-.07	.71*	.70*	.34	-.31	-.41*	-.04	-.07	.28	-.18
STP[l]	-.23	-.32	-.30	-.20	-.14	.31	.27	.01	-.09	-.13	.03
STN[m]	.19	.05	.26	.26	-.40*	-.28	-.15	-.39*	-.12	-.01	-.27
SSTP[n]	-.07	-.11	-.22	-.28	.06	.17	.20	-.00	.36*	.05	.06
SSTN[o]	.22	.37*	.05	-.03	-.07	-.04	-.03	.07	-.13	.14	.17
DSTP[p]	.29	.03	-.04	-.17	-.27	-.11	-.25	.16	.18	-.02	.13
DSTN[q]	-.35	.10	-.02	-.16	.33	.18	.38*	.20	.13	-.08	.03
SLP[r]	-.10	.31	.37*	.29	-.21	-.11	-.07	-.19	-.11	.08	-.07
SLN[s]	-.02	.15	.36*	.35	.36	-.18	.01	-.20	.08	.03	.10

[a]dual task costs, [b]visual continuous performance test, [c]auditory continuous performance test, [d]trail making A test, [e]trail making B test, [f]Stroop word color test, [g]visual span forward, [h]visual span backward, [i]digit span forward, [j]digit span backward, [k]timed up and go test, [l]step time of paretic, [m]step time of non-paretic, [n]single support time of paretic, [o]single support time of non-paretic, [p]double support time of paretic, [q]double support time of non-paretic [r]step length of paretic, [s]step length of non-paretic, *$p<.05$.

nitive abilities measured by neuropsychological testing were related to the DTCs of spatio-temporal gait parameters ranging from weak to strong. In particular, TMA were strongly correlated to the DTCs of gait velocity.

The changes in the gait parameters under dual-task walking are similar to the findings from a previous study, thereby demonstrating that a dual-task condition decreases gait velocity and step length and increases step time and double support time in older adults (Motl et al, 2014; Plummer-D'Amato et al, 2011). A possible explanation for these changes is that the study participants might use a “postural first” strategy, which represents an

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unconscious strategy to avoid hazards in order to prevent falls (Bloem et al, 2006). But there is some difference in our study, the DTCs of SLP are even greater than the DTCs of SLN. This mean that paretic side is more exaggerated than non-paretic side under dual-task condition, and the posture control mechanism of stroke patients slightly differ from older adults.

A previous study showed that as the difficulty of the cognitive task increased more of the gait parameters were impacted until gait was globally affected (Plummer-D'Amato et al, 2010). Moreover, one study reported that, among many possible cognitive tasks, the Stroop task is the most demanding task that has an impact on the DTCs of gait parameters (Patel et al, 2014). For these reasons, in our study, most of the gait parameters were affected and we can maximize the relationship between cognitive ability and the DTCs of gait parameters.

The DTCs of the gait parameters can be affected not only by cognitive capacity but also by the motor capacity of a subject (Woollacott and Shumway-Cook, 2002). In general, stroke patients have additional motor impairments that affect their gait performance, and the results of the functional mobility tests (TUG and the 2 min walk test) for the participants in our study pointed to a risk of falling, but weak correlations were found between those tests and the DTCs of the gait parameters. These results implied that cognitive ability is a more important factor than functional mobility during dual-task walking in the persons with stroke in our study.

Many studies investigating older adults and Parkinson's disease have demonstrated poorer executive/attention domain and gait dysfunction during dual-task walking (Coppin et al, 2006; Hausdorff et al, 2001; Persad et al, 1995). Executive function is defined as a set of the cognitive skills that are necessary to plan, monitor, and execute a sequence of goal-directed complex actions (Hall et al, 2011). The result of our study with stroke patients also shows that TMA and TMB are more strongly associated with gait velocity than other associations between cognitive ability and gait parameters. Gait velocity represents an overall function of walking and the Trail Making test measures executive function and cognitive processing speed. Furthermore, executive function, measured by Trail Making test, plays an important role in the ability to adequately assign attention resources (Coppin et al, 2006; Royall et al, 2002). In a previous study with elderly subjects, the TMB correlated significantly with walking ability, including gait velocity (Coppin et al, 2006; Royall et al, 2002). However, that study dealt with the relationship between TMB and comfortable pace gait velocity using a regression model, whereas our study examined the correlation between the DTCs of gait velocity under a dual-task walking condition. A causal relationship between cognitive ability and the DTCs of gait parameters cannot be explained by the limitations of the statistical method. However, the results of our study suggest that there is a close association between the executive function and walking capacity under dual-task.

Executive function in older adults was only strongly related to walking velocity while performing cognitive tasks (Hirota et al, 2010). In our study, walking velocity is strongly correlated with several neuropsychological tests (TMA and TMB) that measure executive function, processing speed, and working memory. In addition to executive function, processing speed and working memory are also correlated with walking velocity.

The limitation of the current study is its small sample size. However, the purpose of this study was to conduct an exploratory investigation of the interactions between gait and cognitive abilities in people after a stroke. Further research with a greater number of stroke subjects is needed to confirm a statistically significant causal relationship. Cognitive training that addresses the underlying cognitive impairments may also be beneficial for enhancing dual-task walking.

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Conclusion

In this study, the DTCs of spatio-temporal gait parameters were associated with different cognitive domains in stroke patients. TMA and TMB were strongly correlated with the DTCs of velocity and these results provide preliminary evidence for identifying the capacity to perform dual-task walking, especially in stroke patients. An effective therapeutic strategy for dual-task walking could be implemented by recognizing the patient's related cognitive abilities.

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