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Interactions between cognitive tasks and gait after stroke: A dual task study⋆

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Abstract

This study investigated the interactions between gait and three different cognitive tasks in people after stroke. Thirteen people post-stroke who were living in the community, were able to walk 10 m without physical assistance, and could respond verbally to auditory stimuli participated. Participants performed a walking task alone, three different cognitive tasks while seated, and each cognitive task in combination with walking. Gait data were acquired continuously for approximately 3 min. Reaction time and accuracy were recorded for two of the cognitive tasks (visuospatial task, working memory task). Speech samples from the spontaneous speech task were analyzed on several dimensions of language. Significant dual task effects were observed for gait speed, stride time, average stride length, and cadence, but not for stride time variability. Speech produced more gait interference than memory and visuospatial tasks. Interference effects on cognition were minimal; only speech was significantly affected by concurrent walking. Narratives in the dual task condition had more pauses, shorter sentences, but more utterances with new information. Even though participants in this study were mobility-impaired, they prioritized the cognitive tasks. Future research should determine whether dual task training can reduce gait decrements in dual task situations in people after stroke.

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Conflicts of interest statement

There are no conflicts of interest.

Keywords

Cerebrovascular accident; Gait; Cognition; Rehabilitation; Dual task

1. Introduction

The relationship between cognition and motor control has become a focal field of research because it has implications for understanding recovery of motor control after neurological injury, such as stroke. Indeed, there is a growing body of literature from both aging and clinical populations that examines the role of cognition in locomotion. The dual task paradigm is the primary approach used to study interactions between cognitive processing and motor behavior.

Cognitive-motor interference (CMI) 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. Traditionally, the interference has been presumed to occur because of competing demands for attention resources [1]. However, recent studies have suggested that compromised executive control may underlie CMI [2,3]. Identification of the specific cognitive domains associated with gait decline during dual task activities may help inform clinical evaluation and treatment planning. Along these lines, the current study investigates the interactions between gait and three different cognitive tasks in people after stroke.

Previous research has not determined which aspects of cognitive activity cause disruption to gait after stroke. Most gait-related dual task studies have examined the effects of only one cognitive task [4–6]. Recently though, Haggard et al. [7] employed four different cognitive tasks to investigate whether CMI is modulated across different task combinations. They examined a mixed neurological population, comprising patients following stroke, head injury, anoxia, tumor removal, and surgery for epilepsy. There were significant dual task effects on stride time: the greatest decrement occurred in the arithmetic task (8%), followed by the visuospatial decision task and the word generation task (both 7%), then the paired associate monitoring task (6%). Statistical tests on the differences between the different cognitive tasks were not reported. Moreover, because the sample was of mixed etiology, it remains unclear how different cognitive tasks interfere with gait after stroke. Finally, Haggard et al. only examined stride time; to fully understand CMI effects on gait after stroke, other temporal and spatial parameters such as stride length, gait speed, and cadence should be analyzed.

In the present study, we extend the work of Haggard et al. [7] in three ways. Firstly, we use a more homogenous population consisting only of individuals with stroke. Secondly, we analyze additional gait parameters to determine the specific aspects of gait that interact with particular cognitive processes. Finally, we use a more naturalistic speech task. The ecological validity of spontaneous speech is unmatched as a dual task; people frequently walk and talk at the same time. Spontaneous speech involves highly complex coordination of processing and storage because speakers must plan what to say, encode it into words, generate appropriate grammatical structure, and then internally store the plans until they are ready to articulate the words and sentences [8]. Thus, spontaneous speech places demands on attention, working memory, language capacity, and motor programming. In our other tasks, we isolate more specifically the functions of working memory and visuospatial cognition. The aim of this study was to examine the effect of three distinct cognitive tasks: working memory, visuospatial cognition, and spontaneous speech on gait performance in people after stroke.

2. Methods

2.1. Participants and sample characterization

Thirteen patients following stroke (11 males) participated, a small sample selected to demonstrate feasibility of the study protocol and identify preliminary effects in a relatively homogeneous community-dwelling stroke population for who CMI during walking is particularly relevant. The mean age was 60.5 years (S.D.: 15.3, range: 33–86). The mean time post-stroke was 8.7 months (S.D.: 4.8, range: 2.5–17). The stroke was ischaemic in 12 participants. Participants were included if they had experienced a stroke within 5 years and could walk at least 10 m without physical assistance. Participants were excluded if they had a pre-existing neurological disorder, primary hearing impairment, severe visual impairment, severe aphasia or dysarthria affecting their ability to respond verbally to auditory stimuli, an orthopaedic condition affecting their natural gait, or if they were unable to follow a three-step command. All participants signed an informed consent form approved by the Institutional Review Board.

A battery of six cognitive tests was administered to all participants to characterize cognitive abilities: Mini-Mental State Examination [9] (measured global mental state), Digit Symbol Test [10] and Stroop Test [11] (assessed speed of processing and attention), Backward Digit Span [12] and Digit Ordering Test [13] (assessed working memory), and the Vocabulary subtest of the Wechsler Abbreviated Scale of Intelligence [14] (characterized the verbal ability of participants).

Participants' walking speed and motor functions were also assessed. Self-selected gait speed was measured over 10 m using a stopwatch. Motor function was assessed using the lower extremity portion of the Fugl-Meyer [15]. Table 1 displays the baseline measures for the cognitive, gait speed, and motor function assessments.

2.2. Tasks and apparatus

There were three cognitive tasks: auditory 1-back (working memory), auditory clock task (visuospatial cognition), and spontaneous speech. In the 1-back task [16], the participants heard a sequence of letters, presented one at a time, and responded after each letter: "yes" if it was a repeat of the immediately preceding letter, or "no" if it was not. There were 60 letters in the sequence, 12 were critical trials (i.e., required "yes" responses). The auditory clock task was adapted from Haggard et al. [7]. 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. There were 48 trials; 12 were critical trials (i.e., both hands were in the specified half, respond "yes"). For both the 1-back and clock tasks response latency and accuracy were measured.

For the spontaneous speech task, speech samples were elicited from the participants using a set of questions that have been used previously [17,18]. To ensure a sufficient number of utterances were obtained for analysis, participants were encouraged to talk for at least 2 min. If the participant paused for more than a few seconds or stopped responding, the examiner used standard prompts, such as "Can you tell me more about… ?" [18].

The 1-back and the clock tasks were produced using Direct RT software [19] and the stimuli were delivered by a laptop computer. The auditory stimuli were presented through wireless headphones. The participants' responses were recorded by a wireless microphone. The stimulus and response data were synchronized with the gait data during the dual task conditions. Speech samples were recorded using a digital recorder.

Temporal gait data were collected using pressure-sensitive footswitches (B & L Engineering, Tustin, CA) worn inside the participant's shoes. The pressure signals were transmitted wirelessly to a receiver, which then output the signals to Vicon Workstation v4.6 software (Vicon, Los Angeles, CA). Footfall data were sampled at a rate of 360 Hz.

2.3. Procedures

Single and dual task conditions were completed in one test session lasting approximately 1.5 h. All participants completed all eight conditions: single task walking (twice), 1-back (single, dual), clock task (single, dual), speech task (single, dual). Single walking tasks were conducted first and last to enable the effect of fatigue to be evaluated. The order of the three cognitive tasks was randomized, with the single task always being performed before the dual task in order to avoid consecutive walking trials and minimize fatigue.

For the single walking task, participants walked counterclockwise around an oval track (27.5 m length, 0.6 m wide) in the gait laboratory for 3 min. Participants used their usual assistive devices. A physical therapist walked with the participants but did not provide any assistance. For single cognitive tasks the participants were seated. At least seven practice trials were completed for the 1-back and clock task before data recording commenced. Each cognitive task lasted approximately 3 min. In dual task conditions, participants performed cognitive and walking tasks simultaneously. They were not specifically instructed to prioritize either task.

2.4. Analysis

The speech samples were transcribed verbatim and checked for accuracy. Samples were scored using the Systematic Analysis of Language Transcripts [20] on several dimensions, including: number of words, grammatical sentences, total independent and dependent clauses, pauses, conversational filler words (e.g., you know, like, ums and uhs), and utterances providing new information, all of which were rendered as number/utterance to control for differences in narrative length. Additionally, the total number of utterances and words produced was analyzed. These measures address different, independent linguistic constructs and, consequently, do not lend themselves to multivariate analysis. Thus, scores for single and dual task conditions were compared using paired *t*-tests.

The gait-related dependent variables were gait speed, stride time, S.D. of stride time, average stride length, and cadence. Stride time was defined as the elapsed time between heel strike of one foot and next heel strike of the same foot. Average gait speed for each condition was calculated by dividing the total distance walked by duration of the trial. Average stride length was determined by multiplying the average gait speed by the average stride time.

Statistical analyses of the 1-back and clock tasks examined mean reaction time (RT) and accuracy scores for all trials (not just critical trials). Trials in which technical errors occurred or with RTs falling outside three S.D. of the mean were excluded from the RT analysis. To evaluate dual task effects, we applied one-factor repeated measures ANOVA to each variable. Tukey's least squared differences post hoc procedures were used to examine where significance occurred. We considered $p < 0.05$ statistically significant. Throughout the results, we present the partial eta squared (η_p^2) as a measure of effect size; values may range between 0 and 1, with higher values representing higher proportions of variance explained by the independent variable. Due to equipment failure, one participant was dropped from the analysis of the RT data and two participants were omitted from the statistical tests for the gait data (except gait speed). This produced minor variations in the degrees of freedom.

3. Results

3.1. Dual task effects on gait

There was a highly significant effect of dual task on gait speed [$F(4, 9) = 11.08$, $p = 0.002$, $\eta_p^2=0.83$]. Gait speed was significantly slower in the three dual task conditions (Table 2). There was also a significant difference in gait speed between the three cognitive tasks such that gait was slower in the speech task than the 1-back and clock tasks, and slower in the clock task than the 1-back.

There was a significant effect of dual task on stride time [$F(4, 7) = 6.53$, $p = 0.016$, $\eta_p^2=0.79$] (Table 2). Mean stride times in the clock and spontaneous speech conditions were significantly longer than the mean stride times in single task walking conditions. Performing the 1-back task while walking did not significantly increase stride time relative to single task walking. Differences in stride time between the three dual task conditions were not significant.

There were no clear trends between single and dual task performance for stride time variability. Rather, it appeared that stride time variability decreased from the first single walking trial to the last single walking trial (Table 2). This reduction was not statistically significant and had a small effect size ($\eta_p^2=0.24$).

Average stride length was much shorter during the three dual task walking trials than in the two single task conditions (Table 2), confirmed by the statistical analyses [$F(4, 7) = 26.304$, $p < 0.001$, $\eta_p^2=0.94$]. In addition, the two single walking tasks differed from one another (p = 0.05) such that participants took longer strides in the second single walking trial. There were no significant differences in average stride length between the three cognitive tasks.

Cadence was significantly reduced in the three dual task walking conditions compared to the single walking tasks [$F(4, 7) = 10.77$, $p = 0.004$, $\eta_p^2=0.86$] (Table 2). The greatest reduction in cadence occurred in the spontaneous speech task, but the differences in cadence between the three cognitive tasks were not statistically significant.

3.2. Dual task effects on cognition

There was no significant dual task effect on RT for the 1-back task (Table 3). Within-subject variability (S.D.) in RT for the 1-back task did not change across conditions. There was no dual task effect on mean accuracy or variability of accuracy for the 1-back task; the participants were highly accurate in both conditions. Effect size values indicate uniformly low dual task effects on cognitive outcomes (Table 3).

Despite anecdotal reports from the participants that the clock task was the most difficult, there was no dual task effect on mean accuracy or variability of accuracy (Table 3). The mean RT for the clock task was faster during the dual task condition but this difference did not quite reach statistical significance ($p = 0.051$). RT variability within-subjects showed no dual task or practice effects.

There were significant dual task effects on speech production (Table 3). Specifically, in the dual task condition, participants paused more in their narratives [$t(12) = 2.676$, $p < 0.03$] and produced shorter narratives in terms of number of words [$t(12) = 2.288$, $p < 0.05$] and utterances [$t(12) = 2.920$, $p < 0.02$]. There was also a higher proportion of utterances containing new information in the dual task condition relative to the single task condition [$t(12) = 2.521$, $p < 0.03$].

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There was a significant inverse relationship between change in the number of utterances with new information and the number of utterances produced ($r = -0.68$, $p < 0.01$); individuals who showed the most precipitous drops in the number of utterances produced in the dual task condition also showed the largest increases in the proportion of utterances with new information.

4. Discussion

The present study differed from previous research in that it explored the interactions between gait and three different cognitive tasks in a community-dwelling stroke population. Moreover, the length of examination of gait and cognitive performances was considerably longer than that used in previous studies. Thus, we were able to determine the impact of CMI on gait and cognition when attention was divided for several minutes, not just for 8–10 steps. Finally, we examined a range of gait parameters to more fully understand dual task effects during walking.

The significant dual task effect on gait speed is consistent with earlier studies [4,5]; however, the present study is the first to show that distinct cognitive tasks affect gait speed differently in people after stroke. The finding that the 1-back task, which involves working memory, produced the smallest gait speed reduction is supported by research from older adults showing that memory factors, although related to gait speed, are not as influential as other cognitive processes [21].

A possible explanation for the finding that the speech task produced a greater reduction in gait speed than the visuospatial or memory tasks is that additional interference was produced by articulation and respiration in this condition [22]. Yardley et al. [22] argued that disturbance of posture in spoken mental tasks is due to the muscular and respiratory activity of speech rather than competing demands for attention. Thus, it could be reasoned that the greater reduction in walking speed during the speech task in the current study was due to the need to generate more verbal output. While we concede that the changes in respiration produced by the speech task may have affected gait, this theory is not fully supported by the findings for the 1-back and clock RT tasks. The RT tasks required identical verbal outputs, yet there was a significant difference in gait speed between these two tasks, suggesting that factors other than speech respiration contributed to gait interference. Another possible account for the greater reduction in gait speed during the speech task, relative to the RT tasks, may be the high cognitive demands of producing narrative speech [8]. A challenge for future research will be to disentangle the specific contributions of speech respiration and the cognitive demands of spontaneous speech on gait interference. One possibility would be to compare an automatic speech task (such as reciting a well known verse) with spontaneous narrative speech of matched output.

Although cognitive task type did not differentially affect stride time, average stride length, or cadence, the significant dual task effects in these gait parameters corroborate the findings for gait speed. Compared to walking alone, stride time was significantly longer in the clock and speech tasks, which is consistent with previous gait-related dual task studies involving people after stroke [7,23]. The 1-back task may not have been sufficiently attention-demanding to produce a significant increase in stride time. Indeed, mean RTs for the 1-back were faster than the clock task and a ceiling effect was observed for accuracy, suggesting that the 1-back task was too easy.

In contrast to the significant interference effects on gait, the dual task effects on cognitive performance were minimal, with the exception that there were some effects on speech. The most important finding to note is that speech did not *deteriorate* in the dual task condition, but, rather, became more efficient. Specifically, when talking while walking, the participants produced shorter sentences with a greater proportion of utterances with new information. Producing more information in fewer words requires greater processing efficiency and is more demanding on executive resources [24]. We cannot be certain why participants adopted the more efficient (yet more demanding) mode of communication in the dual task condition, but it seems likely that this is why the spontaneous speech task had such an impact on gait performance. Moreover, the significant decline in gait performance accompanied by a more efficient speech pattern suggests that speech was prioritized. These findings are somewhat consistent with Kemper et al. [18] who found that individuals after stroke walked slower and paused more often while talking and walking. However, in contrast to the current results, their participants produced less complex, less informative speech in the dual task condition. This difference may be due to the greater complexity of the walking task by Kemper and colleagues (narrow, highly curved path). The susceptibility of spontaneous speech to dual task interference has also been demonstrated in young and older adults [17,25].

A likely explanation for the absence of dual task effects on RT in the 1-back and clock tasks is a practice effect induced by the order of tasks; the dual task condition was always performed after the single task condition. This explanation seems particularly plausible since a learning effect for the clock task has recently been reported among healthy older adults [26].

The main limitation of the current study is the absence of a control group. However, the purpose of this study was to conduct an exploratory investigation of the interactions between gait and different cognitive tasks in people after stroke. We extended previous research by analyzing several gait parameters to determine whether different cognitive tasks differentially interfere with specific aspects of gait performance. Future research should determine whether interference is different in stroke than in unimpaired participants.

There are potentially important clinical implications of the current results. The finding that spontaneous speech produces greater interference with gait than visuospatial cognition and working memory is relevant because patients typically engage in spontaneous conversation while walking. Perhaps more important is the finding that participants placed higher priority on cognitive tasks despite their gait impairments. Thus, patients may need specific instruction to focus on walking, or to refrain from engaging in simultaneous conversation, to avoid compromising gait, and ultimately, safety. Alternatively, patients may need to practice engaging in conversation during gait training to improve their performance and safety during this dual task, since it is likely that they will simultaneously walk and talk once discharged from therapy. Whether to avoid or to practice dual task situations is a highly deliberated question amongst clinicians. Determining the optimal time in recovery to introduce dual task training will be a priority for future research.

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Table 1

Subject characteristics

Assessment	Mean	(S.D.)	Range
Cognitive Assessments			
MMSE (maximum 30)	26.7	(2.7)	24–30
Digit symbol			
Substitution	33.0	(8.3)	19–45
Copy (time, s)	139.8	(45.0)	83–220
Copy (errors)	0.5	(0.8)	0–2
Backward digit span (maximum 14)	5.2	(1.6)	3–8
Digit ordering (maximum 24)	12.2	(3.9)	7–19
Vocabulary (maximum 70)	53.1	(10.7)	30–68
Stroop test			
Color XXX	50.8	(17.4)	21–72
Color words	24.7	(11.1)	9–39
Gait speed (m/s)	0.78	(0.38)	0.15–1.11
Fugl-Meyer (maximum 34)	24.2	(5.3)	14–30

MMSE denotes Mini-Mental State Examination.

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Table 2

Mean values (S.D.) for gait parameters under single and dual task conditions

Gait parameter	Single task				Dual task					
	Walk 1		Walk 2		1-Back		Clock		Speech	
Gait speed (m/s)	0.724	(0.373)	0.742	(0.395)	0.658§	(0.343)	0.643*	(0.379)	0.612*	(0.356)
Stride time (s)	1.435	(0.471)	1.398	(0.397)	1.455	(0.508)	1.485§	(0.484)	1.495*	(0.463)
Stride time variability (s)	0.110	(0.071)	0.076	(0.052)	0.104	(0.084)	0.082	(0.051)	0.106	(0.072)
Average stride length (m)	1.037	(0.329)	1.065	(0.316)	0.951*	(0.339)	0.958§	(0.282)	0.918*	(0.351)
Cadence (steps/min)	90.164	(20.894)	91.626	(18.517)	87.285§	(21.129)	86.175*	(21.007)	85.739*	(19.414)

* $p < 0.05$ relative to walk 1 and walk 2.

§ $p < 0.05$ relative to walk 2 only.

Table 3

Mean values (S.D.) for cognitive tasks under single and dual task conditions

Cognitive task variable	**Single task**	**Dual task**	***p***	η_p^2
1-Back				
RT (ms)	1763.65 (249.37)	1675.52 (129.13)	n.s.	.203
Accuracy (%)	98.92 (2.06)	98.77 (1.30)	n.s.	.004
Clock task				
RT (ms)	2829.75 (924.49)	2486.28 (713.85)	n.s.	.304
Accuracy (%)	87.38 (10.02)	88.38 (8.94)	n.s.	.137
Spontaneous speech				
Sentence length (words/utterance)	10.00 (2.17)	11.16 (3.53)	n.s.	
Utterances/narrative	30.85 (12.19)	21.00 (6.86)	<0.02	
Words/narrative	312.31 (142.26)	227.15 (78.37)	<0.05	
Fillers/utterance	.53 (.15)	.65 (.18)	n.s.	
Pauses/utterance	.50 (.26)	.76 (.43)	<0.02	
Sentence complexity (clauses/utterance)	1.25 (23)	1.35 (.40)	n.s.	
Proportion of grammatical sentences	.82 (.09)	.86 (.11)	n.s.	
Proportion of utterances with new information	0.37 (0.13)	0.54 (0.23)	<0.03	

n.s. denotes not significant; η_p^2 denotes partial eta squared, a measure of effect size that ranges from 0 to 1.