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Cognitive Motor Interference in Adults with LCVA and Typical Comparison Peers Under Single- and Dual-task Conditions

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Cognitive motor interference in adults with LCVA and typical comparison peers under single- and dual-task conditions

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Accepted in Partial Completion
Of the Requirements for the Degree
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ABSTRACT

The present study aimed to determine if type of cognitive task (i.e., language vs. tone processing; single- vs. dual-task) influences cognitive-motor interference (CMI) in individuals with LCVA.

Design: Between group, cross-sectional, cohort study measured gait speed and cognitive performance (i.e., RT and accuracy) during single- and dual-task conditions.

Participants: Population-based, volunteer sample: 4 adults with LCVA, 4 healthy, age-matched adults, and 4 healthy, young-adults. LCVA participants were a minimum of 6 months post-stroke. Healthy, age-matched individuals were matched to LCVA participants for age (+/- 10 years), education level, and gender. Young, healthy adults aged 18-25 years served as the control group. All participants were fluent in English, reported good hearing/vision, and no neurological impairment.

Outcome Measures: Measures of gait speed (m/s), accuracy, and RT on walking and cognitive tasks were recorded. Neuropsychological test scores were compared to performance on dual-tasks.

Conclusions: Results have implications for treating individuals with LCVA and communication disorders. Performance of LCVA under single- and dual- task conditions demonstrate the importance of not only treating individuals while they are performing a single task, but also under dual-task conditions to ensure gait safety. Gait speed, however does not appear to be impacted when completing the cognitive-linguistic tasks used in the current study, perhaps due to the lack of sensitivity in the outcome measure used in data collection for motor performance. Additional research should be conducted to confirm results due to the inconsistency in current findings when compared to previous research. Furthermore, future research should focus on collecting outcome measures for both motor and cognitive tasks using technology and cognitive tasks that have previously indicated group differences between stroke and typical comparison peers**.**

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TABLE OF CONTENTS

List of Tables

INTRODUCTION

There are one million people living in the United States that have experienced a stroke (National Institute of Neurological Disorders and Stroke; NINDS, 2014) and mounting evidence suggests that many of these individuals will experience attention deficits and cognitive motor interference (CMI), therefore leading to disturbances in dual-attention performance (Bowen et al., 2001; Cockburn, Haggard, Cock, & Fordham, 2003; Dennis et al., 2009; Haggard, Cockburn, Cock, Fordham, & Wade , 2000; Hyndman & Ashburn, 2003; Kemper, McDowd, Pohl, Herman, & Jackson, 2006; Melzer et al., 2009; Murray, 2002; Plummer-D'Amato et al., 2008; Regnaux et al., 2005). However, there is little consensus as to what extent people with left hemisphere strokes have attention deficits when performing dual, cognitive-motor tasks (Murray, 2002), and there is little known regarding the patterns and specific impacts of dual-task interference on cognitive performance (e.g., reaction time and accuracy). Researchers have investigated dual-task cognitive and motor processing, with specific interest in how deficits in attention impact gait and balance performance (Plummer et al., 2008; Hyndman at al., 2006; and Bowen et al., 2001), linguistic performance (Murray, 2002), motor performance (Bowen et al., 2001; Cockburn et al., 2003; Dennis et al., 2009; Haggard et al., 2000; Hyndman et al., 2004; Kemper et al., 2006; Melzer et al., 2009), and the risk for falls (Shumway-Cook, A. et al., 1997; Shumway-Cook, Brauer, & Woollacott, 2000; Haur et al., 2003) in older adults and those following stroke. Despite this emerging evidence, there remains a limited understanding of dual-task performance following stroke and whether hemisphere lateralization effects play a role in an individual's ability to process cognitive and motor tasks simultaneously.

It is of interest to specify tasks for each hemisphere due to the known differences in hemispheric specialization for cognitive tasks, with the right-hemisphere involved in processing non-linguistic, auditory information (tones) and the left-hemisphere responsible for processing linguistic, auditory information (letters) (McKibbon et al., 2003). Performance under dual-task conditions could also correlate to cognitive-linguistic performance in the areas of language and attention due to hemispheric specialization which supports evidence in the research suggesting that attention screenings in individuals with stroke correlate to dual-task performance (Hyndman & Ashburn, 2003). Therefore dual-task cognitive-motor performance and patterns of CMI could be used to predict attention abilities in individuals with stroke. Implications of these findings could improve evaluation and treatment of individuals with LCVA and resultant communication and attention disorders. Performance of LCVA under single- and dual- task conditions could support the importance of not only treating individuals while they are performing a single cognitive-linguistic task, but also under dual-task gait conditions to facilitate safety and performance.

Stroke and hemispheric differences

Stroke is the leading cause of serious, long-term disability in the United States (Kochanek, Xu, Murphy, & Arias, 2014). The exact number or ratio of right-hemisphere versus left-hemisphere strokes is unknown, however evidence suggests that left hemisphere infarcts are more common than right (Hedna et al., 2013). The deficits observed in relation to hemisphere in which the stroke occurs is fairly predictable based on the location, structures, and corresponding functions involved in the infarct. Research has demonstrated that the right-hemisphere is involved with processing non-linguistic sounds (Dick et al., 2007). Activation of the right- and left-hemispheres has been analyzed using linguistic and nonlinguistic sounds to determine localization of auditory processing of information. In a study conducted by Wexler and Hawles (1983), data indicated that the left-hemisphere is commonly superior at analyzing linguistic stimuli and rapid temporal stimuli (McKibbon, Elias, Saucier, & Engenbregston, 2003). The left-hemisphere is superior at processing linguistic stimuli and fine, temporal, non-linguistic stimuli, and according to the temporal processing theory, the left-hemisphere superiority at linguistic processing is due to its dominance at rapid temporal analysis (McKibbon et al., 2003). Dick et al. (2007) found that the left-hemisphere was more activated when processing, language and environmental sound stimuli, whereas the right-hemisphere, demonstrated greater activation for environmental sound stimuli and nonlinguistic stimuli. This finding provides evidence to support using linguistic stimuli (letters) for a left-hemisphere dominant task and non-linguistic tone stimuli for a right-hemisphere dominant task, as is used in the current study to assess LCVA performance under cognitive and motor single- and dual-task conditions.

Aphasia

In addition to processing language and nonlinguistic sounds in different hemispheres, different patterns of impairments in the areas of language, cognition, and social communication are observed with damage from stroke in the left- and right-hemispheres. Approximately 25% to 40% of individuals that have experienced LCVA have aphasia, a loss of language ability, as one of their presenting symptoms (National Institute of Neurological Disorders and Stroke; NIND2014). Aphasia is caused by damage to the portions of the left peri-sylvian language regions of the brain. Aphasia is typically caused by CVA, but can also result from traumatic brain injury, and other neurologic conditions. Nearly one million Americans are living with aphasia (NINDS, 2014), and quality of life is often severely impacted.

Aphasia is defined as an acquired impairment in language production, comprehension, or cognitive processes that underlie language (Patterson & Chapey, 2008, pp. 64). Aphasia is characterized by an impairment or reduction in the ability to access language form, content or use, and the cognitive processes that interact with and possibly underlie language such as attention, memory, and executive functions (Murray & Chapey, 2001). Aphasia is a multimodal disorder that may affect listening, speaking, reading, and writing. All modalities can be impacted, although not necessarily to the same degree, and some modalities can be spared altogether (NINDS, 2014). A hallmark characteristic of aphasia is difficulty retrieving words and producing the words needed to effectively communicate (Nickels, 2002).

Aphasia is diagnosed using a formalized language assessment such as the *Western Aphasia Battery* (WAB; Kertesz, 2006) to determine specific deficits following neurological infarct to the left hemisphere. In recent years, research has indicated that aphasia and language impairments from LCVA could not only impact linguistic abilities but also attention processes. There is inconsistent evidence indicating that attention could possibly impair language or language impairments could potentially deplete attention performance (Murray, 2002). Deficient attention can lead to reduced ability to complete dual-tasks, such as simultaneous walking and talking.

Attention

Several attentional behaviors have been identified and can be assessed directly or indirectly utilizing cognitive-linguistic performance as well as motor performance in individuals with LCVA and concomitant aphasia. These attentional behaviors include: (a) sustained attention, the ability to maintain attention and produce consistent performance over time; (b) focused or selective attention, the ability to focus attention and prioritize part of our external or internal environment in the presence of competing stimuli; and (c) dual attention, the ability to attend to and complete more than one task, or attend and simultaneously process multiple stimuli. These attentional behaviors have been analyzed in linguistic and nonlinguistic tasks in patients with LCVA and aphasia, and there is mounting research that proposes that attention deficits could be responsible for symptoms of aphasia, characterized exclusively as disturbances of language (Murray, 2002). These decrements in attention have been assessed in a variety of ways as in individuals with LCVA. Given the common language impairments, aphasia has been an inclusion criterion and linguistic outcome measures have been used in the majority of the research that is specific to LCVA attention performance.

Sustained attention, the ability to maintain and produce a consistent behavioral response, has been examined as a possible underlying explanation for the language deficits experienced by patients with aphasia (Murray, 2002). Laures, Odell, and Coe (2003) found behavioral differences in individuals with LCVA and aphasia in comparison to healthy subjects while completing two auditory sustained attention tasks. The stimuli included linguistic (i.e., identify a target, abstract word) and nonlinguistic (i.e., identify a target tone) tasks. The individuals with LCVA demonstrated reduced sustained attention on both tasks, as evidenced reduced performance during the linguistic sustained attention condition and during the nonlinguistic sustained attention condition. These findings suggest that individuals with LCVA and resultant aphasia have decreased overall arousal regardless of the linguistic or nonlinguistic nature of the stimuli (Laures, Odell, & Coe, 2003). These and previous research findings suggest that individuals with LCVA are susceptible to complications with sustained attention when completing linguistic and nonlinguistic tasks in auditory modalities, indicating that a decrease in sustained attention capacities could be impacting linguistic performance, and potentially cognition and motor skills.

Investigators have also explored the extent to which focused or selective attention may be impacted in individuals with LCVA and resultant aphasia. Murray, Holland, and Beeson (1997) investigated the ability of healthy individuals and individuals with LCVA to complete a semantic judgment task (i.e., indicate if each word they heard belonged to a target semantic category) under three conditions: isolated stimulus presentation (i.e., semantic task spoken by a woman), a focused attention condition, and a dual-attention condition (i.e., semantic task spoken by a woman presented along with either competing word stimuli spoken by a man or competing tone stimuli). Findings revealed the group with LCVA displayed decreased accuracy under the focused attention task compared to the isolation condition, while competing stimuli had little effect on accuracy in the focused attention condition in the healthy control group. This evidence suggests not only that individuals with LCVA are at risk for focused attention problems with an auditory modality, but also that these deficits can negatively impact the accuracy and efficiency of the individual's expressive and receptive language skills (Murray, 1999).

Laures, Odell, and Coe (2003) and Murray et al. (1997) have employed auditory distraction in an attempt to demonstrate that when individuals with LCVA are dividing their attention between one linguistic task and one nonlinguistic task, the demands for attention resources between the two tasks results in a reduction in linguistic performance. A limitation of both studies is that a divided attention nonlinguistic task using a visual modality was not compared to a nonlinguistic task requiring divided attention in an auditory modality. Both of the previously stated studies involving auditory sustained attention also used linguistic stimuli as targets. It is therefore difficult to know whether the individual's sustained attention deficit should be attributed solely to deficits in attention allocation or partially to the linguistic processing deficits that typically define aphasia in individuals with LCVA. Further research must be completed to determine potential attention deficits in RCVA under dual-task conditions that require the competition between auditory comprehension and verbal expression resources. Given that both tasks used in the majority of research exploring attention decrements in LCVA require competition between auditory perception and verbal expression, further research must be conducted to delineate and explore shared attentional processes in other modalities, such as motor performance and alternative cognitive tasks. In the above research, attention screenings have also not been used to characterize, correlate, and corroborate performance, and therefore it is unsure if decrements in attention under certain conditions are also mirrored on attention screenings. Research using auditory and visual modalities to explore attention decrements in LCVA have also not been repeated and compared to performance in RCVA in the previous studies to determine if attention deficits with tasks that measure linguistic outcomes are observed in strokes that involve both hemispheres.

Erickson, Goldinger, and LaPointe (1996) investigated auditory vigilance in individuals with LCVA and resultant aphasia by assessing their ability to detect nonlinguistic stimuli with full or divided attention. The researchers had 10 persons with aphasia and 10 typical comparison peers listen to a 10-minute series of nonlinguistic acoustic stimuli. The participants were instructed to identify target sounds that were interspersed with non-target sounds across conditions of focused attention (i.e., identify target sounds) and divided-attention (i.e., identify target sounds while sorting cards). Persons with aphasia performed with decreased accuracy on the auditory vigilance task during the divided-attention condition relative to their typical comparison peers (Erickson, Goldinger, & LaPointe, 1996). This research supports the notion that some individuals with LCVA experience deficits in attention. Because the authors did not use linguistic stimuli the attention allocation was separated from deficits in linguistic processing indicating that the deficits in linguistic processing might represent an underlying disruption of resource allocation. Given that the stimuli used in this study did not contain linguistic information, it can be deduced that the impairments in dual-attention were due to reduced attention, which indicated that individuals with LCVA and resultant aphasia will not only experience reduced linguistic outcomes due to reduced attention, but an overall impairment in attentional capacity. It can however be deduced from the participants mean aphasia quotient on the *Western Aphasia Battery* of 63.94 (measured out of 100) that linguistic deficits experienced by these individuals may be due to the inability to properly allocate attention resources. Further research supports this notion and has empirically supported language sharing a common attention mechanism (Murray, 1999) in individuals with LCVA and aphasia. It can therefore be expected for individuals that have had LCVA to demonstrate decreased performance on language and attention tasks due to the presence of neural damage in the left-hemisphere that has been shown to help modulate language and dual-attention performance. The majority of research investigating dual-attention deficits in individuals with LCVA and resultant aphasia has been done using linguistic outcome measures and auditory and visual stimuli due to the consistent deficit of linguistic performance in this specific population.

Resource allocation theory

Evidence of shared mechanisms in language and attention skills have been explored in recent years in individuals with LCVA and resultant aphasia has aimed to delineate how and to what extent these mechanism are mutual. The amounting evidence supporting these findings specifically in individuals with LCVA and resultant language impairments have led to an attention model of aphasia (Murray, 1999; McNeil, Odell, & Tseng, 1991). This model states that observed cognitive-linguistic performance in individuals with LCVA demonstrates that there is a limited capacity of attention that an individual has available which results in language deficits. The extent to which competing tasks interfere with each other (e.g., dual-task interference) is a reflection of the degree to which the given tasks are competing for the same pool of resources (e.g., attention). If both of the competing tasks in a dual-task paradigm (e.g., one linguistic task and one non-linguistic task) rely on a common reservoir of resources (e.g., attention), performing the tasks simultaneously may deplete or exceed the available amount of resources and result in performance decrements (Murray, 1999). Conceptually, the resource demands of the primary, cognitive-linguistic task do not change during the dual-task conditions. The changes that occur are the demands placed on the common resource pool and the strategy used to decide how to allocate a limited amount of shared resources between the tasks (Murray, 1999). Within the attention model of aphasia, if performance is associated with impairments in attention, as opposed to solely cognitive-linguistic impairments in persons with aphasia, optimal performance will be observed during the least demanding, single-task condition. In comparison, during the dual-task condition, when there are more demands, adults with aphasia would demonstrate a suggestively larger deterioration in performance on one or both tasks (Murray, 1999).

Dual-task paradigm

Given that language and attention mechanisms have been found to overlap to some degree, Murray (2000) manipulated attentional demands using a dual-task paradigm with patients with aphasia by varying condition complexity (i.e., single vs. dual-task conditions) to measure the effects of dual-task performance on language function. In the dual-attention condition the participants completed a tone discrimination task, in which they indicated if the presented tone stimulus was high or low, while also completing a phrase completion task. Findings indicated that increased attentional demands had a negative effect on the word retrieval abilities of patients that were mildly aphasic. The patients with aphasia achieved optimal word retrieval performance during the isolation condition (e.g., when the phrase completion task was performed by itself) in which there was not competing attention. When the patients with aphasia were required to divide their attention between more than one task (e.g., dual-task condition), word retrieval performance deteriorated. If word-retrieval performance was unaffected by attentional demands, no differential impairment would have been observed. This study's main outcome measure was word-retrieval performance and data is not provided for the tone task, which would be beneficial to determine the interaction of attention for two tasks that recruit left- (word-retrieval) and right-hemisphere processing (tones). Although this study does not employ a motor task under dual-task conditions, this study further validates evidence that suggests that there is a negative relation between attentional demands and language performance in individuals with aphasia (Murray, 2000), and therefore supports the idea that LCVA experience decreased performance when required to divide attention between two tasks.

Given the prevalence of findings indicating resource allocation impairment in LCVA and a resultant attention model of aphasia, attention mechanisms and modulation have been investigated in not only individuals with LCVA, but also RCVA. Not only have individuals with LCVA and resultant aphasia demonstrated decrements in attention due to stroke. Following stroke, impairments in sustained, divided, and alternating attention have been described in the literature regardless of the hemisphere that is impacted. McDowd, Filion, Pohl, Richards, and Stiers, (2003) examined two aspects of attentional functioning (divided attention and switching attention) in older adult stroke survivors and healthy older adults. The divided attention task involved a 2-choice response time task and a memory task, each performed in isolation and in combination with the other task. In the single-task version of the response time task, participants simply responded as quickly as possible to the color of the letter (red or green) using two colorcoded buttons on the response box. In the divided attention version of the response time task, participants were required to respond to the color of the letters while at the same time noting which of the letters in each series was repeated. In the single-task version of the memory task, participants watched the series of letters as they were presented on the screen and noted which letter was repeated. In the divided attention version, they noted which letter was repeated while at the same time responding to each letter in terms of its color. The switching attention task consisted of two 4-choice response time tasks requiring the participant to respond to number of shapes in the visual field or type of shapes in the visual field, alternating between identifying the number of shapes and the type of shapes. Accuracy and reaction time were measured in all tasks. Data revealed deficits related to stroke in both types of attention when compared to typical comparison peers. Investigators did not compare performance of LCVA and RCVA participants, however a breakdown of demographics was provided. Stroke patients did not demonstrate a significant difference in accuracy when completing alternating attention task, however they did demonstrate a significantly slower reaction time than typical comparison peers. Stroke participants were less accurate in reporting the repeated letter under dual-task conditions than were healthy adults. Because every participant could accurately report the repeated letter under single task conditions, the present findings indicate a divided attention deficit for stroke survivors and not an impact of potential language impairments due to LCVA. The increase in cognitive load by requiring divided attention affected the stroke group more negatively than it did the comparison groups without stroke. Participants with stroke were also slower to respond than were healthy comparison adults under dual-task conditions, with individuals demonstrating decreased performance on the dual-task when compared to single-task response time (McDowd et al., 2003). Due to variable disturbances and challenges experienced by individuals with LCVA and RCVA due to the structures and functions impacted in each hemisphere that were not accounted for in this study and the selected cognitive tasks, dual-task and alternating attention in stroke patients cannot be generalized to every patient. Despite tasks used that recruit both hemispheres for individuals that experienced stroke in different hemispheres, research continues to find that individuals with stroke demonstrate reduced attentional capacity under dual-task conditions when completing a variety of tasks using multiple modalities (auditory and visual). In future studies, specified tasks for each hemisphere should be used to ensure that hemispheric deficits are controlled for when assessing attention in individuals that have had a stroke. LCVA and RCVA performance should also be compared to determine if both groups demonstrate differing decrements in attention.

Growing evidence has demonstrated that attention mechanisms may overlap with not only *linguistic processing* (Murray, 2000), but also *motor processing* (Bowen et al., 2001; Cockburn et al., 2003; Dennis et al., 2009; Haggard et al., 2000; Hyndman et al., 2004; Kemper et al., 2006; Melzer et al., 2009; Plummer-D’Amato et al., 2008; Regnaux et al., 2005) in individuals with LCVA. Although the majority of research analyzing resource allocation and dual-attention processing in individuals with LCVA has focused on the correlation between attention and language due to the consistent impairment of language in this population, growing evidence suggests decrements in attention and dual-task performance in all individuals with stroke and in older adults. In order to analyze cognitive-motor interference effects in individuals with stroke and older adults, researchers have maintained the use of dual-task paradigms to measure performance outcomes.

Cognitive motor interference

Cognitive motor interference (CMI) occurs when a cognitive and a motor task are performed at the same time (Plummer et al., 2013). An example of this that is relevant to rehabilitation is walking while performing a simultaneous cognitive function, such as communicating. Walking while talking, a simple application of a cognitive-motor dual-task performance can create destabilizing effects because of the competing demands for attention resources needed for both tasks. Woollacott and Shumway-Cook (2002) determined that two simultaneously performed tasks require more than the total information processing capacity, the performance on either or both deteriorates.

In cognitive-motor dual-task situations, there are 9 possible scenarios for performance outcome, relative to single-task performance of each task. Plummer et al. (2013) proposed a classification system to describe the potential patterns of interference. The following are possible outcomes: (1) no interference (performance of either task in the dual situation does not change relative to single-task performance); (2) cognitive related motor interference (cognitive performance remains stable while motor performance deteriorates); (3) motor-related cognitive interference (motor performance remains stable while cognitive performance deteriorates); (4) motor facilitation (cognitive performance remains stable while motor performance improves); (5) cognitive facilitation (motor performance remains stable while cognitive performance improves); (6) cognitive priority trade-off (cognitive performance improves while motor performance deteriorates); (7) motor-priority trade-off (motor performance improves while cognitive performance deteriorates); (8) mutual interference (performance of both tasks deteriorates relative to single-task performance). It should be noted that some patterns are more likely than others, and these patterns have been illustrated in recent research findings.

The impact of CMI following stroke has been observed in dual-task performance on gait (Dennis et al., 2009; Haggard et al., 2000; Hyndman, et al., 2006; Kemper et al., 2006; Plummer-D'Amato et al., 2010; Plummer-D'Amato et al., 2008; Regnaux et al., 2005). The pattern of CMI varies depending on the task and the outcome measures. Plummer et al, (2013) found that the pattern of CMI related to gait after stroke appears to be cognitive-related motor interference (i.e. cognitive performance remains stable while motor performance deteriorates) with some cognitive-motor task combinations producing mutual interference (performance of both tasks deteriorates). The frequent pattern of *cognitive-related motor interference* during gait may suggest that people with stroke preferentially prioritize attention to the cognitive task at the cost of gait performance (Plummer et al., 2013). Overall, it has been found that after stroke, individuals demonstrate a diminished ability to perform dual-tasks and demonstrate variable patterns of CMI when compared to typical comparison peers (Bowen et al., 2001; Cockburn et al., 2003; Dennis et al., 2009; Haggard et al., 2000; Hyndman & Ashburn, 2003; Kemper et al., 2006; Melzer et al., 2009; Plummer-D’Amato et al., 2008; Regnaux et al., 2005), referred to as *dual-task interference*. Observed dual-task interference is attributed to a reduction in attentional resources (Huang & Mercer, 2001), much like the observations of dual-task impact on language outcomes in individuals with stroke (Murray 2000, 2002), discussed previously.

The relation between dual-task interference and CMI has been examined with the use of a dual-task paradigm in which participants with and without stroke complete cognitive-linguistic and non-cognitive-linguistic (motor) tasks under a condition of low attentional demand (e.g., complete cognitive-linguistic or non-cognitive-linguistic task alone) or high attentional demand (e.g., complete a cognitive-linguistic task during a divided attention condition in which another concurrent cognitive-linguistic or non-cognitive-linguistic task must be completed). Using a dual-task, cognitive-motor paradigm to analyze attentional demands on cognitive-linguistic and motor performance is important to clinical practice because it has practical implications to patients and clients daily lives. In everyday life, most events and activities require simultaneously processing of multiple stimuli (e.g., walking while conversing) and because of this, a dual-task paradigm has ecological validity.

CMI and control of walking under dual-task conditions has been examined in individuals with stroke and typical comparison peers using reaction time (RT) and gait performance as outcome measures. The involvement of cognitive processes in the control of walking at steady state was studied in 10 healthy subjects and 18 subjects after unilateral vascular brain damage (Regnaux et al., 2005). Investigators employed a dual-task paradigm to compare the performance level of a probe RT in a seated, single-task condition, and during standing or walking on a treadmill (dual-task conditions). The stimulus probe for the RT was an electrical stimulation applied by an electrode to the neck (single shock, duration: 10 ms) delivered by a stimulator. The subject was instructed to respond as quickly as possible to the stimulus by pressing a pressure-sensitive sensor placed in the mouth. The results show a marked increase in RT while walking compared to sitting and standing only in stroke subjects. The authors concluded that walking at a steady state is an attentionally demanding task. Phase-dependent modulations of the RTs were observed during gait cycles suggesting that cognitive processes may play a role in the control of the step cycle during walking. The increase of attentional demand during walking in subjects who had suffered a stroke varied, depending on severity of impairments of walking but also on a reduced general attentional capacity (Regnaux et al., 2005). Although the authors did not compare performance between LCVA and RCVA to determine hemispheric difference, this research further supports the notion that adequate resource allocation is necessary to complete two tasks simultaneously in a dual-task paradigm. In the study, both tasks were motor tasks (walking and oral lever pressing) however, simultaneous information processing was required to maintain performance in both tasks, and stroke patients were unable to maintain adequate attention to complete both tasks as effectively as typical comparison peers. This study highlights that RT and gait outcome measures are appropriate for analyzing dual-task performance and CMI in individuals with stroke.

Without adequate attentional resources for simultaneous completion of two tasks, individuals must decide which task to prioritize depending on the difficulty of the two tasks being performed. The existing research suggests that patients with stroke tend to instinctively prioritize the cognitive task, supported by significant dual-task costs on gait parameters without significant deterioration in cognitive performance (Cockburn et al., 2003; Haggard et al., 2000; Kemper et al., 2006; Plummer-D’Amato et al., 2008). It is unknown why this pattern has been supported in current research; however, it could be due to compensation in gait speed, by slowing down due to the unthreatening environment of the research laboratory when compared to natural environments. Environmental distractions are greater in the real world, and failure to prioritize attention to gait outside the laboratory could have critical implications for safety, such as fall risks that have been highly reported in this population during mobility tasks (Forster & Young, 1995; Nyberg & Gustafson, 1995; Weerdesteyn, de Niet, van Duijnhoven, & Geurts, 2008). However, Plummer at al., (2013) found in a follow-up study that the frequent pattern of *cognitive-related motor interference* during gait may suggest that people with stroke preferentially prioritize attention to the cognitive task at the cost of gait performance (Plummer et al., 2013). Given that findings are inconsistent regarding CMI patterns, further work must be done to determine typical patterns and compare these patterns to individual with stroke.

Individuals with RCVA and LCVA should also be compared to determine if there are differing patterns based on the hemisphere suffering the infarct. Patterns should also be explored using a variety of tasks to determine if patterns change when completing tasks in different modalities and with varying degrees of difficulty.

While task difficulty and prioritization of tasks could be factors affecting dual-task performance, dual-task studies in stroke have not explicitly examined whether hemisphere of brain lesion influences dual-task performance and CMI. The left and right hemispheres are specialized for different types of tasks, and therefore it is possible that the effect of task type on dual-task interference will be different for patients with left or right side hemisphere strokes. The proposed study directly addresses this gap in knowledge. This information has important implications for selecting tasks to accurately and reliably assess dual-task interference after stroke, and for guiding selection of treatment activities to train dual-task performance and consequently improve community mobility and participation after stroke.

Current evidence suggests that conventional rehabilitation does not adequately address gait-related dual-task impairments due to CMI after stroke, which may be contributing to low levels of participation and physical inactivity in community-dwelling stroke survivors, as well as increased fall risks. Clinically, if a patient improves on motor, cognitive, or linguistic performance when in isolation but shows no, or limited improvement in these tasks when they are combined (dual-task), their functional recovery, in terms of everyday independence, may still be compromised. Therefore, dual-task instruction and therapy must be employed to ensure functional recovery and gains. The majority of gait training for stroke patients focuses on functional recovery achieved with exercise under single-task, rather than dual-task, conditions (Kim, Ham, & Lee, 2014). The majority of cognitive rehabilitation also emphasizes functional recovery and this is accomplished through interventions that use single-task conditions or dual-task cognitive conditions that do not include motor tasks, such as walking. Consequently, the therapeutic approaches currently available fall short of addressing cognitive motor deficits that occurs in many individuals that have a stroke.

Wang et al. (2015) completed a systematic review analyzing CMI as a treatment tool for gait and balance in individuals that had suffered a stroke. The systematic review revealed that individuals that have suffered a stroke can potentially decrease the level of CMI by improving gait speed and balance function when dual-task protocols are used therapeutically in comparison to single-task exercise (Her et al., 2011; Zheng et al., 2012). However, in the studies reviewed the performance of individuals with right stroke and left stroke was not compared. The cognitive tasks that Her et al. (2011) administered to the individuals were linguistic in nature, requiring verbal productions, which are the most functional in nature when combined with motor tasks. However, given that half of the participants were left hemisphere stroke patients, they might have required more allocation of resources to this task due to possible linguistic deficits. The results indicate a significant improvement in motor tasks, however performance on linguistic tasks is not provided to determine what type of CMI potentially impacted performance on cognitive-linguistic tasks before and after CMI intervention. Plummer-D’Amato et al. (2011) provided a cognitive-motor dual-task intervention involving concurrent performance of cognitive tasks during gait activities for individuals with stroke. On average, there was a 65% reduction in CMI on gait speed during the auditory Stroop task post-intervention, and a 28% reduction in CMI on gait speed during the clock task. There was a dual-task benefit on reaction time in both cognitive tasks before and after the intervention indicating the efficacy of dual-task interventions on CMI for individuals with stroke. This evidence provides support for interventions incorporating dual-task activities to improve CMI in participants with chronic stroke.

Research has found positive impacts on gait performance following dual-task exercise and intervention using CMI as rehabilitation. Despite evidence that rehabilitation of dual-task improves functional outcomes for stroke patients, further research is necessary to determine the types and doses of cognitive –motor intervention under dual-task conditions needed to produce clinically meaningful changes. In the literature, there is little evidence to support the use of cognitive tasks specialized for the right-hemisphere or left-hemisphere when implementing dual-task exercises with left and right hemisphere stroke patients.

In one study, the therapeutic impacts of completing two tasks simultaneously were assessed for a group of 10 older adults (5 LCVA, 3 RCVA, 2 bilateral CVA) and who were tested at least 6 months after a stroke and 10 typical comparison peers (Kemper et al., 2006). A baseline language sample was compared to language samples collected while the participants were performing concurrent motor tasks (walking and simple and complex finger tapping) or selective ignoring tasks (talking while ignoring concurrent speech and talking while ignoring concurrent noise). Whereas the healthy older adults' showed few negative impacts due to the concurrent task demands, the language samples from the stroke survivors were disrupted by the demands of dual-task completion. Indicating decreased ability to modulate attention for multiple tasks at the same time. Kempler et al. (2006) utilized a language production task however location of lesion from stroke (right vs. left hemisphere) was not controlled and comparisons between LCVA and RCVA participants was not completed to determine differences in dual-task performance between these two groups given known variance in cognitive-linguistic behaviors following LCVA and RCVA. Further research should be completed to determine variability in dual-task performance between these two groups.

Given that older adults and individuals with stroke experience CMI and decrements in one or both tasks when completing dual-task conditions, it is of importance for clinicians to understand how these populations allocate and prioritize their resources to better know how to improve their performance. Older adults with and without stroke have been found to allocate disproportionate attention to walking and talking when completing the tasks simultaneously (Elsevier, 2013). The authors of this study had community ambulators walk on a treadmill and react to obstacles while completing a secondary cognitive task, an auditory Stroop task. Muscle reaction time deteriorated equally in both older adults with and without stroke. Cognitive performance on the Stroop task, however, deteriorated more for the stroke group during the dual-task condition than in the controls therefore indicating that the stroke group employed a "posture-first strategy" (Elsevier, 2013), clearly supporting a variable pattern in CMI for stroke patients and typical comparison peers. This study did not however control for hemisphere of stroke when measuring dual-task performance and therefore further research must be completed to delineate impact of side of lesion during stroke on dual-attention tasks and CMI. Smulders et a., (2014) also investigated CMI in individuals with right-hemisphere cardiovascular accident (RCVA) and healthy subjects while maintaining a standing position and simultaneously having the participants complete three different tasks: a control task, a simple attentional task, and a complex attentional task. The authors determined that in stroke patients the postural sway decreased with the increase in attentional and cognitive load for both the RCVA and typical comparison peers. The data also suggested that the stability of stroke patients in dual-tasking conditions increased by compensating with weight-bearing in the opposite leg that is not being used in the dual-task. Results therefore indicate that both healthy and participants with RCVA adopt a similar postural regulation pattern aimed at maintaining stability (Smulders et al., 2014).

Pohl et al., (2011) conducted research with a group of older adults and analyzed cadence patterns while completing walking tasks in isolation and walking tasks completed simultaneously with a verbal language task. Data indicated that cadence (gait speed) decreased during the dual-task talking and walking condition. Participants with stroke also reduced the grammatical complexity and semantic content of their speech when walking indicating that both tasks were negatively impacted under the dual-task condition (Pohl et al., 2011). Results of this study suggest that individuals that have experienced a stroke who are older in age can be expected to have decrements in performance in both the cognitive and motor tasks (e.g. reduced gait speed). It has been well documented that individuals with stroke demonstrate a marked reduction in gait speed during cognitive-motor dual-task procedures (Bowen et al., 2001; Hyndman et al., 2006; and Plummer et al., 2008). Haggard et al. (2000) also demonstrated substantial gait decrements during simultaneous attention tasks when completing a variety of cognitive tasks in a group of severely injured neurological patients of mixed etiology, therefore indicating that his finding is consistent in individuals with neurologic damage no matter what the cause. Plummer et al. (2013) completed a review of studies assessing CMI in individuals with stroke and found that to assess gait performance, most studies measured gait speed, therefore indicating gait speed would be an effective outcome measure in a dual-task paradigm analyzing CMI in individuals with LCVA. Interestingly, no studies have examined if site of lesion (i.e., left vs. right hemisphere) impacts CMI, dual-task performance, or dual-task intervention in patients with stroke.

Research investigating patterns of CMI over time in individuals with stroke has demonstrated that patterns of CMI change during recovery from stroke (Cockburn et al., 2003).

In this study 10 patients with unilateral stroke that were available for reassessment 1–9 months following their participation in a study of CMI after brain injury, completed the following single- and dual-attention tasks: two one-minute walking trials, two one-minute word generation trials, two one-minute trials of simultaneous walking and word generation, and one 10-meter walk. Outcome measures included median stride duration and mean word generation. Results of the study showed that seven out of ten participants showed an improvement in dual-task gait performance. Three out of ten showed improved cognitive performance and one participant demonstrated a concomitant improvements in gait speed and word generation. The authors concluded that the extent of CMI during rehabilitation when relearning to walk after a stroke reduced over time in the majority of patients. CMI effects were more evident in improved stride duration than improved cognitive performance (Cockburn et al., 2003). A limitation of this study was that the experimental group consisted of individuals with traumatic brain injury. However, given that individuals with stroke experience neurologic damage, it can be assumed that individuals with stroke would experience similar patterns. This study would need to be repeated with individuals with LCVA and RCVA to corroborate the findings. Given that CMI changes during recovery and rehabilitation, patterns during dual-attention tasks in typical peers, LCVA and RCVA need to be investigated further to ensure support is being provided for stroke rehabilitation patients to ensure reduction of CMI over time to positively impact functional mobility and cognitive performance.

Cognitive tasks that have been coupled with motor tasks in a dual-task paradigm to determine decrement of performance in one or both tasks to improve understanding of CMI have been highly variable (speech production, working memory tasks, identification tasks). However, the type of cognitive task performed while walking influences the degree of dual-task interference following stroke (Plummer-D’Amato et al., 2008; Plummer et al., 2013; Plummer-D’Amato et al., 2010). Spontaneous speech was found to produce significantly greater dual-task costs on gait speed than simpler, working memory tasks (Plummer-D’Amato et al., 2008).

***N*-back task and working memory**

The *n*-back task is a cognitive task that requires participants to monitor a sequence of items (e.g., letters, tones) presented to them via a sensorimotor channel, and respond whenever the current item is the same as the one presented a given number, *n*, positions before it (Dobbs & Rule, 1989). The *n* parameter allows for manipulation of task difficulty using the same cognitive paradigm. This task requires constant updating of working memory (WM). Working memory (WM) refers to a temporary system for mental manipulation and maintenance of verbal, visual, and auditory information (Baddeley, 2012). WM also serves a role in cognitive executive functions, namely attention (Salis, Kelly, & Code, 2015). WM is the activated component of memory that falls within the focus of attention (Baddeley, 2012). The incidence of working memory deficits in individuals with LCVA is poorly understood and has not been systematically studied. Five studies reported the prevalence of post-stroke memory dysfunction at different post-stroke intervals. The prevalence of post stroke memory dysfunction varied from 23% to 55% 3 months post-stroke, which declined from 11% to 31% one year post-stroke, with the majority of memory impairments being correlated with verbal memory (Snaaphan & de Leeuw, 2007). Given that all participants were a minimum of one-year post-stroke, residual memory and WM impairments in participants in the current study were determined to be null for the sake of the experiment.

Despite the linguistic, attention, and WM interactions and relationships in LCVA being poorly understood, it has been suggested that WM limitations are a source of the linguistic processing and attentional deficits observed in individuals with LCVA. To investigate differences in WM between LCVA and RCVA, Laures-Gore, Marshall, and Verner (2011) used digit span forward (DF) and digit span backward (DB) tasks, which are frequently used to study WM in both healthy, LCVA, and RCVA populations. A total of 17 LCVA and 14 individuals with RCVA participated in a DF and DB span tasks. Modifications to the span tasks were implemented to accommodate language deficits when needed. A series of two digits were orally presented to each participant continuing to a maximum of eight digits. There were seven trials per digit series. Participants were asked to point to the correct order of digits on a written one- to nine-digit list provided on individual note cards or to verbally repeat the numbers if the participant was able to do so. Results indicated that LCVA participants demonstrated shorter digit spans than the RBD group, and therefore poorer WM. Both groups performed worse on the DB span tasks than the DF span tasks. The results demonstrate that there are differences in performance on digit span tasks between RCVA and LCVA and therefore digits would not be an effective tool to use in a dual-task condition for LCVA and RCVA participants. Results also indicated that for cognitive tasks requiring language differences between LCVA and RCVA groups may be explained by decreased attentional capacity or inefficient resource allocation in LCVA due to deficient language processing as a result of aphasia and therefore decreased resources to allocate to this task (Laures-Gore, Marshall, & Verner, 2011). Although the authors claim that the WM impairment observed in LCVA is in the area of verbal WM due to the task being a WM task, it cannot be ruled out that the impairments observed being due to language as the participants with LCVA and resultant aphasia ranged from mild to severe according to scores on the WAB.

Although the evidence to support or refute impairments of WM in individuals with stroke, research has indicated that *n*-back tasks are effective in measuring dual-task performance and CMI, with the *n*-back task being the cognitive task, and walking comprising the motor task, to investigate stroke-impacts and age-related effects of cognitive task difficulty on motor performance. In a study completed by Huxhold, Li, Schmiedek, and Lindenburger (2006), age-related effects of cognitive task difficulty were used to measure impacts on postural sway. In this study the introduction of the cognitive task, a 1-back, led to decrements in postural sway in both older-adults and younger-adults. When the cognitive load was increased from 1-back to 2-back, the older-adults demonstrated increased swaying behaviors, measured with treadmill technology, whereas younger adults did not increase postural sway (Huxhold et al., 2006). Although the authors were not measuring gait speed, the results indicated an impact on the motor task in the dual-task protocol, therefore indicating the presence of CMI under this dual-task condition.

CMI has been analyzed using specific variations in gait measures and *n*-back tasks. Lovden, Schaefer, Pohlmeyer, and Lindenberger (2008) analyzed gait variability (i.e. stride and step variability while walking on treadmill) with the introduction of an *n*-back cognitive task to determine impacts of dual-attention and found that both younger adults and older adults experience decrements under dual-task conditions, however the cognitive task will demonstrate decrements over the motor task. Older adults were defined as 60-70 or 70-80 years, and younger adults were aged 20-30 with half of the participants being male and half female. The *n*-back task consisted of a sequence of 26 digits presented auditorily via loudspeakers. The task required participants to monitor the number sequence and indicate whenever the currently presented digit coincided with the one that was given *n* steps earlier in the sequence. Responses were given verbally with “yes” or “no” indicating the same or otherwise. Data indicated that both groups showed increased deficits as the task complexity increased (1-back to 4-back), but the difference between groups was not noticeable. Interestingly, the author does not analyze specific performance on the n-back tasks of increasing difficulty in this study and accuracy is the only outcome measure for this cognitive task. There is information to gain by analyzing overall cognitive performance and specific changes and decrements in cognitive performance, to improve understanding of motor impacts on cognition and changes in performance of older adults to better identify potential impacts on fall risks and in this population

In a follow-up study using the same protocol as Lovden et al., (2008), Verrel, Lovden, Schellenbach, Schaefer, and Lindenberger, (2009) altered the outcome measure for gait to whole-body coordination to determine dual-task, cognitive-motor difference in younger and older adults. Whole-body coordination was measured using walk variability and patterns reflecting heel strike and toe off on the treadmill. The cognitive task was the same *n*-back tasks completed in the Lovden et al. (2009) protocol using a sequence of 26 digits. Contrary to what was found by Lovden et al. (2008), data indicated that for all participants gait patterns became more regular when performing a simple cognitive task (1-back) when compared to walking without a cognitive task. Data also suggests that increased cognitive load (1-back to 2-, 3-, and 4-back) led to age-differential effects with young-adults' gait patterns becoming more regular and older adults' becoming more irregular (Verrel et al., 2009). Cognitive performance was shown to improve under dual-task conditions, demonstrating a cognitive gain instead of cost for all participants. This unexpected finding could be accounted for due to practice effects of the cognitive task across the trials (Verrel et al., 2009).

Schaefer, Schellenbach, Lindenberger, and Woollacott (2014) investigated the consistency of these prioritization behaviors in older adults and typical comparison peers when walking in a virtual environment while completing a cognitive, 3-back task. The *n*-back task was a series of 32 digits ranging from 1-9 presented via loudspeakers. Participants were asked to say "tap" if the current number was the same as the digit presented 3 positions prior. Cognitive performance was measured in correctly identified targets, with each trial containing 7 target digits. The authors compared performance of young-adults (20-30 years old) to older-adults (60-70 years old). Outcome measures included missteps on the virtual walkway and gait speed. Older-adults were observed to increase their walking speed when terrain of the walkway was altered whereas younger adults maintained their walk speed. Older-adults also experienced an increased number of missteps on the virtual walkway when completing the *n*-back task simultaneously, therefore indicating a decrement in motor performance when completing dual-task conditions with higher cognitive demand. Although data did not suggest the use of a "posture first" strategy in older adults, both the younger adults and older adults showed consistent decrements in motor performance with increased number of missteps when completing the dual-attention, cognitive-motor condition.

Research has investigated the effects of two cognitive tasks on gait at preferred walking pace, and at a faster pace, using a dual-task paradigm (Dennis et al., 2009). In this study 21 chronic stroke patients and 10 age-matched control subjects performed 2 single motor tasks (walking at preferred and at fast pace around a walkway), and two cognitive tasks (serial subtractions of 3 and a visual–spatial decision task) under single- and dual-task conditions in randomized order. The stroke group was not divided into LCVA and RCVA and performance between the groups was not compared. Cognitive accuracy score and gait speed were measured. The healthy control group showed no effects of CMI. The stroke group decreased their walking speed while concurrently performing a serial subtraction task during both preferred and fast walking trials and made more mistakes in the visuo-spatial task during fast walking. The findings show that in stroke patients under dual-task conditions, the cognitive task appeared to take priority over maintenance of walking speed. During fast walking under the dual-task conditions, stroke participants appeared to favor walking over the cognitive task. Results may indicate that individuals with stroke could spontaneously favor one activity over the other (Dennis et al., 2009), or cognitive and motor demands could impact which task is prioritized depending on ability to allocate resources. Overall, stroke participants demonstrate different patterns of CMI than typical comparison peers indicating the need for further research to delineate these dual-attention and CMI differences in typical peers to ensure proper trajectory of treatment and evaluation under dual-task conditions to ensure improved community mobility for safety purposes and to decrease fall risks.

Findings from research have indicated inconsistencies regarding patterns of CMI in older adults when completing a cognitive-motor task using the *n*-back task in a dual-task paradigm. Some research suggests a decrement in motor performance (Lovden et al., 2008; Huxhold et al., 2006; Schaefer et al., 2014). Not all research indicates a decrement in motor performance for older adults under dual-task conditions with some data indicating improved cognitive performance when compared to motor performance (Verrel et al., 2009). Individuals with stroke have also been shown to prioritize gait and cognitive performance in dual-task situations when completing a motor and cognitive task (Dennis et al., 2009). Given these variable findings, further research must be done to delineate motor tasks and cognitive tasks that result in performance interactions due to competition in allocation of resources. Although motor patterns have been investigated in greater depth (Lovden et al., 2008; Huxhold et al., 2006; Verrel et al., 2009, Schaefer et al., 2014), components of cognitive performance (i.e., accuracy and reaction time) have not been analyzed to determine impacts of CMI on cognitive performance. The *n*-back paradigm under dual-task conditions has not been used to analyze interactions of cognitive and motor performance in individuals with stroke. Given that *n*-back tasks have been used to investigate dual-attention and cognitive-motor interference in typical adults when compared to younger adults, it can be assumed that this would be an effective way to investigate performance in individuals with stroke when compared to typical comparison peers and younger adults. Consistent performance between younger adults and older adults indicates that these two groups would be appropriate to compare individuals with stroke performance to identify differences in dual-task and cognitive-motor performance.

Impairments in mobility and CMI are high priority in neurologic physical therapy (PT) interventions and current research with stroke patients to determine dual-task performance and patterns of CMI. Current research has focused on the interactions between attention and postural control and gait in older adults (Woollacott & Shumway-Cook, 2002). Much of the present research requires participants to walk while simultaneously completing another task (cognitive-linguistic or motor). Difficulties with dual-task performance appear to be associated with increased fall risk in older adults (Shumway-Cook, Woollacott, & Kerns, 1997; Shumway-Cook, Brauer, & Woollacott, 2000; Haur et al., 2003). Melzer et al., (2009) investigated speed of voluntary stepping in individuals with stroke and typical comparison peers and determined that the significant increase in the step phase's duration (defined as the time on the treadmill until the time off) during single- (walking) and dual-task (walking while completing Stroop task) conditions in participants with stroke could be a factor contributing to the large number of falls seen in stroke patients. A clear understanding of how attention and gait interact would be beneficial for evaluation and treatment procedures and to reduce fall risk for individuals with neurologic damage.

One reason that older adults and individuals with strokes might demonstrate increased fall risk could be due to impaired ability to flexibly allocate attention between two tasks. Sui Chou, Mayr, van Donklear, and Woollacott, (2008) investigated this factor by having 12 healthy young adults and 12 healthy elderly adults perform obstacle avoidance while walking and completing an auditory Stroop task either alone or simultaneously. Using an attentional allocation index (AAI) to compare performance of healthy young and older adults and to measure the flexibility of allocation of attention, results showed a tendency in older adults toward a decreased ability to flexibly allocate their attention between the two tasks, with small AAI values. The decreased ability to allocate attention in older adults was found to be more prominent in the auditory Stroop task performance than in the obstacle avoidance task, therefore allocating the resources differently than younger comparison peers. This study suggests that an important factor contributing to decreased dual-task performance in older adults when simultaneously performing a motoric and secondary cognitive task is a reduced ability to flexibly allocate attention between the two tasks, with the general ability to switch attention flexibly being predictive of the ability to maintain task focus (Sui et al., 2008). Although many studies have analyzed attention differences in older adults and individuals with stroke when completing a motor and cognitive task simultaneously, the mechanisms of performance variability are poorly understood and inconsistent. Additionally, little research has been completed to determine specific hemispheric differences in attention and CMI in individuals with and without LCVA under dual-task conditions when compared to typical peers.

A series of studies have been completed in an attempt to systematically describe attention and dual-task performance during mobility tasks after stroke (Hyndman & Ashburn, 2003). Participants included 48 individuals with chronic stroke (26 RCVA, 21 LCVA, 1 brainstem stroke). Investigators categorized fall frequency to determine how attention under dual-task conditions is related to fall risk. Attention was measured using four subtests of the Test of Everyday attention. Data suggests that 43 percent of individuals with stroke demonstrated divided attention impairment and 31 percent showed sustained attention difficulties. Sustained and divided attention deficits were also correlated with functional impairments and falls, highlighting attention deficits in individuals with stroke might contribute to fall risk (Hyndman & Ashburn, 2003). This study provides further evidence to suggest that individuals that have experienced a stroke demonstrate impaired attention on attention screening tools and when completing dual-attention tasks. These impairments can negatively impact fall risk, which can lead to a sequelae of complications. However, there are no published studies that assess how attention is impacted for individuals with LCVA and RCVA when completing hemisphere-dominant tasks to control for prospective hemispheric deficits. The present study aims to determine dual-task performance and impacts on attention when completing cognitive tasks specified for each hemisphere (tone task and letter task).

Little research has been done looking precisely at site of lesion in relation to dual-task performance in stroke patients. The vast amount of research that has been completed specifically with LCVA patients has focused on aphasia and decrements in performance of language in individuals with LCVA. Murray (2002) suggests that in order to minimize dual-task interference and reduction in performance when carrying out multiple tasks that individuals must have one or both of the following: (1) sufficient attentional resources or capacity to share between the target and competing target; (2) an efficient allocation strategy for sharing or distributing attentional resources between the two tasks as might be required when one task requires greater attention. The collective research findings suggest that individuals that have experienced stroke are at risk for attention deficits that may negatively impact expressive and receptive language abilities, (Murray, 2002) and motor performance (Bowen et al., 2001; Cockburn et al., 2003; Dennis et al., 2009; Haggard et al., 2000; Hyndman et al., 2004; Kemper et al., 2006; Melzer et al., 2009; Plummer-D'Amato et al., 2008; Regnaux et al., 2005) due to diminished attention resources and inability to most efficiently and effectively allocate attentional resources.

Despite growing literature that suggests individuals with stroke, and specifically LCVA demonstrate decrements in cognitive-linguistic performance and the presence of CMI under dual-task conditions due to diminished ability to allocate attentional resources, there is little research investigating site of lesion on cognitive, linguistic and motor performance under dual-task conditions. There is also little research investigating performance on cognitive-linguistic tasks specialized for right and left hemisphere under single- and dual-task conditions. Outcome measures that have been used to analyze CMI and dual-task performance in LCVA include cognitive outcomes (*n*-back, screenings), linguistic performance (word–retrieval, serial naming, digit span, grammatical forms), and gait and balance measures (speed, postural patterns/variation, sway), with research indicating decrements under dual-task conditions in all measures used, albeit inconsistent findings. Specific to cognitive-linguistic performance under dual-task conditions, more studies have examined accuracy of performance over RT. However, stroke patients might show subtle differences that are not detected with accuracy but with an alternative measure, and therefore the current study will analyze level of accuracy and response time under single- and dual-task conditions to determine if RT is a more sensitive outcome measure for individuals with LCVA in detecting dual-task disruption and CMI. Stimuli presented in dual-task conditions to investigate attention differences and resultant CMI in individuals with stroke has also varied widely (auditory, visual, tactile).

Purpose of the Study

Given the wide diversity in previously researched tasks and presentation of stimuli with the use of dual-task paradigm, the current study seeks to determine if CMI is present in LCVA participants when compared to typical age-matched peers and young-healthy adults when completing cognitive-linguistic tasks specified for each hemisphere (right, tone; left, letter). Additionally, the present study will analyze both accuracy and RT of cognitive-linguistic performance, and gait speed to determine the differences in performance of LCVA participants in relation to typical comparison groups. Neuropsychological screening scores will be compared to dual-task performance to determine if a correlation is present between cognition capability and dual-task interference.

The potential to understand CMI in individuals with LCVA and how it relates to cognitive tasks that are specific to right and left hemisphere function will have therapeutic implications in the evaluation and intervention process for individuals that experience LCVA and resultant CMI and dual-task performance decrements. The information gained from this study would help inform clinicians as to how and why recognizing attention deficits and motor difficulties under dual-task conditions due to the likelihood of attention, language, and motor impairments being concomitant in this population. In regards to treatment and rehabilitation of patients LCVA resultant and CMI and dual-task performance difficulties, the literature addressing the boundary of attentional, cognitive-linguistic, and motor mechanisms under dual-task conditions does not offer much guidance to the therapist (Murray, 2000; Hula & McNeil, 2008). Therefore, there is considerable need for research in this area. Results have implications for improving treatment for individuals with LCVA and communication disorders. Performance of LCVA under single- and dual- task conditions demonstrate the importance of not only treating individuals while they are performing a single cognitive-linguistic task, but also under dual-task conditions to ensure gait safety while performing cognitive-linguistic tasks. If neuropsychological screening scores correlate to dual-task performance and presence of CMI, this finding could have implications for screening attention with dual-task conditions.

Hypotheses

The present study aimed to determine the differences in single- vs. dual-task cognitive-motor performance between individuals with LCVA and healthy young and age-matched adults and within the single- and dual-task conditions for LCVA participants. The following hypotheses were investigated:

1. Participants with LCVA will demonstrate reduced accuracy and response time during dual-task conditions as compared to healthy age-matched and young adults;
2. Participants with LCVA will demonstrate reduced accuracy and response time during dual-task conditions when compared to single-task conditions;
3. LCVA participants will demonstrate reduced accuracy and response time during the cognitive-linguistic task developed for left-hemisphere when compared to typical comparison groups;
4. Neurocognitive test scores will predict dual-task performance.

It was predicted that LCVA participants would demonstrate reduced accuracy and response time on the cognitive-linguistic tasks under dual-task conditions when compared between groups to typical comparison peers and within the LCVA group to single-task performance due to consistent findings that support diminished dual-processing in individuals that have experienced a stroke (Bowen et al., 2001; Cockburn et al., 2003; Dennis et al., 2009; Haggard et al., 2000;

Hyndman et al., 2004; Kemper et al., 2006; Melzer et al., 2009; Plummer-D'Amato et al., 2008; Regnaux et al., 2005). Typical young-healthy participants were used as comparison for the LCVA and age-matched groups as Mani, Bedwell, and Miller, (2005) found age-related variations in the cognitive skills of older-adults. Due to these observed differences in cognitive performance, the young-healthy group was utilized to compare the LCVA and age-matched group to determine the changes in performance on the dual-task conditions. When comparing performance on right- and left-hemisphere cognitive tasks (tone vs. letter) it is hypothesized that LCVA participants would demonstrate reduced accuracy and RT on the letter-task than the tone-task due to the resultant language impairments as a result of left-hemisphere infarct. It is also hypothesized that when Neuropsychological test scores are compared to performance on each dual-task condition a correlation between test score and performance would be present. More specifically the experimenters predicted that RBANS Attention subtest scores would correlate with dual-task performance due to both the subtest and dual-task conditions measuring attention performance, as Hyndman & Ashburn (2003) found the *Test of Everyday Attention* to be predictive of dual-attention task performance in individuals with chronic stroke.

METHODS

Study design

The study design was a prospective, non-randomized, cross-sectional study with pre-fixed task order and randomized trials.

Participants

Three groups of participants volunteered for this study. The experimental group consisted of 4 individuals with left-hemisphere cardiovascular accident (LCVA) and two control groups. The average age was 68.25 years for the LCVA group, with an average education of *M* =16.25

years. One control group consisted of 4 individuals that were broadly age-matched (approximately +/- 10 years), with the average age of this group being 62.25 years. The age-matched group was also matched for education-level to the LCVA group, with an average education level of *M* =16.25 years. The final group was made up of 4 young-healthy individuals (aged 18-25 years) with an average age of *M* = 21.00 years, with an average education level of *M* =17.00 years that served as typical comparison peers and baseline performance for the other two groups. Consent was obtained from participants when they arrived at the Western Washington University (WWU) Speech-Language-Hearing Clinic on their first of two experimental sessions. Modified language was used for participants with LCVA and resultant language impairments to ensure comprehension, when necessary. Participants in all groups were proficient speakers of English, reported good hearing and vision, and reported no known neurological conditions, using a screening questionnaire prior to beginning data collection. Participants were recruited by contacting local clinics, hospitals, centers and groups as well as via printed flyers that were posted in local businesses, clinics, centers, and hospitals. Participant's personal information was protected using a coding system. Data and personal information was locked in a research suite in the Communication Sciences and Disorders (CSD) department at WWU to ensure confidentiality.

Exclusion criteria for the healthy age-matched and young participants included the following: (1) prior history of stroke or pre-existing neurological condition, (2) inability to follow 3-step instructions, (3) primary uncontrolled hearing impairment, (4) severe uncontrolled visual impairment, (5) severe dysarthria or aphasia affecting ability to respond verbally to auditory stimuli, (6) lower extremity amputation, (7) any orthopedic problem affecting gait, (8) reported major depression, (9) bilateral and cerebellar strokes. All participants were required to be able to walk at least 50 meters without physical assistance (assistive devices were permitted for stroke participants, as needed).

All participants completed the *Test of Nonverbal Intelligence*, *Second Edition* (TONI-2; Hammill, Pearson, & Wiederholt; 2009) and *Repeatable Battery for the Assessment of Neuropsychological Status-Update* (RBANS-Update; Randolph, 2010) to describe cognitive level and to further characterize the sample population. The RBANS (Randolph, 1998) is a brief test measuring attention, language, visuospatial/construction abilities, and immediate and delayed memory. It consists of 12 subtests, which yield 5 Index scores and a Total Scale score. Normative information from the manual, which is used to calculate the Index and Total scores, is based on 540 healthy adults who ranged in age from 20 to 89 years old (Duff & Ramezani, 2015).

Due to the scoring of the RBANS being based on healthy adults, the TONI-2 was administered to all participants as well, to ensure improved reliability and validity of performance for participants with LCVA and resultant aphasia. The TONI-2 is a language-free intelligence evaluation that requires no reading, writing, speaking, or listening on the examinee's part, aside from basic instructions, and therefore was more suitable for individuals with LCVA and resultant language impairments involved in the study. The TONI-2 measures intelligence, aptitude, abstract reasoning, and problem solving and is ideal for evaluating those with decreased or limited language ability (Erhan, Fatih, & Nicola, 2012). It should be noted however, that the TONI-2 is not statistically normed on individuals with stroke and therefore both of these measures were not intended as inclusionary criteria in the study. The scores on these assessments were used to characterize the experimental groups and compare experimental performance.

Experimental Group

The experimental group consisted of 4 individuals, 2 males and 2 females, with diagnosis of aphasia as a result of LCVA as verified by participant report. Participants were a minimum of 6 months post stroke as reported by the individual and were volunteers recruited from hospitals, clinics, and centers (including local aphasia support groups in Whatcom County). Fliers were distributed to attendees of the support group meetings and individuals were asked to contact the researchers if they were interested in participating in the study as well as met the given criteria. Aphasia was verified and characterized by type and severity using the *Western Aphasia Battery-Bedside* (WAB-Bedside, Kertesz, 2006). The WAB-Bedside is an assessment that is used to identify and classify aphasia types as well as assess linguistic skills most frequently impacted by aphasia. Aphasia severity and aphasia type was utilized to further characterize the participants of the study, however not as inclusionary criteria. A score of 0-25 indicates *very severe* aphasia, 26-50 indicates *severe* aphasia, 51-75 is reflective of *moderate* aphasia, and 76-93.8 indicate *mild* aphasia (Kertesz, 2006).

Table 1. LCVA: TPO and WAB

LCVA Participant	TPO [month/year (total months)]	WAB-Aphasia Score
1	08/2014 (17)	98.00
2	08/1998 (101)	92.00
3	09/2014 (16)	95.00
4	08/2014 (18)	78.00

Control Groups

One control group consisted of 4 typical comparison peers, 2 males and 2 females that broadly matched the experimental group for gender, age (+/- 10 years) and education level. This age-matched group served as a between groups comparison for the participants with LCVA. The other control group consisted of 4 typical comparison peers, 2 males and 2 females, to serve as young-healthy adults, aged 18-25 years to serve as a baseline comparison for the LCVA and age-matched groups. The participants were volunteers recruited via word of mouth and with fliers from the WWU community and student body, and local businesses, retirement communities, and recreation centers in Bellingham, WA.

Materials

Tasks

All participants completed the single and dual, experimental tasks. Gait speed and cognitive performance were measured during single- and two different cognitive-motor, dual-task conditions: one task involving cognitive-linguistic function specialized for the left cerebral hemisphere, the letter-task, and the other involving a right-hemisphere dominant task, the tone-task. Two different hemispheric tasks were developed because the different constructs (letter/tone) may tax distinct cognitive resources and hence have differential effects on gait. Furthermore these differences might be variable for LCVA and typical comparison peers (age-matched and young-healthy), so all three groups were compared in regards to cognitive (accuracy and RT) and motor (gait speed) performance. The tasks and stimuli used in the current study were developed and pilot tested under the direction of Dr. Plummer at the University of North Carolina (UNC), Chapel Hill. The tasks used in the current study were part of a larger study being completed in coordination with UNC and WWU, and therefore it should be noted that participants completed extra trials that required other tasks in order to complete the protocol of the larger study, however not all data was used as outcome measures or data in the current study.

The first cognitive task, a left-hemisphere dominant task, known as the letter task, was a 3-back task in which letters of the alphabet were presented auditorily to the participant via a Bluetooth wireless microphone headset. Participants heard a letter of the alphabet presented one at a time and were required to respond “yes” or “no” based on whether the letter was the same as the letter presented three letters prior. The participants were required to complete the entire trial, which contained 30 stimulus tones or letters per condition. When completing the tone and letter single-task conditions, each participant was sitting comfortably in a chair at a desk in a quiet research suite in the WWU CSD department.

The designated right-hemisphere dominant task was a two-back tone-task. In this task, participants heard a musical tone and were required to respond “yes” or “no” based on whether the tone was the same pitch as the tone heard two tones prior. It should be noted that the stimuli were pilot tested by Dr. Plummer at UNC with results and statistics indicating that the 3-back letter and 2-back tone were statistically similar regarding the level of difficulty for a typical group of young-healthy individuals.

Accuracy and reaction time (RT) were measured for the cognitive tone- and letter-tasks under single- and dual-task conditions. RT and accuracy of responses were measured for each task using a Logitech H800 Bluetooth and wireless headphone set equipped with a microphone and by the experimenter using paper and pencil coding system. The Logitech H800 Bluetooth and wireless headset was also used to present the stimuli in the cognitive single- and dual-task conditions, with the volume adjusted to a comfortable listening level.

The single-task gait condition was completed on a 10-meter walkway in a quiet 2-meter wide hallway. The single gait task was completed prior to the start of the cognitive-linguistic single- and dual-task conditions. Two walking trials were completed, one 20-meter trial and one 40-meter trial. The experimenter recorded the time in seconds for each walking trial using a stopwatch. For the gait task, the participants were instructed to stand at one end of the walkway, the “start line.” The participants were instructed to walk at a comfortable, self-selected pace down and back one or two times (20 m and 40 m) on the 10-meter walkway when the experimenter said “go.” The 10-meter walkway was marked with blue tape on the ground to help identify distance.

Prior to the start of experimental testing, all participants were randomly assigned to the order of single- and dual-task completion in a semi-fixed order. The tone and letter tasks were completed in two sets, one tone set and one letter set, with random selection by the experimenter of the tone set or letter set to be completed first. One trial of the letter- or tone-task consisted of a sequence of 30 tone or letter stimuli. The orders of the conditions within each tone and letter task set were as follows: single-task gait (20 m and 40 m trials), seated cognitive single-task practice, seated cognitive single-task (letter/tone), cognitive-motor dual-task condition (walking and tone/letter), and seated cognitive single-task (letter/tone). Single-task cognitive-linguistic performance (letter/tone) was repeated after dual-task testing to assess for fatigue effects. Participants rested between conditions as needed, with a longer break between the two sets of tasks (letter/tone). All participants completed the same trial for the cognitive single-task tone and letter practice trial to ensure consistency. All participants performed two practice blocks of each cognitive task, the tone task or letter task, before commencing the experimental conditions to ensure comprehension and ability to complete the experimental tasks in isolation, and to also minimize learning effects across trials. The LCVA and age-matched participants completed the same trials in the same order for both the tone and letter tasks to ensure consistency for comparison. The experimenter randomly selected which task the participant would complete first, the right-hemisphere dominant task (tone task) or left-hemisphere dominant task (letter task) in order to counterbalance and control for practice effects, carry over effects and fatigue.

Instructions of the tone and letter task were presented verbally and in writing to the participants and were as follows: The participants were instructed to listen to the letter/tones presented via the headset, which was set to a comfortable listening volume. The participants were instructed to respond “yes” if the letter heard was the same as the letter heard 3 letters prior and “no” if it was not the same. Instructions were the same for tone task, the only difference being the letters were 3-back and the tones were 2-back. The participants were given a verbally presented example and further explanation if it was warranted. Each participant was instructed to respond as quickly and accurately as possible, however the participants were told that 100% accuracy was not expected due to some degree of difficulty for the experimental conditions. Comprehension of instructions was verified intermittently. The participants were also informed that the computer program would wait for a response before playing the next letter/tone in the 30-letter or tone string. Additionally participants were informed that the microphone would sense a response even if the response was not “yes” or “no” so the participants were asked to refrain from thinking aloud (e.g., “um,” “hmm”) or coughing when possible to improve response validity and reliability. If a mistake was made, the experimenter instructed the individual to keep responding to the stimuli until the 30 stimuli in the trial were complete. Immediately before the trials began the participants were reminded one final time to respond as quickly and accurately as possible to ensure the most accurate performance of the participants. Instructions were printed and read to the participants to safeguard for consistency.

For the dual-task, cognitive-motor conditions, the participants were instructed to walk across the 10-meter walkway while performing the letter/tone task. Participants were instructed to begin walking when the experimenter said, “go”. At the same time, the experimenter pressed the spacebar on the computer to start the cognitive trial and started the stop-watch to initiate timing.. All participants were reminded to respond as quickly and accurately as possible and were instructed to continue walking and responding until they heard the experimenter say “stop”, which occurred following the final response of the participant immediately after the last presented stimuli in the trial. The experimenter then recorded on a data sheet the time in seconds and the number of meters walked during the trial. This data was used to calculate the meters per second walked during the dual-task condition.

Stimuli

Cognitive-linguistic tone and letter task stimuli were produced using sound files and DirectRT computer software (Empirisoft, 2014). DirectRT is a software program used to create reaction time tasks that require precision timing (Empirisoft, 2014). The letter stimuli for the left-hemisphere dominant, cognitive task set consisted of a sequence of 30 letters presented in a pre-fixed, random order. The letter stimuli were presented by a female voice saved as sound files. The files were saved in the DirectRT program along with the excel spreadsheet file corresponding to DirectRT instructions for the program. Six letter files were used for the experimental trials, one of which was consistently used as the practice trial and the remaining five were randomly pre-selected for the pre-fixed order in the experimental single- and dual-task condition order stated above.

Tone stimuli for the right-hemisphere-dominant cognitive task were generated using sound files of pure tones, and excel spreadsheets corresponding to instructions were saved in the DirectRT program file. The stimuli for one trial consisted of a sequence of 30 tones presented in pre-fixed, random order. Tones ranged from 200-2000 Hz, varying by increments of 25 Hz. Preliminary pilot data collected by Dr. Plummer at the University of North Carolina, Chapel Hill indicated that this degree of variance was most effective when identifying Hz changes in the tones presented using DirectRT. Similarly to the letter stimuli, 6 tone files were used for the experimental trials, one of which was consistently used as the practice trial and the remaining five were randomly pre-selected for the pre-fixed order in the experimental single- and dual-task condition order stated above.

Stimuli were presented and controlled by the experimenter using a Dell XPS 13 Ultrabook computer using Direct RT software. Stimuli were presented with a consistent, silent inter-trial interval. This inter-trial interval was defined as the time from response offset to the onset of the subsequent stimulus. The next stimulus was prompted to begin using the Direct RT program that automatically moved to the subsequent stimuli when an auditory response was received through the headset.

Responses from the single- and dual-task cognitive-linguistic conditions were audio recorded using the Logitech H800 Bluetooth and wireless headset, as well as hand recorded by the experimenter using pencil and paper and a coding system for “yes” and “no’ responses. The responses were recorded and scored for accuracy of response on the same day by the author of the data. Each response was analyzed independently. For participants that made multiple responses to a single item, the final response from the participant was the response that was scored. If no response was given, the experimenter scored the trial as incorrect.

Procedure

Data collection occurred over two sessions. Sessions were completed in a quiet room and in the hallway free of distractions at the WWU Speech-Language-Hearing Clinic. The first session lasted approximately two hours and was used to complete participant consent forms, language and cognitive screenings. The second session lasted approximately two hours and was used to collect data from the experimental conditions. The clients were seated at a table in front of a Dell XPS 13 Ultrabook computer. Instructions and stimuli materials were presented verbally by the experimenter and in writing. To begin the task, the experimenter read the prepared instructions aloud and asked the participant to follow along with the experimenter while reading the instructions simultaneously. The experimenter asked the participant intermittently to confirm complete understanding of the instructions and expectations.

Participants were asked to complete the tone task and letter task in isolation and concurrently with a gait-task. Prior to the start of the single- and dual-task conditions, participant's gait speed was obtained and recorded to serve as a comparison during the dual-task conditions. Practice for the single-task tone and letter conditions preceded experimental conditions. Practice trials consisted of participants performing experimental tasks in isolation (e.g., tone task, and letter task) twice. Experimental single- and dual-task conditions were pre-selected and presented by the experimenter in a semi-fixed order, aside from the single-condition practice set of the letter and tone task. Experimental dual-task conditions were also pre-selected and completed in a randomly selected yet pre-fixed order. The semi-fixed order, as opposed to pure random order of task completion, helped to avoid confusion over task and condition expectations. The presentation of isolation conditions first was to ideally reduce fatigue by having the simplest isolation conditions prior to the dual-attention conditions, as well as ensure comprehension and ability to complete the experimental conditions.

Data analysis

Measures of gait speed (m/s), and accuracy and RT on cognitive tasks were recorded for single- and dual-task conditions to compare performance of LCVA participants to typical comparison peers. Performance on single- and dual-task conditions was compared between the LCVA and age-matched comparison peers, LCVA and young-healthy participants, age-matched comparison participants and young-healthy participants. Performance within the LCVA, age-matched, and young-healthy participants was compared for single- and dual-task conditions. LCVA performance on the left-hemisphere (letter) cognitive single- and dual-task was compared to performance on the task specialized for right-hemisphere (tone) single- and dual-task conditions. Scores on the cognitive screenings were compared to dual-task performance within the experimental groups to determine if a correlation between scores and dual-task performance could be identified.

The Logitech H800 Bluetooth wireless headset was synced with the DirectRT software and recorded each participant’s RT during the cognitive-linguistic single- and dual-task conditions. The experimenter manually recorded accuracy to the tone-task and letter-task as well as gait speed (meters/second) for each condition, which was calculated by the experimenter. The files for single- and dual-task conditions (tone, letter, and gait) were uploaded into a computer database and imported to the statistical software SPSS (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.), which was used to analyze the data.

Descriptive statistics were calculated for the clinical characteristics of each group. The means (*M*) and standard deviations (*sd*) are presented for each participant group (individuals with LCVA and typical comparison groups). The proposed research questions were analyzed using a one-way analysis of variance (ANOVA) to examine mean differences in performance on psychological tests and single- and dual-task performance (gait speed, RT, and accuracy) among groups (individuals with LCVA, age-matched group, young-healthy comparison group). Bonferroni post hoc analysis was then completed when significant differences between groups were found on the ANOVA to determine where the differences between the three groups were indicated. A two-tailed Pearson correlation examined whether there was a relationship between scores on neuropsychological testing and performance on dual-task trials

RESULTS

Demographics

Descriptive statistics (i.e., mean and standard deviation) for age and education are displayed in Table 2. There was no difference noted between the LCVA and age-matched control groups for age [F (1, 6) = 2.28, p = 0.18] or education [F (1, 6) = 0.27, p = 0.77]. Similarly, no differences in education were noted between the LCVA, age-matched, and young-adult groups [F (2, 9) = 0.74, p = 0.50].

Table 2. Descriptive statistics by group

Group	Gender: M/F	Age	Education
LCVA	2/2	68.25 (4.27)	16.25 (2.06)
Age-matched	2/2	62.25 (6.70)	16.25 (2.06)
Young-adults	2/2	21.00 (.08)	17.00 (0.00)

LCVA: Time post-onset and WAB score

Individuals with stroke (i.e. LCVA group) ranged from 16-101 months post-stroke with the average being *M* = 38 (42) months. Scores on the WAB Bedside indicated the presence of *mild* aphasia in participants 2 and 4, and were reflective of typical language performance in participants 1 and 3. Table 3 displays the time post-onset (TPO) and WAB Bedside scores for each participant in the LCVA group.

Table 3. LCVA: TPO and WAB Score

LCVA Participant	TPO [month/year (total months)]	WAB-Aphasia Score
1	08/2014 (17)	98.00
2	08/1998 (101)	92.00
3	09/2014 (16)	95.00
4	08/2014 (18)	78.00
Mean (*sd*)	38 (42)	90.75 (8.85)

Test performance

When neuropsychological test scores on the RBANS were compared between the groups, ANOVA indicated a significant difference in performance on the RBANS-A subtest between groups. Bonferroni post hoc analysis indicated that the age-matched adults performed significantly better compared to the LCVA group [MD = -28.00, p = 0.03, CI (95%) = -53.67-2.33]. There was no difference in performance on the RBANS-A subtest between the LCVA and the young-healthy group [MD = -18.00, p = 0.21, CI (95%) = -43.67-7.67]. There was no difference between groups on any of the other RBANS subtests (Table 4). No significant differences were indicated when TONI scores were compared between the groups [F (2, 9) = 1.76, p = 0.30].

Table 4. RBANS test performance: Between groups ANOVA [Mean (*sd*)]

Test	LCVA	Age-matched	Young-adult	F (2,9)	p (sig.)
RBANS-IM	86.50 (20.47)	94.25 (19.07)	78.00 (6.00)	0.97	0.42
RBANS-VC	1000.00 (23.19)	101.75 (18.34)	111.75 (10.87)	0.49	0.63
RBANS-L	86.00 (7.44)	99.75 (8.26)	83.75 (21.33)	1.56	0.26
RBANS-A	***81.25 (12.61)***	***109.25 (12.89)***	***99.25 (11.59)***	***5.26***	***0.03***
RBANS-DM	92.00 (22.69)	83.50 (13.18)	88.00 (12.19)	0.26	0.78
RBANS-TS	86.00 (19.93)	96.75 (14.41)	88.25 (6.13)	0.60	0.57

RBANS = *Repeatable Battery of Neuropsychological Status*
IM = Immediate memory
VC = Visuospatial/Construction
L = Language
A = Attention
DM = Delayed memory
TS = Total score

Single-task performance: Gait speed, letter-task, and tone-task

There was a significant difference in letter RT between groups, as would be expected that the LCVA group would perform slower, possibly due to aphasia. No other differences on other single-tasks were found between the groups. One-way ANOVA analysis indicated that there was a significant difference between groups for single-task letter RT [F (2, 9) = 3.29, p = 0.03], with LCVA group responding slower than both the age-matched and young-healthy groups. No significant differences were indicated between groups on the single-task letter accuracy, tone RT, and tone accuracy.

Single-task vs. dual-task performance among groups

There were no significant differences indicated for gait speed (m/s), accuracy, or RT when single-task and dual-task performance were compared between experimental groups for each experimental condition.

Dual-task performance between groups

One-way ANOVA analysis indicated that there was a significant difference among single-task and dual-task conditions for tone accuracy and tone RT between the groups. Bonferroni analysis indicated that the significant difference in single- and dual-task performance for tone accuracy and tone RT was between the LCVA and young-healthy adults, with [MD = -3.75, p = 0.05, CI (95%) = -7.51-0.01] for tone accuracy and [MD = 1728.06, p = 0.03, CI (95%) = 191.06-3265.06] for tone RT. Bonferroni post hoc analysis indicated that the difference was between the LCVA and the young-healthy groups in both cases. LCVA and age-matched adults both demonstrated reduced performance on the letter task in terms of accuracy and RT under dual-task conditions when compared to young-adults; however this data was not found to be significant. Analysis indicated that differences between the groups was approaching significance for the dual-task letter accuracy [F (2, 9), p = 0.05], with LCVA [*M* = 19.75 (3.86)], age-matched [*M* = 19.75 (2.99)], and young adults [*M* = 25.75 (3.40)]. The age-matched and young-healthy adults were notably faster to respond under all dual-task conditions when compared to LCVA, however this was not found to be significant for dual-task letter RT.

Table 5. Single- vs. dual-task performance: One-way ANOVA [Mean (*sd*)]

Single-Task	LCVA	Age-Matched	Young Adult	F (2, 9)	p = (sig)
Gait Speed m/s	0.81 (0.39)	1.09 (0.12)	1.11 (0.98)	1.90	0.20
Letter (RT)	***3375.96 (1497.77)***	***1776.00 (435.81)***	***1690.51 (547.76)***	***3.93***	***0.05***
Letter (acc.)	23.50 (3.72)	21.88 (1.70)	24.63 (1.44)	1.22	0.34
Tone (RT)	6188.27 (1545.56)	2508.63 (1370.39)	1437.12 (460.89)	2.71	0.12
Tone (acc.)	23.75 (2.22)	26.00 (2.94)	27.50 (1.29)	2.80	0.11

Dual-Task	**LCVA**	**Age-Matched**	**Young Adult**	**F (2, 9)**	**p = (sig)**
Gait Speed Tone task	0.75 (0.37)	0.90 (0.12)	0.89 (0.17)	0.49	0.63
Gait-Speed Letter task	0.71 (0.33)	0.93 (0.14)	0.90 (0.06)	1.28	0.33
Letter (RT)	3050.92 (1395.38)	1561.73 (361.83)	1697.43 (702.65)	3.16	0.09
Letter (acc.)	***19.75 (3.86)***	***19.75 (2.99)***	***25.75 (3.40)***	***4.07***	***0.05***
Tone (RT)	***2857.93 (1201.01)***	***1675.16 (265.29)***	***1129.87 (366.77)***	***5.69***	***0.03***
Tone (acc.)	***23.00 (2.45)***	***25.25 (1.71)***	***26.75 (0.96)***	***4.35***	***0.04***

Correlation analysis: Neuropsychological tests and dual-task performance

A two-tailed Pearson correlation was used to determine relationships between the neuropsychological test/subtest scores and performance on the dual-task conditions for all participants. There was a significant correlation noted between scores on the RBANS-L and performance on dual-task letter response time [r = -0.72 (p = 0.01)]. This indicates that language ability predicts performance on dual-task letter response time. The Stroop task was correlated to both dual-task letter RT [r = 0.59 (p = 0.04] and dual-task tone accuracy [r = -0.77 (p = 0.00)], indicating that selective attention abilities could potentially be predictive of response time and accuracy under dual-task conditions.

DISCUSSION

Participants in this study were individuals that have experienced LCVA, relatively healthy, age-matched adults and healthy young-adults. These individuals completed cognitive and motor tasks under single- and multiple, dual-task conditions to determine the impact of CMI on gait speed, and accuracy and RT on two cognitive tasks. The cognitive tasks recruited left-and right-hemisphere processing regions. Comparisons were made to determine whether hemisphere lateralization impacted cognitive-motor dual-task processing in the groups assessed. At present, research has fallen short in delineating CMI and dual-task performance differences in individuals with LCVA and RCVA in comparison to typical peers. Interestingly, there has been no research examining the impacts of dual-task performance and CMI on cognitive tasks that are specialized to engage the right- and left-hemisphere in individuals that have experienced neurologic damage from stroke with resultant deficits in skills that require efficient right- and left-hemispheric functioning.

In the present study, LCVA were found to perform with reduced cognitive accuracy and RT under all dual-task conditions (gait-letter and gait-tone), however data did not indicate that all differences were significant. Contrary to what was hypothesized, LCVA performed with significantly reduced accuracy and RT on the right-hemisphere, tone task, but not the left-hemisphere, letter task, as predicted. This could be attributed to the difficulty of the tasks or a reflection of the tasks that were chosen not being specific enough to left- and right-hemisphere processing. The *n*-back tasks used were a working memory task that possibly did not capture the functions of the left- and right-hemisphere, but merely measured working memory function. Further research should be done to investigate and determine cognitive tasks that are more specific to right- and left-hemispheric processing in individuals with stroke to better determine patterns of CMI under dual-task conditions for both LCVA and RCVA in comparison to typical peers.

Although the tasks did not capture functioning of the right- and left-hemispheres as they were intended to do, LCVA performed with decreased accuracy and RT on the tone task. These findings still provide support for the mounting evidence that suggests that individuals with stroke experience dual-task performance decrements when compared to typical comparison peers (Murray, 2002; Plummer et al., 2013). LCVA demonstrated a significant difference in performance on dual-task tone RT when single-task performance was compared to dual-performance, with the largest difference lying between LCVA and young-healthy adults. This could be attributed however to attentional resource depletion, poor resource allocation, or language impairments, and it cannot be determined which with the measures and tasks used.

Gait differences within the groups and between the groups indicated no differences when single-task condition was compared to dual-task conditions. This indicates that gait speed was not altered in all participants in the dual-task conditions to indicate the presence of CMI when completing a motor and cognitive task simultaneously. This is a different finding than the literature indicates, as many studies have demonstrated decrements in both gait speed and cognitive performance under dual-task conditions, indicating the presence of CMI for this population (Plummer et al., 2011, 2013; Bowen et al., 2001; Baetens et al., 2013). This finding could be due to the lack of sensitivity of the technology used to measure gait speed (stop watch). Previous research has utilized a dynamic walkway to measure not only gait speed, but step variation and level of sway, which previous research indicates as sensitive measures that revealed CMI in individuals with stroke.

A neuropsychological subtest for attention, RBANS-A, was correlated to the dual-task, tone RT condition, which could be attributed to the attention required to respond rapidly under dual-task conditions. Given that the LCVA group demonstrated significant decrements in dual-attention performance on the tone task, it is expected that they also would perform worse on separate measures of attention. This could have clinical relevance, as it may indicate that scores on tests of attention could serve to predict dual-task abilities for individuals with LCVA.

Although the RBANS-L was correlated to performance on the dual-task letter RT, this finding is not substantiated due to the known language deficits of the LCVA group. Given that 2/4 of the LCVA group obtained a score on the WAB Bedside that reflected *mild* aphasia it is not surprising that this correlation was found. With impaired language, individuals will more than likely demonstrate reduced accuracy on the RBANS due to the linguistic nature of the test, and these individuals will also likely require increased RT to complete the dual-attention letter task which also requires intact language skills. It therefore cannot be determined if performance on the RBANS subtests were decremented and correlated to dual-task performance due to linguistic performance or impairments in attention for the LCVA group.

Limitations/strengths

The current study encountered many limitations that should be addressed in future research. The current study consisted of a small sample size (*n*=4) due to attrition and limited resources (time, experimenters to complete testing). Due to challenges that arose when recruiting individuals for the LCVA and age-matched groups, the parameters for the age-matched group was increased from =/- 5 years to +/- 10 years. Ideally the parameters in age should be smaller (+/- 5 years) to ensure similar cognitive profiles between the groups. Although no significant difference was found between the LCVA and age-matched group’s age, the results would be more reliable with a smaller difference in age between the comparison peers and LCVA group. Additionally, given that the sample included only four individuals from each group, results more than likely do not generalize to larger populations. The study needs to be repeated with a larger sample to corroborate and increase the validity of the findings.

The RBANS is a language-based assessment that is not normed on individuals with LVCA and resultant aphasia. As discussed above, 2/4 LCVA participants scored within the range of *mild* aphasia on the WAB-Bedside, which may have impacted their performance on the subtests of the RBANS. If so, the validity of any statistical differences between groups may be called into question. However, Murray (2002) determined that language impairments observed in individuals with aphasia could be a result of impairments in attention, as depicted in the scores of LCVA participants on the RBANS-A. In further research, a non-verbal test of attention would be beneficial to rule out language impairments that could negatively impact cognitive and attention screening. LCVA participants without resultant aphasia should also be used in the study to improve the validity of cognitive-linguistic assessment scores and comparisons to dual-task performance.

Technical problems arose during data collection that could have influenced the results of this investigation. The Logitech headset used in data collection was less sensitive to female pitch and therefore it did not respond to the “yes” or “no” verbal response consistently and required the participant to repeat the response before advancing to the next stimuli. Investigators attempted to adjust sensitivity of the microphone on the headset with no ability to successfully alter the microphone. This technical difficulty impacted the recorded RT of the participants and increased the level of frustration and fatigue of the participants, therefore more than likely impacting the overall results.

For the letter-task, grapheme names and sound files that contained minimal pairs (*s*, *f*), or sounds that varied by one placement of articulation during production, were presented via the headset. For the graphemes that “sound” similar, more than 50% of participants verbally reported one or more instances of perceptual challenge during data collection. These challenges arose for some participants despite reporting normal hearing and demonstrating comprehension and accurate completion of practice experimental tasks. It is hypothesized that the female voice files and the pitch of the female voice used in the files played a role in the perceptual challenges, consequently impacting the results of the letter task for all participants. In future studies, differences in performance for the three groups using male versus female voice files and altered pitch should be investigated to ensure accurate perception of stimuli to increase the validity of the results.

Although group differences were found in dual-task performance within the current study, no significant differences in gait speed were determined. One reason the findings might not be as robust as in previous studies could be the technology that was used to measure gait performance (i.e., stop watch). Sensitivity of a stop-watch versus balance and gait technology used in other studies examining gait differences in individuals with stroke (Plummer et al., 2013) and older adults (Hausdorff et al., 2008) resulted in more significant differences between groups, leading to more beneficial information for therapy and evaluations with these populations. This study should be duplicated using a measurement that has been proven effective in measuring CMI to ensure valid findings.

Furthermore, given that an exclusion criteria for the typical comparison groups was the presence of aphasia, future research should control for this factor when selecting LCVA participants. LVCA participants used to investigate cognitive-linguistic performance should be assessed using tasks and cognitive-linguistic assessments that do not have high demands on language. LCVA participants should also be matched for aphasia severity to control for the linguistic limitations imposed that results extraneous variables. Including participants with variable severity of aphasia reduces the level of control and ability to compare performance to typical peers. It cannot be determined if the linguistic impairments result in decremented dual-task performance or if the observed decrements are due to impaired dual-attention processing. Future research should control for aphasia when investigating CMI in the stroke population.

All participants, even the LCVA participants with aphasia, were highly familiar with the graphemes presented in the study, however not the tones. Most of the individuals in the study reported increased difficulty with the tones used in the tone-task over the letters in the letter-task due to lack of familiarity. Given that the participants were less accustomed with the tones, results suggest that they more than likely had to allocate an increased amount of resources to this task, therefore reducing performance on the gait and tone-task. A language task that requires increased complexity for participants could be used to demonstrate a decrement in cognitive-linguistic performance for LCVA participants. Further research should investigate RCVA performance on the letter- and tone-task to validate hypotheses that performance should be reduced on the tone task over the letter task.

Despite the above limitations, strengths of the study included an attempt to control for hemispheric differences in relation to cognitive task (letter/tone) under dual-task conditions. Although the tasks chosen fell short in being specific enough for the left- and right-hemispheres, no other research has investigated cognitive tasks specific to hemisphere. In individuals with stroke it is important to recognize differences in right- and left-hemisphere function related to location of neurologic damage from stroke, and the present study attempted to control for functional hemispheric differences by considering performance on a tone and letter cognitive task under single- and dual-task conditions. Additionally, other studies do not consistently report specific performance (accuracy and RT) on cognitive measures under dual-task conditions when investigating CMI and dual-task performance in individuals with stroke. The current study reports data on both motor and cognitive performance and does not rely on decrements in motor outcome measures to identify the presence of CMI in the LCVA population, while considering decrements in both cognitive and motor function.

Clinical implications

Results of the present study have implications for evaluating and treating individuals with LCVA and resultant communication disorders. Decremented performance of LCVA under dual-task conditions demonstrate the importance of not only treating individuals while they are performing a single cognitive-linguistic task, but also under dual-task conditions to ensure gait safety while performing cognitive-linguistic tasks. Additional research should be conducted with increased control for aphasia in stroke participants to confirm findings and determine variations and differences in RCVA performance under single- and dual-task conditions in comparison to LCVA and typical experimental groups. Given that the majority of other studies exploring CMI and dual-attention in stroke measure gait and posture performance, but do not report specific outcomes of cognitive performance, it is of interest for dual-task studies to provide information regarding statistical significance of dual-task changes in both the motor and cognitive tasks. Specific differences and changes on cognitive performance can help understand how motor performance and cognitive-linguistic performance impede or benefit each other, and under what conditions and with what outcome measures these interactions are demonstrated. Cognitive and motor abilities of participants should be carefully characterized using standardized and well-recognized clinical measures as well as tasks specialized for the individuals completing the measures. Further research needs to be conducted to determine what outcome measures for motor performance are most sensitive in detecting and characterizing CMI in the stroke population to improve research findings and improve application to treatment for this population. Other important participant characteristics such as time post-stroke, site of lesion, education level, and age should also be controlled and reported and perhaps used as comparison criteria to delineate differences in these characteristics of individuals with stroke to positively impact the knowledge base and clinical actions of therapists during rehabilitation. Additional consideration of the complexity and specificity of assigned tasks, particularly cognitive tasks is warranted to gain a better understanding of performance variations between RCVA, LCVA, and typical comparison peers.

Speech-language pathologists (SLPs) are uniquely qualified to implement dual-task interventions to remediate CMI following stroke with cognitive and linguistic tasks that are specific to side of lesion (right vs. left hemisphere). Working closely with physical and occupational therapists, SLPs can implement verbal and non-verbal cognitive tasks (e.g. reciting a grocery list, auditory Stroop task, *n*-back task) in conjunction with gait activities. It is important for SLPs to gain understanding and competence in dual-task methodologies to effectively remediate CMI following stroke to ensure development of community mobility while simultaneously completing a cognitive task.

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