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DUAL-TASK PERFORMANCE IN HEALTHY YOUNG AND HEALTHY OLDER ADULTS: THE EFFECT OF COGNITIVE SECONDARY TASKS

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DUAL-TASK PERFORMANCE IN HEALTHY YOUNG AND HEALTHY OLDER ADULTS: THE EFFECT OF COGNITIVE SECONDARY TASKS

(Dual-Tasking and Gait Performance)

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ABSTRACT

Performing two tasks at once (dual-tasking) is a common part of our daily lives, and this practice can impact on individual performance of one (or both) tasks. For example, walking while talking can produce dual-task interference that may alter gait parameters, lead to postural instability and increase one's risk of falling. The impact of dual-task interference is dependent upon age, as well as other factors specific to the secondary task. The current study employed a dual-task paradigm to examine the impact of task complexity, articulation, task type, and age on gait. Participants were asked to walk a distance of approximately 20 feet while performing working memory tasks. Results suggest that both articulation and task complexity hamper gait performance, and that dual-task interference increases with age. Furthermore, these results indirectly suggest that some of the effects of task complexity may be nullified through the use of auditory cueing. [147 words]

Keywords: dual-task, gait, cognitive secondary tasks, healthy older adults, visual-spatial, digit-span

CO-AUTHORSHIP STATEMENT

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Chapter 1: INTRODUCTION

1.1 An Evolving Perspective on Gait

Gait is a complex sensorimotor action dependent upon the execution of locomotion, the generation of rhythmic patterns, and the ability to adapt to environmental changes (Snijders, Verstappen, Munneke, & Bloem, 2007). Research has implicated 'central pattern generators', suggesting that spinal networks are responsible for generating the rhythmic activity necessary for locomotion (Lacquaniti, Grasso, & Zago, 1999). Functional MRI techniques have demonstrated the involvement of these aforementioned spinal networks in both running and walking (Jahn et al., 2004).

Traditionally, gait has been conceived as a wholly automatic or reflexive process, controlled by subcortical mechanisms (Snijders et al., 2007), a hypothesis that implicitly assumes an absence of higher-level processing. There is, however, increasing evidence to suggest a cortical component in conjunction with sensorimotor processes (Beauchet et al., 2003; Lundin-Olsson, Nyberg, & Gustafson, 1997; Woollacott & Shumway-Cook, 2002). Specifically, an increased role for attentional processes has been identified, as researchers have begun to suggest that gait is an attention-demanding task (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001). The 'dual-task paradigm' has been utilized by researchers to investigate this interaction between attention and gait.

1.2 The Dual-Task Paradigm

Concurrent task performance, or doing two things at once, is a common part of our daily lives. The ability to execute and maintain gait, while performing simultaneous cognitive, verbal, or motor tasks is presumably beneficial in a multitude of ways (e.g. walking while talking). The "dual- task paradigm", in which participants perform two or

more tasks concurrently, has been used by researchers to examine the attentional demands of gait. This design requires the execution of a primary task (e.g. walking), and the concurrent performance of a secondary task (e.g. talking) (O'Shea, Morris, & Iansek, 2002).

If continuous gait demands attention, and the attentional capacity of any individual is limited, then any division of attentional resources may result in interference, particularly when the capacity limits of the system are exceeded. "Dual-task interference" can be defined as a decline in performance on one or both tasks (Woollacott & Shumway-Cook, 2002). Furthermore, the dual-task design posits that the more demanding the primary motor task, the fewer resources available to be allocated to secondary task performance. Thus, secondary task performance may be taken as a direct quantification of residual attentional capacity (Huang & Mercer, 2001).

1.3 Age-Related Changes in Gait Pattern

Gait instability, characterized by inconsistency or variability in stride patterns, is an important predictor of falls in the elderly (Barak, Wagenaar, & Holt, 2006; Brach, Berthold, Craik, VanSwearingen, & Newman, 2001; Hollman, Kovash, Kubik, & Linbo, 2007). Normal aging is associated with changes in the functional mechanisms responsible for gait, including the sensory, musculoskeletal, and neurological systems – which, in turn, affect posture and gait dynamics (Mbourou, Lajoie, & Teasdale, 2003). Moreover, Tabbarah, Crimmins, and Seeman (2002) suggest that aging produces changes in cognition that are inextricably linked to physical performance, and furthermore, that declining cognitive ability affects one's ability to complete attention-demanding tasks. For instance, Oxley et al. (1997) proposed that older pedestrians may be more at risk

when crossing the road, due to their inability to successfully divide attention between the various sources of incoming information (e.g. flow/direction of traffic, gait, traffic lights). Moreover, there is evidence to suggest that older adults experience greater gait variability as compared to young adults (Kang & Dingwell, 2007; Oberg, Karsznia, & Oberg, 1993) and this variability is exaggerated under dual-task conditions (Beauchet et al., 2003; Dubost et al., 2006; Hollman et al., 2007). The various measurements used to quantify gait alterations include, but are not limited to, gait velocity, step length, step width, stance time, and step time and/or cadence (Brach et al., 2001; Hausdorff, Rios, & Edelberg, 2001; Oberg et al., 1993). Additional measures include double and single support time, as well as swing time (Tabbarah et al., 2002). Step length and gait velocity are purportedly the changes most frequently seen with advancing age (Oberg et al., 1993).

The aforementioned dual-task paradigm has proven useful in evaluating divided attention as well as predicting falls among the elderly. Lundin-Olsson, Nyberg, and Gustafson (1997) conducted a prospective study involving 58 elderly adults and found that twelve of them stopped walking when a conversation was initiated. Furthermore, ten of these adults fell in the six month follow up. The researchers concluded that the tendency to "stop walking while talking" was highly predictive of falls in the elderly with a sensitivity of 95%, but a low specificity of 48%. Building on the above work, Verghese et al. (2002) utilized a "walking while talking" (WWT simple and WWT complex) paradigm to predict likelihood of falling amongst elderly adults as measured over a twelve month period. Poor performance, measured by decreased gait velocity, on the WWT (simple) predicted 55% of falls with a specificity of 89%, while poor performance on WWT (complex) predicted 71% with a specificity of 70%.

Much research (e.g. O'Shea et al., 2002; Schaafsma et al., 2003) has examined gait variability among older adults suffering from neurological pathologies (e.g. Parkinson's disease, Alzheimer's disease, Huntington's disease etc.). For instance, O'Shea et al. (2002) studied the effects of both motor and cognitive secondary task performance on walking among individuals with from idiopathic Parkinson's disease. This study found marked impairment of gait parameters under both dual-task conditions, with participants demonstrating a decline in stride length, a reduction in gait velocity, a decrease in cadence, and an increase in duration of double-limb support. Furthermore, Camicioli, Howieson, Lehman, and Kaye (1997) found that older individuals with Alzheimer's disease walked significantly slower than healthy elderly adults, when performing a secondary verbal fluency task.

Recent research, however, has suggested that dual-task interference is linked to gait variability among neurotypical older adults as well. It is important to note that research concerning dual-task performance in the elderly has largely focused on two groups; those with and those without a history of falls. Research concerning the latter will be discussed first.

1.4 Dual-Tasking in Older Adults without a History of Falling

Beauchet et al. (2003) compared stride-to-stride variability in stride length and velocity in a group of healthy older adults (*M*=83.4 yrs), and a group of young adults (*M*=22.5 yrs) utilizing the dual-task paradigm. Participants were asked to walk down a 15m walkway at a self-selected speed, while counting backwards aloud from fifty. The findings suggested that older adults showed increased stride-to-stride variability in both stride length and stride velocity under dual-task conditions. No significant effects were

shown for the younger adults. It was concluded that the secondary cognitive task of counting backwards caused difficulty in allocating attention between the two tasks, thereby frustrating the automaticity of gait.

Dubost et al. (2006) investigated stride time variability in a group of healthy older adults (60-71 years) utilizing a dual-task paradigm. Participants were asked to perform under four conditions: (1) walking at a normal self-selected speed; (2) walking at a slow self selected speed; (3) verbally generating animal names while sitting; and (4) enumerating animal names while walking at a self selected speed (dual-task condition). Results demonstrated that the dual-task condition produced greater stride time variability and decreased stride velocity. These dual-task changes in stride time were accounted for by the concurrent performance of the verbal fluency task (enumerating animal names) and gait, suggesting that shared attentional resources between the two tasks may be responsible for the reduction of automaticity of gait within the elderly population. In essence, greater attentional resources are allocated to the maintenance of gait in older adults; ergo, greater difficulty is experienced when trying to perform a task requiring divided attention.

Similarly, Hollman et al. (2007) conducted a cross-sectional study examining whether signs of gait instability (increased variability and decreased velocity) occur in older adults (70+) as compared to middle (40-55 yrs) and younger adults (20-35 yrs) under dual-task conditions. All participants were non-fallers, free of neurological pathology. Participants were instructed to walk along an 8.3m walkway at a normal selected speed, followed by the dual-task condition in which participants walked while reciting a five letter word backwards (e.g. "earth"). Gait velocity reduction was

significant in all three groups under the dual-task condition, but the older adults showed the greatest difference in gait velocity between normal versus dual-task condition [*M*=121.9cm/sec (normal) versus *M*=97.4cm/sec (dual-task)]. Stride-to-stride variability in gait velocity was greatest among older adults (*M*=9.0cm/sec), as compared with the middle-aged participants (*M*=5.1cm/sec) and the young adults (*M*= 5.2cm/sec). The decrease in gait velocity was hypothesized to act as a coping mechanism to compensate for the cognitive and attention demanding challenge of the dual-task. It was concluded that older adults have greater difficulty multi-tasking as the limits of their processing capacity may be more easily exceeded than those of middle-aged and younger adults.

Lindenberger, Marsiske, and Baltes (2000) proposed that dual-task interference increased with age, comparing older adults (60-70 yrs) with middle-aged and young adults on a dual-tasking paradigm using a long-term memory task (cued recall of sixteen words) as the secondary task, and gait as the primary task. Participants were to walk while encoding an auditorily-presented word list, and then recall the words using a pre-specified mnemonic strategy. Results demonstrated a significant interaction between age and walking condition, with older adults experiencing greater dual-task interference in walking accuracy as compared to middle aged and younger adults. It was concluded that sensorimotor aspects of performance are progressively reliant on cognitive processes with increasing age, and that older adults are increasingly unable to compensate for these deficits.

1.5 Dual-Tasking in Older Adults with a History of Falling

Collectively, the literature suggests that the gait of older adults with a history of falling is significantly different from the gait of older adults with no history of falls

(Hausdorff, Edelberg, Mitchell, Goldberger, & Wei, 1997). For example, using a sample of older adults, Hausdorff et al. (1997) compared 'fallers' with 'non-fallers' and found the former to display greater stride-to-stride variability. Based on this, one could infer that dual-tasking would result in markedly different performance between these groups as fallers would demonstrate pronounced balance impairment (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997).

Condron and Hill (2002) utilized a dual-task paradigm to examine differences in postural stability between healthy young adults, healthy older adults, and older adults with minor risk for falls. Risk of falling was identified through self-reported falling over the previous twelve months, and through tests that screened for disease or physical impairment that may limit balance or mobility. Participants were asked to stand on an instrumented force platform to obtain centre of pressure measures under single and dual-task conditions. The platform conditions were dynamic (stable platform, tilting side to side, and tilting front to back). Under the single task condition, subjects were only asked to balance, whereas under dual-task conditions subjects were asked to balance while counting backwards by threes from a randomly selected three-digit number. Findings suggested an age-related increase in postural sway with older adults demonstrating significantly greater sway on the dynamic platform conditions both with and without the secondary task compared to the young adults. The older adults with minor risk for falls, however, performed substantially worse (showing significantly greater postural sway) than the healthy older adults when asked to balance on the platform that tilted front to back while performing a concurrent task.

In replication of previous findings (Condron & Hill, 2002; Hausdorff et al., 1997),

Toulotte, Thevenon, Watelain, and Fabre (2006) found that under conditions of dual-task interference, older adults with a history of falling exhibited lower cadence and gait speed, as well as longer stride, step, and single-limb support time, as compared with older adults with no history of falling. These individuals at risk for falling were defined as those experiencing at least one fall in the two years preceding the study. Participants performed on ten single and ten dual-task tests. The former involved walking freely over a 10m walkway while staring ahead at a red light, while the latter involved having the participants walk with a glass of water in their dominant hand. As expected, elderly fallers experienced a greater increase in gait variability than elderly non-fallers under the dual-task condition. The researchers postulated that elderly fallers may suffer from impaired peripheral systems (i.e. vestibular, ocular, proprioceptive) which could account for the greater difficulty experienced when trying to allocate central processing resources between two tasks simultaneously.

1.6 Models of Interference

Despite the findings that gait variability increases under dual-task conditions, the cognitive mechanisms of this phenomenon are not well understood (Klingberg, 1998), and various hypotheses have been proposed. The first model suggests that interference results from a central overload when two separate tasks compete for limited attentional resources, and central processing capacity is exceeded (Huang & Mercer, 2001). This theory is termed the 'capacity' or 'resource-sharing model' (O'Shea et al., 2002; Pashler, 1994) and is highly dependent upon the difficulty or complexity of the secondary task. Bloem et al. (2001) found evidence for a 'dose-response' relationship, in that older adults made more motor errors as secondary task complexity increased.

Pellecchia (2003) examined postural sway, and proposed that an increase in postural sway is dependent upon the difficulty of the concurrent cognitive task. To test this, twenty healthy adults participated in three cognitive tasks of varying complexity. The first, a digit reversal task, orally presented two digit pairs to participants and asked them to reverse the digits. In the second task, a two-bit classification task was performed, in which participants were to construct a two-digit number out of single digits and further classify whether the newly formed number was high (>50) or low (<50), odd or even. Lastly, participants were given a digit subtraction task, in which they were asked to count backwards from a randomly chosen three digit number. Four experimental conditions were included: (1) quiet; (2) standing and digit reversal; (3) standing and two bit classification; and (4) standing and digit subtraction. The study found that the digit subtraction task resulted in the greatest amount of postural sway as it was the most complex. Complexity was defined in terms of the amount of information reduction that the task required. It was concluded that the more complex a secondary task, the greater information processing requirements.

The second perspective posits a more 'structural' approach. This theory suggests that when two concurrent tasks necessitate similar categories of information, interference will arise (Allali et al., 2007; Huang & Mercer, 2001; O'Shea et al., 2002; Pashler, 1994). This is sometimes termed the 'bottleneck model' in that two tasks of the same type create bottleneck interference as they compete for the same pathway (O'Shea et al., 2002; Pashler, 1994). An alternative to the 'bottleneck model' is the 'cross-talk model', which is also based on structural theory. Contrary to the bottleneck model, the 'cross-talk model' suggests that two similar tasks will enhance performance (reduce interference) by

utilizing the same pathway, thereby using fewer attentional resources (Allali et al., 2007; O'Shea et al., 2002; Pashler, 1994).

Maylor and Wing (1996) investigated postural stability in older and younger adults utilizing five separate cognitive tasks involving working memory, including 'random digit generation', 'Brooks' spatial memory task', ' backward digit recall', 'silent counting', and 'counting backward by three'. The results demonstrated larger differences in postural stability between the groups when performing 'Brooks' spatial memory' and 'backward digit recall' tasks, with the older participants displaying more exaggerated postural sway. The authors claimed that both of these cognitive secondary tasks tax the visuospatial sketchpad component of working memory model proposed by Baddeley (1984). Thus, Maylor and Wing (1996) suggest that greater postural instability may come about only when the visuospatial sketchpad is utilized, a finding which supports the basis of structural interference as gait processes also tax the visual pathway, presumably causing interference.

Sparrow, Bradshaw, Lamoureux, and Tirosh (2002) attempted to provide evidence for the structural model of interference, by conducting a study that examined the effects of aging on the attentional demands of walking. Two groups of participants were tested, one comprised of healthy older adults, and the other of healthy young adults. Each group performed two separate gait tasks, one in which they were asked to walk along an eight metre walkway at a comfortable speed, and one in which they were asked to simultaneously perform a 'targeting' task that required them to walk the 8m walkway whilst stepping to place either foot between narrow target strips running in the direction of the walkway. Both types of gait were assessed concurrently with either an auditory,

visual, or visual and auditory reaction time (RT) task. A response button connected via a cable to a computer was held in the left hand of the participant as they walked in order to make their response. The auditory RT stimulus consisted of a computer "chime" while the visual RT stimulus consisted of a red letter 'R' that appeared on the computer screen situated at the end of the walkway. The results demonstrated 'structural interference' for the visual RT task during gait, in that both tasks were drawing on the same sensory input – the visual pathway. Further, the visual RT increased to a greater extent in the older group when performing on the targeting task (the secondary task), supporting a structural form of interference. The researchers suggested that this finding has important "real world" implications for older adults, in that the performance of a demanding gait task (e.g. crossing the street) may be hampered by the performance of a secondary task occupying the visual pathway (e.g. watching flow and/ or direction of traffic).

1.7 Working Memory Tasks

Engle (2002) defines the central executive, a subset of Baddeley's (1984) working memory model, as a system that allows for the active maintenance of information in the presence of interference. In addition, it is often referred to as a system for executive attention which allows for goal-directed and consciously controlled behaviour (Engle, 2002; Fisk & Warr, 1996). Therefore, working memory tasks, which are representative of central executive functioning, can be utilized to assess attention under dual-task conditions (Engle, 2002). Consequently, many studies have incorporated working memory tasks into their procedures (Lindenberger et al., 2000; Maylor & Wing, 1996; Sparrow et al., 2002).

Baddeley (1992) defines 'working memory' as a system of the brain responsible

for temporary storage and manipulation of information necessary to perform complex cognitive tasks. Working memory is subdivided into three systems; the central executive, the phonological loop, and the visuospatial sketchpad. The central executive is assumed to be responsible for coordinating the two 'slave systems' (phonological loop & visuospatial sketchpad) and is an attention-controlling system. The phonological loop involves a phonological store in which speech based information can be stored briefly by means of subvocal repetition. Lastly, the visuospatial sketchpad allows for the manipulation of visual information. In light of this model, much literature has implied that one's level of 'executive functioning' (which essentially coordinates the other two subsystems) co-varies with dual-task performance. Succinctly, lower level executive functioning is posited to be predictive of poorer dual- task performance. Additionally, there is evidence for an age-related decline in executive functioning (Ble et al., 2005).

1.8 The Role of Executive Function

The relationship between specific cognitive functions and gait performance under the dual-task paradigm has been difficult to assess, as the two processes share variance (Holtzer, Verghese, Xue, & Lipton, 2006). Much research indicates that the ability to divide attention between tasks is dependent on executive functioning. Executive function can be defined as the cognitive ability to perform complex, goal directed, and self-serving actions. Ble et al. (2005) evaluated a group of elderly adults free of neurological pathology, using the Mini Mental State Exam (MMSE) as well as forms A and B of the Trail Making Test, in order to assess cognitive ability. In order to remove the upper extremity motor speed element from the test, the researchers utilized a difference score that was calculated as the time on part B minus time on part A. The physical performance

measures used in this study consisted of walking at a usual pace over a 4m course as well as walking at a fast pace over a 7m obstacle course. The researchers proposed the latter to be a more complex motor task requiring greater attention. The results demonstrated a strong independent negative correlation between the difference score and walking speed within the 7m obstacle course (i.e., individuals with minimal differences between Trails A and B walked the fastest). There was, however, no significant correlation found between the difference score and walking speed on the 4m course. Ble et al. (2005) concluded that since the 7m course required a faster pace and the avoidance of obstacles, it necessitated greater attentional/executive demands. Conversely, the 4m course was to be performed at a usual pace with no obstacles, which is likely less attention demanding and more automated. The researchers stressed the importance of executive function in complex mobility tasks, especially among the elderly, as there is evidence for age-related decline in executive function.

Building on the work of Ble et al. (2005), Coppin et al. (2006) hypothesized that individuals with poor executive function would demonstrate reduced gait speed under complex walking conditions. In order to examine the extent to which the tasks were affected by executive function, Coppin et al. (2006) added a secondary physical task to the walking conditions. A group of older adults not diagnosed with dementia (65+) were again administered the Mini Mental State Exam, and the difference score was calculated within the Trail Making test. To obtain baseline measures, participants were asked to walk at both a usual and fast pace over a 7m course, as well as walking at a fast pace over 60m. The dual-task conditions involved: (1) talking while walking over a 7m course at a usual pace; (2) picking up an object while walking at a usual pace over a 7m course; (3)

carrying a light package while walking at a usual pace over a 7m course; (4) stepping over two obstacles along the 7m course at usual pace; and (5) walking a 20m course three times at a usual pace while wearing a weighted vest. Participants with poor executive function walked significantly more slowly under some conditions (picking up an object, walking over obstacles, and wearing a weighted vest), but not others (walking while talking, carrying a package). The researchers concluded that the association between executive function and gait speed is task dependent, varying according to the degree to which it requires the individual to adapt to the demands of the task. In other words, demands for executive attention may have been low in the latter two tasks and higher in the former. In accordance with Ble et al. (2005), Coppin et al. (2006) concluded that poor executive function is also associated with a reduction in gait speed, while dual-task interference is dependent upon level of executive functioning as well as task nature.

Allali et al. (2007) observed participant ability to perform two cognitive tasks (counting backwards and or counting forwards) while walking, in a group of older adults with frontal lobe dysfunction. Adults suffering from moderate to severe frontal lobe dysfunction displayed significantly increased stride time variability when walking while performing a mental arithmetic task. This finding was exaggerated in those walking while counting backwards. The researchers concluded that the interference in their study resulted from central overload as two different processes (motoric and cognitive) competed for attention. Furthermore, they stated that the inability to appropriately allocate attention between tasks may have been a result of executive dysfunction due to frontal lobe impairment.

Springer et al. (2006) examined the effects of executive function on dual-task

performance on gait variability in healthy older adults, healthy young adults, and idiopathic elderly fallers. Participants were observed under four conditions: (1) baseline; (2) walking while performing a simple task (listening to text played on headphones while walking, followed by ten multiple choice questions pertaining to the text); (3) walking while performing a complex task (identical to the simple task with the exception of phoneme monitoring, wherein participants had to count how many times two pre-specified words appeared in the text); and (4) walking while performing an arithmetic task in which participants were asked to serially subtract seven from five hundred, aloud while walking. The gait parameters measured included gait velocity, swing time, and swing time variability. Contrary to previous findings (Beauchet et al., 2003; Dubost et al., 2006; Hollman et al., 2007; Lindenberger et al., 2000), the results demonstrated no support for an age-related increase in dual-task interference on gait variability, as gait parameters under dual-task conditions were similar for both young adults and elderly non-fallers. Older adults with a history of falling did, however, show greater gait impairment under dual-task conditions when compared to the other two participant groups, a finding that confirms previous research in this domain (Condron & Hill, 2002; Hausdorff et al., 1997; Toulotte et al., 2006). Based on these results, Springer et al. (2006) suggested that a decline in executive function may combine with problems of gait stability, which causes participants to have difficulty allocating appropriate attentional resources to balance and gait. Thus, Springer et al. (2006) concluded that executive function changes may play a causal role in falls.

To date, research on the effects of cognitive functioning that falls outside the scope of executive function is limited within the dual-task interference literature. Holtzer

et al. (2007) conducted a cross-sectional study to examine the effects that verbal IQ, cognitive speed, executive function, and memory had on an individual's propensity for falling within a sample of older adults with a history of falling. Results indicated that executive function and cognitive speed were most strongly related to falls among healthy, community-dwelling older adults. Though the results of this study implicate the role of executive function, it was not conducted under dual-task conditions.

1.9 Gait is Dynamic Posture

Gait and posture have long been described as distinct phenomena; however, research since has suggested that this is an illusory distinction. Shkuratova, Morris, and Huxham (2004) propose that motor control and postural control are inextricably linked, as all motor tasks demand ongoing postural alterations, in order to maintain successful execution of gait. Further, Grasso, Zago, and Lacquanti (2000) suggest that the integration between the motor functions of gait and posture is grounded in shared processes. For example, the forward progression involved in locomotion is largely reliant on postural adaptability to possible destabilizing factors (e.g. uneven terrain).

1.10 No Age Related Decline in Dual-Task Performance

As mentioned, Springer et al. (2006) found no significant age-related differences in dual- task performance when comparing healthy older to healthy young adults, suggesting that gait parameters of healthy older adults are not significantly impaired when simultaneously performing a secondary task. This finding was supported by Schrodt et al. (2004), who examined the effect of a cognitive secondary task on fast walking while stepping over an obstacle, in a group of community-dwelling older adults. In this study, participants were required to perform a "1-back task" in which participants

listened to auditorily-presented numbers randomly generated from one to nine and responded to each number by repeating the previously presented number (1-back). No significant changes in gait parameters were found under the dual-task condition. The researchers concluded that although community dwelling older adults may experience interference during dual-task performance, they are sufficiently able to allocate appropriate attention to gait maintenance without experiencing the gait variability that may lead to increased risk for falling.

In summary, there is increasing evidence to suggest that gait parameters are impaired by dual-task interference, in healthy older adults (Beauchet et al., 2003; Condron & Hill, 2002; Dubost et al., 2006; Hollman et al., 2007). Despite consistent findings that dual-task performance interferes with gait, however, there is less agreement on the factors thought to cause this interference. Various studies have reported that effects are exaggerated during the performance of visuospatial tasks (Maylor & Wing, 1996; Sparrow et al., 2002), while others have found that changes are predominantly influenced by articulation during the performance of verbal tasks (Dault, Yardley, & Frank, 2003; Plummer-D'Amato et al., 2008; Yardley, Gardner, Leadbetter, & Lavie, 1999). In addition, other studies show dual-task interference to be predominantly caused by task complexity (Bloem et al., 2001; Pellecchia, 2003). This underscores the importance of utilizing carefully selected tasks that produce cognitive interference, while allowing symmetrical manipulation of other contributing factors.

1.11 The Role of Articulation in the Dual-task Paradigm

One such contributing factor that has emerged recently as an important area of research within the area of dual-task interference, concerns the role of articulation as a

potential factor in dual-task interference (Dault et al., 2003; Plummer-D'Amato et al., 2008; Yardley et al., 1999). As mentioned, impairment of gait parameters is typically attributed to interference arising from simultaneous task performance. Given that most of the cognitive secondary tasks that have been employed previously involve a speech component (Beauchet, Dubost, Herrmann, & Kressig, 2005; Dubost et al., 2006; Lundin-Olsson et al., 1997), it is possible that articulatory mechanisms might be a contributing factor in dual-task interference.

Yardley et al. (1999) suggested that the respiratory patterns involved in speech may have a destabilizing effect on postural control. To test this, postural sway was evaluated in healthy volunteers under four conditions: (1) counting backwards by multiples of seven aloud; (2) counting backwards by multiples of seven silently; (3) repeating a random number aloud; and (4) performing no concurrent mental task. The findings indicated that the effects of articulation as opposed to mental activity increased postural sway, as silent counting had no effect on balance, while counting aloud (attention and articulation) and repeating a number aloud (articulation) increased sway to the same extent. The researchers concluded that in order to effectively observe the effect of a concurrent cognitive task on postural control, articulation must be eliminated, or at least systematically controlled.

Dault et al. (2003) attempted to replicate and extend the research of Yardley et al. (1999) by looking at an other dimensions concerning postural sway. A group of healthy young participants were analyzed under three separate conditions: (1) seated; (2) standing on a stable force platform; and (3) standing on an unstable force platform. While standing on the force platform, each participant was to perform a series of secondary tasks

involving silence or a verbal response. The 'silent task' involved having participants standing quietly while listening to pre-recorded letters that spelled out a nonsense phrase. At the end of each trial, participants were asked to articulate the phrase they had memorized. This task was manufactured to maximize attentional load while eliminating articulation. Conversely, a 'combination task' was administered which was the same as the abovementioned task, but required participants to repeat each letter after being heard. This design allowed for the simultaneous manipulation of both attentional load and articulation. An 'articulation task' was administered which consisted of repeating each letter aloud without having to actually form the word. This task enabled for articulation while minimizing cognitive complexity. Finally, a 'motoric task' which required participants to bite on a plastic tube, (opening and closing jaw) was given to allow for the examination of motor influence while minimizing attentional load. The findings indicated that both the 'articulation' and 'combination' task (both involving articulation) promoted an increase in postural sway path (frequency of sway). This result is consistent with the findings of Yardley et al. (1999) in that the respiratory patterns prompted by articulation may have led to an exaggeration of sway.

Though the aforementioned 'articulatory' findings are posture-specific, it is imperative to note that gait can be recognized as dynamic postural control, as mentioned earlier; thus, their generalization to gait processes is justifiable. To the best of our knowledge, however, the investigation of articulation as it affects gait has been limited to the work of Plummer-D'Amato et al. (2008). These researchers examined the interaction between three separate cognitive tasks and gait, in post-stroke patients: (1) a working memory task in which participants heard a sequence of letters and answered 'yes' or 'no'

as to whether the letter was a repeat of the one preceding (n-back task); (2) a visual-spatial task (auditory clock task) in which participants heard a time (e.g. two-oh-seven) and responded 'yes' or 'no' as to whether both clock hands fell within a specified portion of a clock; and (3) a naturalistic speech task in which participants were given a series of prompt questions in which they were to respond to during the gait task. It is important to note that both the working memory and the visual spatial task did not control for articulation, as they both required verbal responses. It was found that the naturalistic speech task produced a more substantive decrease in gait velocity than did both the memory and visual-spatial task. Moreover, it was postulated that articulatory-induced gait interference may be due either to the respiratory or the cognitive demands of the communicative task.

1.12 The Present Investigation

Three related studies are presented within this thesis. In the first study, cognitive complexity and articulation were manipulated within the same cognitive task, to determine the extent to which these task factors impacted on the magnitude of dual-task interference. By symmetrically manipulating both of these factors within a single task, it was hoped that their relative and independent contribution could be better understood. Based on previous research (Dault et al., 2003; Yardley et al., 1999), it was hypothesised that 'articulation' within a secondary task, would be sufficiently demanding to produce interference effects above those produced by the cognitive demands of the task.

In the second study, the magnitude of interference resulting from a verbal secondary task was compared with the interference that resulted from a visual-spatial secondary task. A number of secondary tasks have been employed within the dual-task

literature, and it remains unclear as to whether different tasks have differential effects on gait parameters. It was hypothesized that two different working memory tasks, each designed to tax a different component of Baddeley's (1984) working memory model, would have different effects on continuous gait. These task differences were intended to allow for an evaluation and comparison of the two primary theories of dual-task interference: the capacity/resource sharing model, and the structural model of interference.

In the third study, participant age was employed as a predictor of dual-task interference, through the use of two participant populations: healthy young adults (21.41-29.71 yrs), and healthy older adults.(59.11-81.09 yrs) Based on previous research (e.g. Lindenberger et al., 2000; Hollman et al., 2007), it was hypothesised that there would be an explicit age-related decline in dual-task performance; thus, it was expected that healthy older adults would demonstrate greater gait impairment as compared to healthy young adults while dual-tasking.

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Chapter 2: DUAL-TASK PERFORMANCE IN A HEALTHY YOUNG ADULT POPULATION: RESULTS FROM A SYMMETRIC MANIPULATION OF TASK COMPLEXITY AND ARTICULATION[1]

Traditionally, gait has been viewed as an entirely automatic or reflexive process, controlled by subcortical mechanisms (Snijders, Verstappen, Munneke, & Bloem, 2007), a conception which implicitly assumes an absence of higher-level processing. Increasing evidence, however, suggests a cortical component in combination with sensorimotor processes (Beauchet et al., 2003; Yogev-Seligmann, Hausdorff, & Giladi, 2008). Specifically, an increased role for attentional processes has been identified, as researchers have begun to recognize that gait is an attention demanding-task (Yogev-Seligmann et al., 2008). The 'dual-task paradigm' has been utilized by researchers to investigate this interaction between attention and gait.

Concurrent task performance, or "doing two things at once", is a common part of our daily lives. The ability to sustain locomotion, while performing simultaneous cognitive, verbal, or motor tasks is presumably beneficial in a multitude of ways (e.g. walking while talking), and the 'dual-task paradigm', wherein participants perform two simultaneous tasks, has been used by researchers to examine the attentional demands of gait. This design effectively examines the impact of secondary task performance (e.g. talking) on the concurrent performance of a primary task (e.g. walking) (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001).

If continuous gait demands attention, and the attentional capacity of any individual is limited, then any division of attentional resources may result in interference,

[1] A version of this chapter has been published. (Armieri, A., Holmes, J.D., Spaulding, S. J., Jenkins, M.E., & Johnson, A.M. (2009). Dual-task performance in a healthy young adult population: Results from a symmetric manipulation of task complexity and articulation. *Gait & Posture, 29*(2), 346-348.)

particularly when the capacity limits of the system are exceeded. 'Dual-task interference' can be defined as a decline in performance on one or both tasks (O'Shea, Morris, & Iansek, 2002). Furthermore, this paradigm posits that the more demanding the primary motor task, the fewer resources available to be allocated to secondary task performance. Secondary task performance may, therefore, be taken as a direct quantification of residual attentional (Huang & Mercer, 2001; Woollacott & Shumway-Cook, 2002).

Various studies have purported that 'task complexity' is the predominant cause of dual-task interference (Huang & Mercer, 2001; Yogev-Seligmann et al., 2008). Recent research has suggested, however, that articulation (i.e., the act of speaking aloud) is a significant predictor of both posture (Dault, Yardley, & Frank, 2003; Yardley, Gardner, Leadbetter, & Lavie, 1999) and gait (Plummer-D'Amato et al., 2008). To our knowledge, however, there has been no research that has demonstrated the effect of dual-task interference on continuous gait within a dual-tasking paradigm that involves the symmetrical manipulation of articulation and cognitive complexity. In other words, is there an additive effect of articulation, over and above the effect of cognitive load? The primary purpose of the present study, therefore, is to examine the respective impacts of complexity and articulation on continuous gait within a single working memory task.

Methods

Participants

Fourteen healthy young adults between the ages of 18 and 30 (11 women; M=22.14, SD=2.28) were recruited at the University of Western Ontario. Subjects were excluded from the study if they suffered from cognitive impairments, neurological disease, and/or physical limitations to normal ambulation.

Instrumentation

Spatial-temporal properties of gait were quantified using the GAITRite® electronic walkway system (software version 3.8), an instrumented carpet that is approximately 20 feet long, and contains 13,824 pressure sensors along its span. Six variables were assessed using the proprietary GAITRite software: velocity, step time, swing time, stance time, step length, and base of support.

Procedure

Following determination of eligibility based upon inclusion criteria, participants were required to read a letter of information describing the study procedure, and sign a consent form indicating their willingness to participate in the research. Participants were then asked to provide their birth date for the calculation of age.

The cognitive secondary task consisted of a digit span task, in which participants were presented with a digit sequence, asked to memorize it, and then asked to repeat the digits at the conclusion of the motor task. The motor task required participants to walk twenty feet on the instrumented carpet. Cognitive complexity of the secondary task was manipulated using three blocks of random, non-repeating sequences of digits (three, five, and seven digits in length). Articulation was manipulated in two blocks: either by having participants continuously rehearse the digits aloud, or continuously rehearse the digits silently during the performance of the gait task. Cognitive complexity was completely crossed with articulation, and the experimental blocks were randomized to counterbalance for carry-over effects. Participants completed three trials within each experimental block.

Participants were not specifically instructed to prioritize one task over the other, but were asked to perform both tasks to the best of their ability

Statistical analysis

All dependent variables were analyzed within a 3 x 2 multivariate analysis of variance using complexity (low complexity, medium complexity, and high complexity) and articulation (no articulation and articulation) as within-subject factors. Significant multivariate effects were further evaluated using univariate analyses, evaluated against an unadjusted alpha, as this analytic strategy has been shown to be effective in the control of multiple comparison bias (Hummel & Sligo, 1971). All univariate analyses were evaluated using the Greenhouse-Geisser epsilon correction for lack of sphericity. Significant interaction terms were parsed by evaluating the effect sizes of the simple main effects, and significant main effects were evaluated utilizing repeated contrasts. These effect size estimates were presented as partial eta squares, which may be interpreted as the percentage of variance accounted for by an effect after controlling for all other effects in the model.

Results

Descriptives for all dependent variables are presented in Table 2.1. The multivariate effect of the interaction between complexity and articulation was statistically significant [F (12, 44) = 3.19, $p < 0.002$]. Similarly, significant multivariate effects were demonstrated for the main effects of articulation [F (6, 8) = 12.66, $p < 0.001$] and complexity [F (12, 44) = 3.77, $p < 0.001$]. Univariate analyses are presented in Table 2.2. Four of the six parameters (velocity, step time, swing time, and stance time) were significantly predicted by the interaction between cognitive complexity and articulation. The mean plots for these univariate effects are presented in Figures 2.1-2.4. This significant interaction term was further parsed by evaluating the effect size of complexity

effects of complexity are most pronounced under conditions of articulation. Step length demonstrated a significant main effect of both articulation and complexity. Base of support demonstrated no significant univariate effects. Post hoc examination of the main effect of complexity revealed a statistically significant difference between medium complexity and high complexity, and between low complexity (three digits) and high complexity (seven digits), but no statistically significant difference between low complexity and medium complexity (five digits). Post hoc analysis of the main effect of articulation revealed significantly lower scores when asked to repeat the digit sequence aloud.

Table 2.1
Means (and Standard Deviations) Across All Conditions

	LC/NA	LC/A	MC/NA	MC/A	HC/NA	HC/A
Velocity (cm/sec)	143.99 (10.72)	139.21 (10.85)	145.36 (11.01)	138.09 (11.96)	140.44 (11.06)	128.31 (13.52)
Step Time (sec)	0.50 (0.03)	0.52 (0.03)	0.50 (0.03)	0.52 (0.03)	0.51 (0.04)	0.55 (0.04)
Swing Time (sec)	0.39 (0.03)	0.40 (0.02)	0.39 (0.02)	0.40 (0.03)	0.40 (0.03)	0.43 (0.04)
Stance Time (sec)	0.62 (0.04)	0.63 (0.04)	0.61 (0.04)	0.63 (0.04)	0.62 (0.04)	0.68 (0.05)
Step Length (cm)	72.54 (6.44)	71.99 (6.30)	72.75 (6.03)	71.51 (5.98)	71.69 (6.00)	70.54 (6.13)
Base of Support (cm)	10.04 (3.17)	9.75 (4.29)	10.56 (2.95)	10.33 (3.25)	10.07 (3.21)	10.17 (3.24)

Note. LC=low complexity; MC=medium complexity; HC=high complexity; NA=no articulation; A=articulation.

Table 2.2
Univariate Analyses (Main effects and Interactions) of Complexity and Articulation

Interaction (complexity by articulation)

	F	*d.f.*	η^2	*p*
Velocity	15.19	1.90, 24.67	0.539	0.001
Step Time	23.45	1.61, 20.92	0.643	0.001
Swing Time	10.20	1.61, 20.91	0.440	0.001
Stance Time	29.49	1.58, 20.53	0.694	0.001

Main effect of complexity

	F	*d.f.*	η^2	*p*
Step length	4.21	1.46,18.94	0.245	0.041
Base of support	2.26	1.22, 15.84	0.148	0.150

Main effect of articulation

	F	*d.f.*	η^2	*P*
Step length	10.78	1, 13	0.453	0.006
Base of support	0.47	1, 13	0.035	0.505

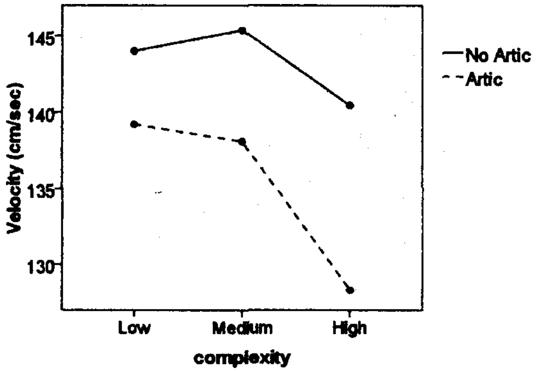

Fig. 2.1: The Effect of Complexity on Gait Velocity

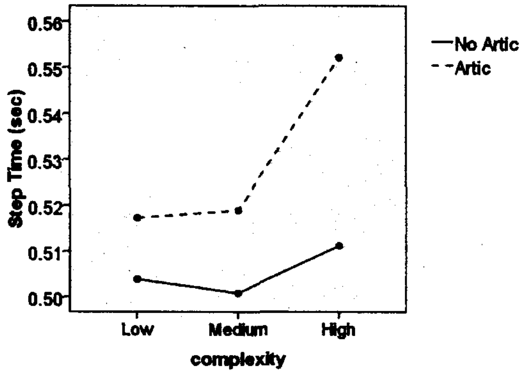

Fig. 2.2: The Effect of Complexity on Step Time

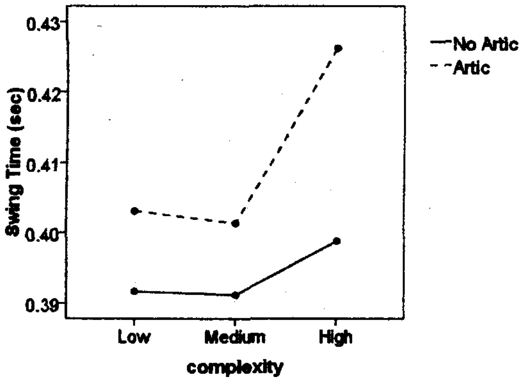

Fig. 2.3: The Effect of Complexity on Swing Time

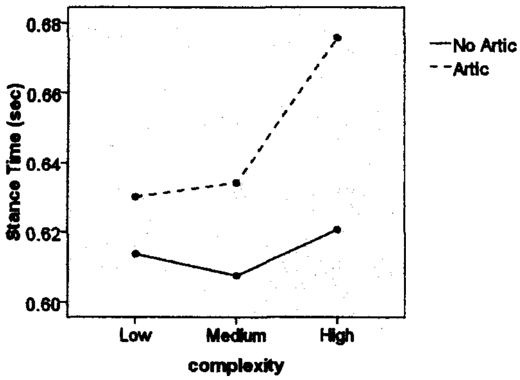

Fig. 2.4: The Effect of Complexity on Stance Time

Discussion

These results replicate earlier findings which report a significant effect of both task complexity and articulation on spatial-temporal parameters of gait (Dault et al., 2003; Plummer-D'Amato et al., 2008; Yardley et al., 1999). Moreover, these data suggest that parameters of gait are more profoundly affected by task complexity when articulation is involved. In other words, individuals are at greatest risk for fall when performing a relatively complex secondary task which also involves verbalization.

Given that most cognitive secondary tasks, within the published dual-task literature, involve some degree of articulation, this is an important demonstration of a potential experimental confound. Although the present paradigm does not allow for an evaluation of the etiology surrounding the effect, there are several potential explanations for it. Articulation may increase respiratory demands, which in turn produces a destabilizing effect on gait. Alternatively, the motor demands inherent in speech production may interfere with the motor demands of continuous gait (Dault et al., 2003; Pellecchia, 2003; Yardley et al., 1999). Moreover, an oral cognitive task may be more cognitively demanding than a non-oral cognitive task. Yet another alternative explanation may be found within the 'resource sharing model'. The marked effect of articulation on gait under dual-task conditions may simply be due to the overtaxing of attentional resources. By incorporating a verbal component, the conventional dual-task paradigm is arguably transformed into a 'triple-task paradigm', and this added load may compete for attentional resources.

Future research should strive to disentangle the mechanism(s) of gait disruption inherent in tasks that require articulation. As mentioned, efforts should focus on

discerning the relative contribution of both motoric and cognitive aspects of articulation. As well, it would be useful to investigate the effect of visual-spatial cognitive tasks in addition to verbal cognitive tasks. Some researchers posit that the performance of visual-spatial tasks alongside gait will exacerbate interference, by way of 'structural interference'. Structural interference, perhaps better known as 'bottle-neck theory', posits that the performance of gait alongside a visual-spatial task will produce dual cognitive load in the visual pathway, causing congestion akin to a bottleneck (Bloem et al., 2001)

Future replication of this paradigm should also make an attempt to adjust for individual cognitive ability, such as intelligent quotient, cognitive speed, or executive function. Though a range in digit span abilities can be expected, the present study utilized a relatively homogeneous graduate student sample; thus, substantive variance in cognitive ability was not expected to be an issue. Finally, future research may choose to quantify secondary task performance in order to effectively examine task prioritization – that is, some individuals may adopt a 'posture-first' strategy, while others choose to adopt a less safe 'posture-second' strategy.

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Chapter 3: DUAL-TASK PERFORMANCE IN A HEALTHY YOUNG ADULT POPULATION: THE EFFECT OF TASK TYPE

Dual-task methodology is commonly used to examine the role of cognition in motor performance (Beauchet et al., 2003; Hollman, Kovash, Kubik, & Linbo, 2007). Within this framework, individuals are asked to perform two tasks simultaneously: a primary task and a secondary task (Huang & Mercer, 2001). The primary task, typically gait and/or postural maintenance, is assumed to require some degree of attentional control; thus, when a concurrent secondary task is performed, attention is presumably divided (Melzer, Benjuya, & Kaplanski, 2001; O'Shea, Morris, & Iansek, 2002). Often, this division of resources results in 'interference', especially when capacity limits are exceeded. Dual-task interference can be conceptualized as a decline in performance on one or both tasks (Woollacott & Shumway-Cook, 2002). Any deviation from baseline gait and/or postural maintenance under dual-task conditions is viewed as a reflection of the attentional-demands inherent in the secondary task (Huang & Mercer, 2001).

Thus far, the 'dual-task paradigm' has been tested with a variety of different secondary tasks. Still, little is known as to whether the type of secondary task is an important factor in evaluating gait interference (Beauchet, Dubost, Gonthier, & Kressig, 2005). While some studies purport that different tasks will produce disparate effects, (Beauchet et al., 2005; Plummer-D'Amato et al., 2008), others suggest that any such differences are more a reflection of differences in task complexity, as opposed to fundamental differences in the cognitive processes demanded by the task (Bloem, Steijns, & Smits-Engelsman, 2003). Nevertheless, several theories have been developed to accommodate the incongruent effects varying task-types produce on continuous gait (Huang & Mercer, 2001). In this regard, as noted by Klingberg (1998), the

neurophysiological basis of deterioration in dual-task performance remains largely unknown.

Currently, there are several plausible models of dual-task interference demonstrating evidential support. Within the 'capacity' or 'resource-sharing model' (Pellecchia, 2003), primary task performance is dependent upon the 'complexity' of the secondary task. In this model, interference purportedly results from a 'central overload' when two tasks vie for limited attentional resources and central processing capacity is exceeded (Huang & Mercer, 2001). The 'structural interference model' (also known as 'bottle-neck' theory), on the other hand, posits that when two concurrent tasks access similar cognitive substrates, interference will occur (Allali et al., 2007; Huang & Mercer, 2001; Maylor & Wing, 1996; O'Shea et al., 2002). More specifically, since gait demands visual-spatial processing (Marigold & Patla, 2007), this model would propose that concurrent performance of a secondary visually-oriented task will trigger greater interference than a non-visually-oriented task. Finally, in direct opposition to the tenets of the 'structural interference model', the 'cross-talk model' suggests that task similarity *reduces* dual-task interference, as the use of similar pathways frees up other attentional resources (O'Shea et al., 2002).

The present study builds upon a paradigm described in detail by Armieri, Holmes, Spaulding, Jenkins, and Johnson (2009), wherein dual-task performance was evaluated utilizing a secondary cognitive digit-span task. Differences between 'verbal interference' and 'visuospatial' interference were assessed by introducing a visual-spatial secondary task that required individuals to mentally track the movement of a star, within three connected boxes. To the extent that both of these tasks represent equally complex

cognitive loads, the difference in task type will provide insight into the primary model of interference operating within this dual-task procedure. Specifically, if the visuospatial task produces greater interference than the verbal task, it suggests particular importance for the 'bottleneck theory' of interference (Lindenberger, Marsiske, & Baltes, 2000; Maylor & Wing, 1996; O'Shea et al., 2002; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002). If, however, the visuospatial task produces less interference than the verbal task, then this provides evidence for the primacy of the cross-talk model.

Methods

Participants

Twenty healthy young adults between the ages of 18 and 30 (10 women; *M*=24.43, *SD*=2.10) were recruited at the University of Western Ontario. Subjects were excluded from the study if they suffered from cognitive impairments, neurological disease, or physical gait restrictions.

Instrumentation

Spatial-temporal properties of gait were quantified using the GAITRite® electronic walkway system (software version 3.8), an instrumented carpet that is approximately 20 feet long, and contains 13,824 pressure sensors along its span. Five variables were assessed using the proprietary GAITRite® software: velocity, step time, swing time, stance time, and step length.

Procedure

For the visuospatial secondary task, an adaptation of the 'Star Movement Task', (St George, Fitzpatrick, Rogers, & Lord, 2007) was employed. This task involved having participants envision a rectangle divided into three boxes, labelled (from left to right) as

"A", "B", and "C". Participants were then told to imagine a star within the middle box (i.e. box B) and were subsequently given a set of directional movements in which the star could make either left (L) or right (R). Participants were then asked to report on which box the star resided based on the instructed movements. Before performing the task as a cognitive secondary task (i.e., while walking), all participants were given three practice trials to complete while seated. During these practice trials, participants were shown the diagram that they were to envision throughout their walk along the instrumented carpet. This diagram is presented in Figure 3.1.

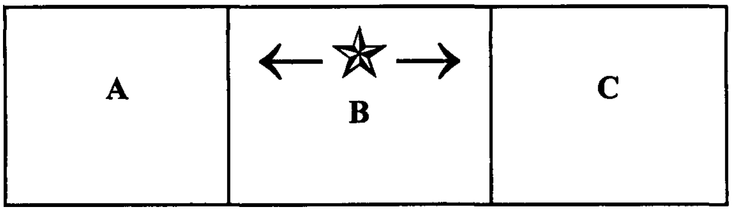

Fig. 3.1: The three boxes within the 'star movement task'.

Cognitive complexity of the task was manipulated by increasing the number of directional movements. The administration of each set of directions (baseline, three, four, and five) was scaled to coincide with the duration of a single walk down the GAITRite (estimated at 7 seconds, based on pilot data collected at the University of Western Ontario). Thus, in the "low complexity trials", participants were given three directions (e.g. L-R-R) at a rate of 1 direction every 2.33 seconds, for "medium complexity trials" participants were given four directions (e.g. R-L-L-R) at a rate of 1 direction every 1.75 seconds, and for the "high complexity trials", participants were given five directions (e.g. L-R-R-L-L) at a rate of 1 direction every 1.40 seconds. Though speed of administration increased with successive levels of complexity, it was scaled to a single walk – thus,

complexity was manipulated by increasing the number of bits of information, not the length of the task. Directions were administered to participants while walking, to ensure that the task manipulated the visuospatial sketchpad (and did not become a very simple working memory task). All directional movements were pre-recorded using a metronomic device, and thereafter issued to participants via computer speakers.

The other cognitive secondary task, a digit span task, was identical to non-articulatory conditions of the task used by Armieri et al. (2009). Participants were presented with a digit sequence, were asked to mentally rehearse it throughout the time spent walking along the instrumented carpet, and were then asked to repeat the digits at the conclusion of the motor task. Participants were instructed to perform both tasks to the best of their ability. The cognitive complexity of this secondary task was manipulated using four blocks of random, non-repeating sequences of digits (baseline, three, five, and seven digits in length).

Both cognitive secondary tasks were performed concurrently with a walk of approximately twenty feet along the instrumented carpet. Experimental blocks were randomized within each cognitive task, to counterbalance for carryover effects, and the order of the cognitive tasks was similarly counterbalanced. Participants completed three trials within each experimental block.

Statistical Analysis

All dependent variables were analyzed within a 4 x 2 repeated measures multivariate analysis of variance using complexity (baseline, low complexity, medium complexity, high complexity) and task (digit span and star movement) as within-subject factors. The same baseline was used within each task. Significant multivariate effects

were further evaluated using univariate analyses, and were compared against an unadjusted alpha, as this analytic strategy has been shown to be effective in the control of multiple comparison bias (Hummel & Sligo, 1971). All univariate analyses were evaluated using the Greenhouse-Geisser epsilon correction for lack of sphericity. Significant interaction terms were parsed by evaluating the effect sizes of the simple main effects, and significant main effects were evaluated utilizing repeated contrasts. These effect size estimates were presented as partial eta squares, which may be interpreted as the percentage of variance accounted for by an effect after controlling for all other effects in the model.

Results

Descriptives for all dependent variables are presented in Table 3.1. The multivariate effect of the interaction between 'complexity' and 'task' was significant [F (15, 165) = 3.32, p<.001]. Likewise, a significant multivariate effect was demonstrated for the main effect of complexity [F (15, 165) =2.70, p<.001) and the main effect of task [F (5, 15) = 6.30, p< .002].

Table 3.1
Means (and Standard Deviations) Across All Task Conditions

		Digit Span			Star Movement		
	Base	3 digits	5 digits	7 digits	3 moves	4 moves	5 moves
Velocity (cm/s)	132.45 (12.53)	132.25 (15.02)	130.12 (13.68)	124.26 (17.59)	122.44 (13.33)	125.18 (15.03)	126.08 (13.52)
Step time (sec)	0.52 (0.04)	0.52 (0.04)	0.52 (0.04)	0.54 (0.05)	0.53 (0.04)	0.53 (0.04)	0.52 (0.03)
Swing time (sec)	0.40 (0.03)	0.40 (0.02)	0.41 (0.02)	0.42 (0.03)	0.41 (0.03)	0.40 (0.03)	0.40 (0.02)
Stance time (sec)	0.64 (0.05)	0.64 (0.05)	0.64 (0.05)	0.66 (0.07)	0.65 (0.06)	0.65 (0.06)	0.64 (0.05)
Step length (cm)	68.62 (5.12)	68.38 (5.80)	67.59 (5.47)	66.53 (6.11)	64.56 (5.69)	65.42 (5.68)	65.50 (6.15)

Univariate analyses are presented in Table 3.2. All five parameters (velocity, step time, swing time, stance time, and step length) were significantly predicted by the interaction between cognitive complexity and task type, and so the univariate main effects (of complexity and task type) are not presented. The mean plots for these univariate effects are presented in Figures 3.2-3.6. The interaction term was parsed by examining the effect size of cognitive complexity under both the 'digit span task' and the 'star movement task'. These results, presented in Table 3.3, demonstrate that all parameters except 'step length' are significantly more affected by complexity during performance of the digit span task.

Table 3.2
Univariate Analysis of the Interaction Between Complexity and Task Type

	F	*d.f.*	η^2	*p*
Velocity	7.64	2.47, 46.86	0.287	0.001
Step time	5.44	2.10, 39.96	0.223	0.007
Swing time	5.86	2.27, 43.08	0.236	0.004
Stance time	5.11	2.09, 39.80	0.212	0.010
Step length	10.36	2.57, 48.91	0.353	0.001

Table 3.3
Univariate Effects of Complexity for Each Task

	Digit Span Task			Star Movement Task		
	F	*d.f.*	η^2	*F*	*d.f.*	η^2
Velocity	8.57	2.53, 48.11	0.311	7.73	2.59, 49.24	0.289
Step time	7.37	1.59, 30.12	0.277	1.58	2.39, 45.49	0.077
Swing time	6.33	1.59, 30.26	0.250	1.02	2.14, 40.67	0.051
Stance time	6.93	1.66, 31.52	0.267	2.52	2.48, 47.18	0.117
Step length	7.68	2.85, 54.19	0.288	15.26	2.67, 50.78	0.445

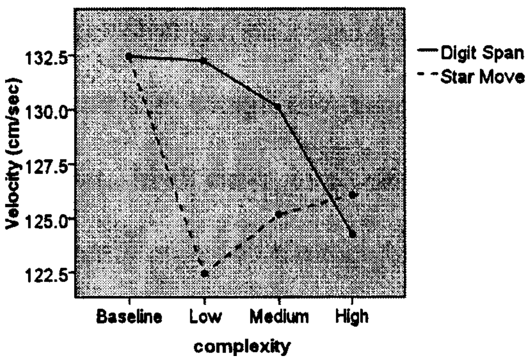

Fig. 3.2: The Effect of Complexity on Gait Velocity

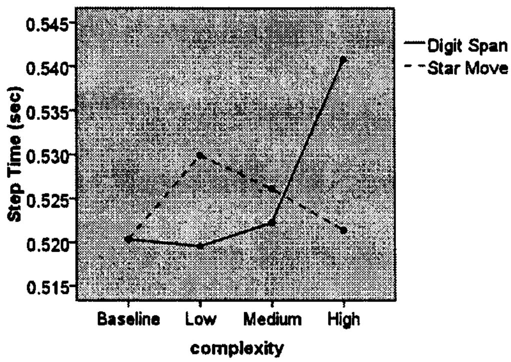

Fig. 3.3: The Effect of Complexity on Step Time

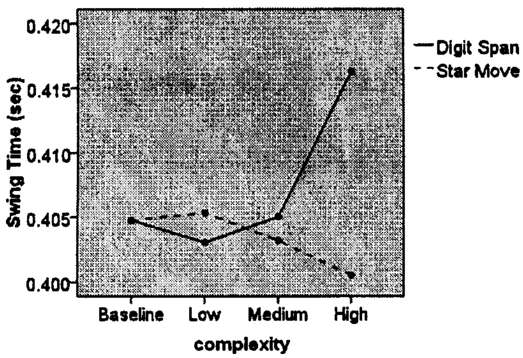

Fig. 3.4: The Effect of Complexity on Swing Time

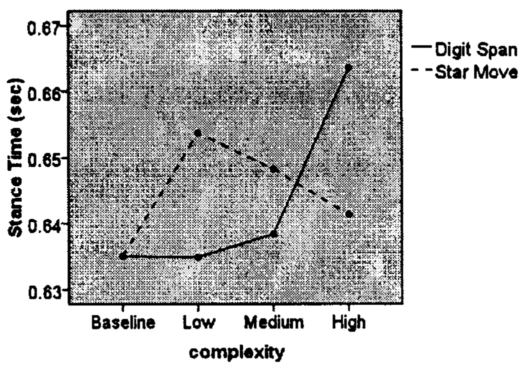

Fig. 3.5: The Effect of Complexity on Stance Time

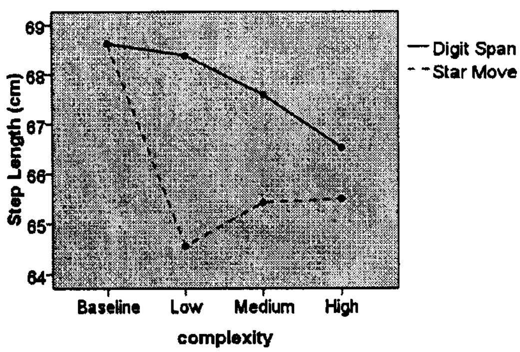

Fig. 3.6: The Effect of Complexity on Step Length

Post hoc evaluation of the simple main effect of complexity within the digit span task demonstrated a statistically significant difference between medium complexity (five digits) and high complexity (seven digits), and this finding was consistent across each parameter. In all cases, increases in the complexity of the secondary task produced significantly more interference (e.g., slower velocity, shorter step-length, etc.). Post-hoc evaluation of the simple main effect of complexity within the star movement task demonstrated a statistically significant difference between baseline (no movements) and low complexity (three movements) for velocity, stance time, and step length; but no statistically significant difference between successive levels of complexity. In the above cases, increases in the complexity of the secondary task produced significantly less interference (e.g. faster gait velocity, decreased stance time, and longer step length).

Discussion

The current results do not conform to the expectations of the structural model of interference (Allali et al., 2007; Huang & Mercer, 2001; Maylor & Wing, 1996; O'Shea et al., 2002). This model would predict a greater level of cognitive interference from the visually-intensive star-movement task, as compared with the verbally-mediated digit span task, given the primarily visual nature of the primary task. The results of this study suggest that the digit-span task produced significantly more interference within the primary gait task, as compared with the star movement task. Participants demonstrated a significant decrease in gait velocity and step length, while step time, swing time, and stance time increased. A reduction in velocity and step length, combined with a corresponding increase in stance time and swing time may be viewed as a coping mechanism for handling the attentional demands of dual-task performance (Brach, Berlin, VanSwearingen, Newman, & Studenski, 2005; Hollman et al., 2007; Kim & Brunt, 2007; Verghese et al., 2007). Moreover, an increase in step time signifies postural instability under dual-task conditions (Woollacott & Shumway-Cook, 2002). The present results suggest, therefore, that young adults are able to maintain an acceptable level of dual-task performance until the transition is made from five digits (medium complexity) to seven digits (high complexity). This suggests that there may be a 'breaking-point' at which processing capacity is exceeded.

Furthermore, although concurrent performance of the visuospatial task demonstrated significant dual-task interference at low-complexity relative to baseline, subsequent increases to the complexity of the task did not produce any additional impairment of gait parameters. Conversely, the digit span task showed an additive effect

of cognitive complexity - that is, increased bits of information (digits) within the secondary task produced increased dual-task interference.

Taken in concert, these findings indicate greater support for the 'capacity-resource sharing' model of interference, and suggest that the digit span task may require greater processing resources than the star movement task, thereby surpassing system capacity limits, and causing interference across gait parameters (Huang & Mercer, 2001).

Another possible explanation may be that increases in cognitive complexity within the visuospatial task were offset by participant use of the directional movements as external regulatory mechanisms. In other words, gait may have 'improved' (in stability and speed), as the speed of the external cues increased. This hypothesis is supported by an examination of the descriptive data in Table 1, which suggests that as complexity of the star movement task increases (three moves to five moves), velocity and step length show non-significant increases, while step time, stance time, and swing time show non-significant decreases. As these changes are indicative of greater postural and gait stability (Hollman et al., 2007; Kim & Brunt, 2007; Verghese et al., 2007), it appears that gait may actually become increasingly stable, possibly due to the effects of the external cueing mechanism. Schrodt et al. (2004) draw a similar conclusion concerning effects demonstrated during a rhythmic secondary task, proposing that this counter-intuitive effect may be mediated by either cueing or arousal due to the quick paced auditory presentation of the numbers. This effect of external rhythmic cueing has been similarly supported by research on individuals with Parkinson's disease (Lim et al., 2005).

Along similar lines, it is also possible that the interference effect from baseline to low complexity was simply due to an inability to entrain. Since the administration of movements was scaled to the length of a seven second walk, the tempo at three movements was likely an ineffectual cue (due to the fact that it would produce an uncomfortably slow or fast velocity for participants).

In conclusion, therefore, the present should be taken to be a cautious refutation of the structural theory of interference, as it still remains unclear as to the extent to which performance was mediated by external rhythmic cueing. Future amendments to this protocol should strive to control for the possibility of cueing within the star movement task. Ideally, the dimensions of the visual grid should be altered (e.g., to a 3x3 grid, a 4x4 grid, and possibly even a 5x5 grid) to increase the range of task complexity that can be manipulated, without substantively increasing the number of movements within a walk. In doing so, the number of administered movements could be held constant, thereby rendering tempo a non-issue. Additionally, a greater range of directional movements could be employed, including "left", "right", "up", and "down". Another potential confound of the current study is the fact that all instructions were presented verbally throughout the star movement task. Although this method of administration was unavoidable, it may be the case that the interference effect between baseline and low complexity was incurred simply by attending to audible stimuli. In this regard, it remains unclear whether interference was due to the visual-spatial task itself, the attentional demands inherent in listening to external audio, or both.

Despite the unintended confounding of these additional factors within the visuospatial task, these results suggest an important extension to the dual-task paradigm.

These findings should be replicated within other populations, in order to examine the potential interaction between complexity, task type, and group differences such as age (e.g., older adults versus younger adults) or disease state (e.g., individuals with Parkinson's disease versus neurotypical age-matched controls).

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Chapter 4: THE EFFECTS OF AGE ON DUAL-TASK PERFORMANCE

It is well-established that normal aging is associated with a decline in the functional mechanisms responsible for gait, such as the sensory, musculoskeletal, and neurological systems (Mbourou, Lajoie, & Teasdale, 2003). This typically results in an increase in gait instability, typified by inconsistent stepping patterns, as well as reduced postural control (Hollman, Kovash, Kubik, & Linbo, 2007), and these gait parameters may serve as markers for fall risk among older adults (Barak, Wagenaar, & Holt, 2006; Brach, Berthold, Craik, VanSwearingen, & Newman, 2001; Hollman et al., 2007). It is not usually under conditions of normal walking that healthy older adults experience heightened fall risk, but rather when performing a secondary task concurrent with gait, such as walking while talking (Beauchet et al., 2003; Lundin-Olsson, Nyberg, & Gustafson, 1997) . This process of attention-splitting, better recognized as 'dual-tasking', is a frequently employed method for evaluating the interplay between attention and gait within a scientific setting (O'Shea, Morris, & Iansek, 2002).

Although conventional conceptualizations of gait typically rely on subcortical control mechanisms, studies employing a dual-task paradigm have provided evidence for an attentional component (Beauchet et al., 2003; Lundin-Olsson et al., 1997; Woollacott & Shumway-Cook, 2002). This appears to be particularly true for older adults, as these individuals require greater attentional resources to compensate for declining functional mechanisms (Beauchet et al., 2003; Dubost et al., 2006; Hollman et al., 2007; Lindenberger, Marsiske, & Baltes, 2000). It is expected, therefore, that efficient allocation of attention under dual-task conditions would be considerably more difficult for these individuals (Hollman et al., 2007), as residual processing capacity would be

limited. Some studies have, however, suggested that age-related effects of dual-task interference are more dependent upon increased levels of pathology, rather than the normal processes of aging (Springer et al., 2006); .

The present study builds upon a paradigm described in detail by Armieri, Holmes, Spaulding, Jenkins, and Johnson (2009) wherein dual-task performance was examined utilizing a secondary cognitive digit span task. More specifically, the task properties of complexity and articulation were symmetrically manipulated to examine both their interactive and independent influence on gait processes. Armieri et al. (2009) replicated earlier findings that suggested a significant effect of articulation (Dault, Yardley, & Frank, 2003; Plummer-D'Amato et al., 2008; Yardley, Gardner, Leadbetter, & Lavie, 1999) and also demonstrated that there is a significant interaction between articulation and cognitive complexity, and suggested that the effects of cognitive complexity are greatest under conditions of articulation.

In the present study, between-group differences in dual-task performance were evaluated by comparing a sample of healthy young adults with a sample of healthy older adults. Spatial-temporal parameters of gait (including velocity, step length, step time, stance time, and swing time) were evaluated using a GAITRite instrumented carpet, in an effort to determine the extent to which primary task performance was impacted by secondary task performance. Previous findings suggesting that age has a significant impact on one's ability to effectively prioritize the concurrent demands of the primary and secondary tasks lead us to hypothesize that older adults would experience greater dual-task interference than the younger adults. Furthermore, we would predict a significant three-way interaction of group, articulation, and complexity, as the addition of

the articulation component of the task produces what is (effectively) a 'triple task' – and the increased complexity of this task is likely to have a greater effect on the older adults.

Methods

Participants

Eighteen healthy older adults between the ages of 55 and 80 (10 women; *M*=67.85, *SD*=6.43) were recruited from the Canadian Centre for Activity and Aging located in London, Ontario. All participants were capable of unassisted ambulation, had not experienced a fall in the previous six months, and were not suffering from any physical and/or neurological diagnoses that may affect normal gait. Twenty healthy young adults between the ages of 18 and 30 (10 women; *M*=24.43, *SD*=2.10) were recruited as a comparison group. Younger adults were also screened for physical or neurological deficits that might impair gait.

Instrumentation

Spatial-temporal properties of gait were quantified using the GAITRite® electronic walkway system (software version 3.8), an instrumented carpet that is approximately 20 feet long, and contains 13,824 pressure sensors along its span. Five variables were assessed using the proprietary GAITRite® software: velocity, step time, swing time, stance time, and step length.

Procedure

Following determination of eligibility based upon inclusionary criteria, participants were required to read a letter of information describing the study procedure, and sign a consent form indicating their willingness to participate in the research. Participants were then asked to provide their birth date for the calculation of age.

The cognitive secondary task consisted of a digit span task, in which participants were presented with a digit sequence, asked to memorize it, and then asked to repeat the digits at the conclusion of the motor task. The motor task required participants to walk twenty feet on the instrumented carpet. Cognitive complexity of the secondary task was manipulated using four blocks of random, non-repeating sequences of digits (baseline, three, five, and seven digits in length). Articulation was manipulated in two blocks: either by having participants continually rehearse the digits aloud, or continually rehearse the digits silently, throughout the performance of the gait task. Cognitive complexity was completely crossed with articulation, and the experimental blocks were randomized to counterbalance for carry-over effects. Participants completed three trials within each experimental block.

Participants were not specifically instructed to prioritize one task over the other, but were asked to perform both tasks to the best of their ability.

Statistical analysis

All dependent variables were analyzed within a 2 x 4 x 2 multivariate analysis of variance using age as the between subject factor (young adults and older adults) and complexity (baseline, low complexity, medium complexity, and high complexity) and articulation (no articulation and articulation) as within-subject factors. Significant multivariate effects were further evaluated using univariate analyses, evaluated against an unadjusted alpha, as this analytic strategy has been shown to be effective in the control of multiple comparison bias (Hummel & Sligo, 1971). All univariate analyses were evaluated using the Greenhouse-Geisser epsilon correction for lack of sphericity. Significant interaction terms were parsed by evaluating the effect sizes of the simple

main effects, and significant main effects were evaluated utilizing repeated contrasts. These effect size estimates were presented as partial eta squares, which may be interpreted as the percentage of variance accounted for by an effect after controlling for all other effects in the model.

Results

Descriptives for all dependent variables, within each experimental block, are presented in Table 4.1 and Table 4.2. The multivariate effect for the interaction between complexity and articulation was significant [F (15, 318) = 3.00, p<.001]. Further, the multivariate main effects for complexity [F (15,318) = 4.80, p<.001], articulation [F (5, 32) =14.47, p<.001], and age group [F (15, 32) = 12.98, p<.001] were significant. The three-way multivariate interaction between complexity, articulation, and group was, however, non-significant [F (15, 318) = 1.05].

Univariate analyses of the interaction term (complexity x articulation) are presented in Table 4.3. The univariate interaction was significant for all five parameters (velocity, step time, swing time, stance time, and step length). The mean plots for these univariate effects are displayed in Figures 4.1- 4.5. These significant interactions were further parsed by evaluating the effect size of the complexity under each level of articulation (articulation and no articulation). These results, presented in Table 4.4, demonstrate that the effect of complexity is most pronounced under conditions of articulation. Post-hoc evaluation of the main effect of complexity collapsed across age yields a significant difference between each increasing level of complexity. Post hoc analysis of the main effect of articulation revealed significantly lower scores when asked to repeat the digit sequence aloud.

Evaluation of the between subject factor at the univariate level demonstrated no significant difference on any of the parameters between the groups.

Table 4.1

Means (and Standard Deviations) Across Younger Adults

	Baseline	LC/NA	LC/A	MC/NA	MC/A	HC/NA	HC/A
Velocity (cm/sec)	132.45 (12.53)	132.25 (15.02)	127.00 (14.72)	130.12 (13.68)	125.31 (15.92)	124.26 (17.59)	119.83 (16.37)
Step Time (sec)	0.52 (0.04)	0.52 (0.04)	0.53 (0.05)	0.52 (0.04)	0.53 (0.05)	0.54 (0.05)	0.55 (0.06)
Swing Time (sec)	0.40 (0.03)	0.40 (0.02)	0.41 (0.03)	0.41 (0.02)	0.41 (0.03)	0.42 (0.03)	0.43 (0.04)
Stance Time (sec)	0.64 (0.05)	0.64 (0.05)	0.65 (0.06)	0.64 (0.05)	0.66 (0.06)	0.66 (0.07)	0.68 (0.08)
Step Length (cm)	68.62 (5.12)	68.38 (5.80)	66.84 (5.32)	67.59 (5.47)	66.51 (5.82)	66.53 (6.11)	65.80 (5.51)

Note. LC=low complexity; MC=medium complexity; HC=high complexity; NA=no articulation; A=articulation.

Table 4.2

Means (and Standard Deviations) Across Older Adults

	Baseline	LC/NA	LC/A	MC/NA	MC/A	HC/NA	HC/A
Velocity (cm/sec)	137.28 (14.32)	138.24 (18.73)	130.46 (18.11)	133.79 (21.77)	128.72 (18.34)	130.36 (21.73)	116.78 (22.25)
Step Time (sec)	0.52 (0.04)	0.52 (0.05)	0.54 (0.06)	0.53 (0.06)	0.54 (0.06)	0.54 (0.06)	0.58 (0.08)
Swing Time (sec)	0.39 (0.03)	0.39 (0.03)	0.39 (0.03)	0.39 (0.04)	0.40 (0.04)	0.40 (0.04)	0.42 (0.05)
Stance Time (sec)	0.65 (0.06)	0.65 (0.08)	0.68 (0.08)	0.67 (0.09)	0.69 (0.08)	0.68 (0.09)	(0.74) (0.12)
Step Length (cm)	71.24 (5.94)	71.25 (5.80)	69.39 (5.17)	69.92 (6.12)	69.17 (5.49)	69.15 (5.88)	66.75 (7.01)

Note. LC=low complexity; MC=medium complexity; HC=high complexity; NA=no articulation; A=articulation.

Table 4.3

Univariate Analysis (Interaction Effect) of Complexity by Articulation

	F	*d.f.*	η2	*p*
Velocity	8.53	1.77, 63.88	0.192	0.001
Step time	8.41	1.53, 55.00	0.189	0.002
Swing time	7.01	1.71, 61.54	0.163	0.003
Stance time	8.86	1.47, 53.04	0.197	0.001
Step length	4.67	2.22, 79.83	0.115	0.010

Table 4.4

Univariate Effects of Complexity under Conditions of Articulation and No Articulation

	No Articulation			Articulation		
	F	*d.f.*	η2	*F*	*d.f.*	η2
Velocity	10.01	2.46, 88.53	0.218	33.01	*2.29, 82.53*	0.478
Step time	9.51	2.10, 75.44	0.209	26.58	2.03, 73.09	0.425
Swing time	8.02	1.96, 70.63	0.182	21.54	2.21, 79.58	0.374
Stance time	9.42	2.18, 78.57	0.207	26.95	1.96, 70.68	0.428
Step length	11.69	2.55, 91.70	0.245	19.88	2.19, 78.81	0.356

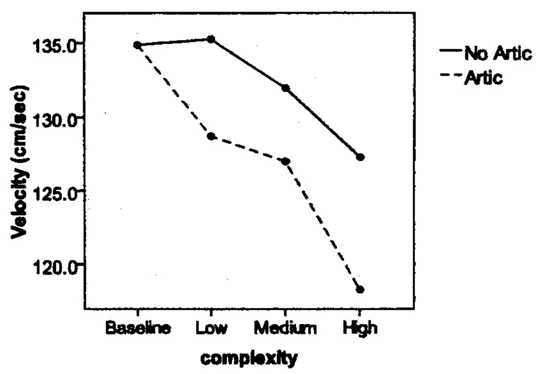

Fig.4.1: The Effect of Complexity on Gait Velocity

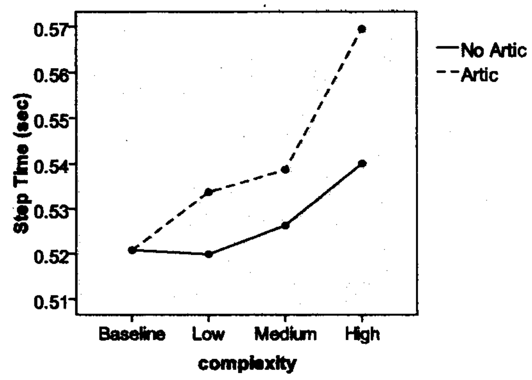

Fig. 4.2: The Effect of Complexity on Step Time

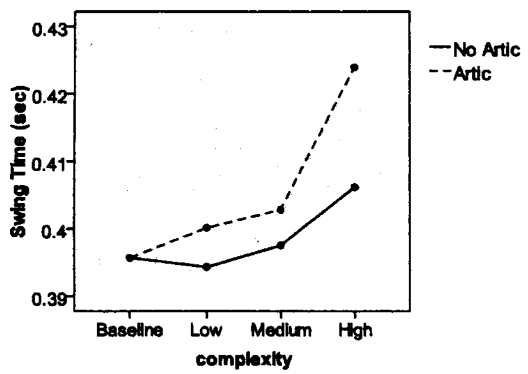

Fig.4.3: The Effect of Complexity on Swing Time

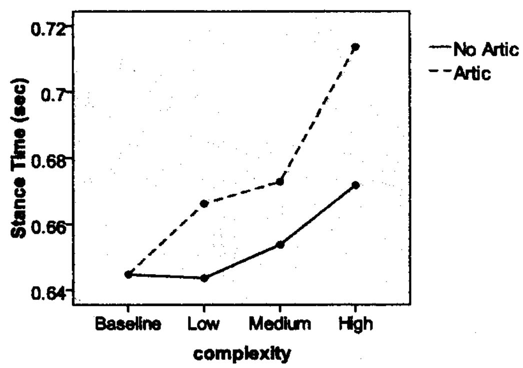

Fig.4.4: The Effect of Complexity on Stance Time

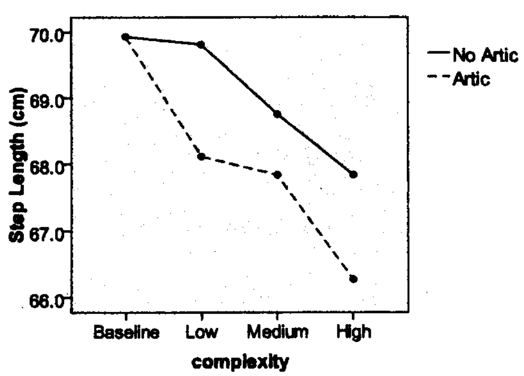

Fig.4.5: The Effect of Complexity on Step Length

Discussion

Consistent with previous findings, the above findings substantiate an additive effect of articulation, over and above the cognitive demands produced by simple working memory (Armieri et al., 2009; Dault et al., 2003; Plummer-D'Amato et al., 2008; Yardley et al., 1999). Furthermore, these results indicate that continuous gait is most profoundly affected by task complexity under conditions of articulation. More specifically, velocity and step length decreased, while step time, stance time, and swing time increased – a pattern indicative of gait instability (Brach et al., 2001; Kim & Brunt, 2007). In other words, the likelihood of gait interference and subsequent fall risk is greatest when individuals are asked to perform on a cognitively challenging task while speaking aloud.

Not surprisingly, the results yielded a significant multivariate main effect suggesting that the parameters of gait are significantly different between older and younger adults. Interestingly, this finding was demonstrated at a multivariate level, but not at a univariate level, which suggests that the differences between the groups are sufficiently subtle as to be statistically significant only when combined into an optimally weighted canonical variate. The group variable did not, however, show a significant interaction with cognitive complexity, or with articulation, suggesting that dual-task interference is relatively uniform across the age ranges evaluated within this study.

As acknowledged by Armieri et al., (2009), the specific etiology of the articulatory effect are not well understood. It is plausible that the respiratory patterns inherent in speech production may have a destabilizing effect on gait, or perhaps the motor aspects of speech (e.g. jaw movements) interfere with the motoric aspects of gait (Dault et al., 2003; Plummer-D'Amato et al., 2008; Yardley et al., 1999). Alternatively, the effect may be rooted in the capacity-resource sharing model of interference, in that

the introduction of the verbal aspect may have over-taxed attentional capacity causing interference. A more economical explanation may simply be that an oral-cognitive task is more difficult than a non-oral cognitive task (Armieri et al., 2009).

Within both age groups, the data seems to endorse a 'posture-second strategy'(Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001) by which individuals prioritize the secondary task over gait and balance (i.e. primary task), consequently increasing fall susceptibility (Bloem, Grimbergen, van Dijk, & Munneke, 2006). This strategy runs contrary to the more appropriate 'posture first strategy,' wherein attentional resources are first allocated to the safety-promoting posture task (gait), rather than to the cognitive secondary task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Within both groups, this relatively unsafe method of prioritization is illustrated by the continued increase in gait interference with successive levels of complexity, under the digit span task.

Though much research has reported on gait changes within older adults as a result of concurrent task performance (Bloem et al., 2001; Lundin-Olsson et al., 1997; Verghese et al., 2002), the neurophysiological underpinnings of dual-task interference are still not well understood. Specifically, the extent to which gait interference is contingent upon attributes specific to the secondary task. In this regard, future research must attempt to disentangle the mechanism(s) behind the effect of articulation (Armieri et al., 2009). Moreover, not only do the results highlight the need to control for verbalization within secondary tasks, but they also bear relevance for older adults who attempt to dual-task, while speaking aloud. For instance, the results caution against traversing a street cross-walk while carrying on casual conversation, as the likelihood of fall risk is gravely

magnified. Conclusively, the results support the idea that articulation is an important factor in understanding dual-task interference, and they also emphasize the intricacies inherent in the frequently cited 'walking while talking' paradigm.

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Chapter 5: GENERAL DISCUSSION

Research concerning the complex relationship between cognition and the maintenance of gait and posture, continues to expand. It is well established that specific gait alterations under dual-task conditions are reflective of underlying instability, and may place older individuals at risk for fall (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008). A majority of studies, however, have largely focused on dual-task performance within neurologically, or balance impaired, populations (Bloem, Grimbergen, van Dijk, & Munneke, 2006; Camicioli, Howieson, Lehman, & Kaye, 1997; O'Shea, Morris, & Iansek, 2002). In this context, inefficient division of attention has been mainly attributed to a deficiency in executive functioning (Allali et al., 2007) or to overall 'frailty' (de Hoon et al., 2003). Nevertheless, in the absence of apparent neuropathology or frailty, the inability to successfully divide attention amid walking and a secondary task is not well understood.

If, however, clinicians are unaware of the dual-tasking risks faced by healthy older adults, then interventions will be issued only to those diagnosed with pathology, thereby neglecting those without apparent pathology until they experience a fall (Shkuratova, Morris, & Huxham, 2004). This underscores the importance of examining unimpaired individuals in an effort to better understand the role of cognition in the control of stability (Woollacott & Shumway-Cook, 2002). To this effect, an important first step in enhancing our understanding is to examine dual-task performance within healthy young adults (Woollacott & Shumway-Cook, 2002). An increasing number of studies have utilized healthy young adults, and while the results demonstrate less exaggerated dual-task effects as compared with older adults, the findings nonetheless

highlight many of the attentional demands of gait (Yogev-Seligmann, Hausdorff, & Giladi, 2008). The overarching aim of the present thesis, therefore, was to investigate the interplay between cognition and gait by purposefully examining the precipitating factors of dual-task interference, including task properties, task type, and age.

The first study (Armieri, Holmes, Spaulding, Jenkins, & Johnson, 2009) demonstrated that the secondary task properties of complexity and articulation interact to produce gait interference. In other words, the interference incurred while walking and performing on a complex secondary task is seemingly amplified when speaking aloud. These findings have important implications for future research. As it stands, a large proportion of secondary tasks employed within the dual-task literature involve a verbal component. In order to effectively examine working memory demands of a secondary task, it is imperative that one control for articulatory effects.

Although certain properties within a task, such as articulation and complexity, affect gait, the type of task being performed in conjunction with walking is also important. Findings of the second study suggest that certain tasks may have different effects on gait. A between-task evaluation of a phonological loop 'digit-span task' and a visual-spatial 'star movement task' demonstrated substantively different results. Among young adults, performance of a digit span task produced significant gait interference when increasing task complexity from 'medium' to 'high' complexity, but little effect at lower levels of task complexity. In contrast, the visual spatial task had no significant impact upon gait parameters.

Several explanations for the above findings are possible. Firstly, the verbal (i.e., digit span) task may simply necessitate greater attentional resources than the visual-

spatial (i.e., star movement) task, consequently overloading the central processing system – a conjecture which supports the capacity/resource sharing model of interference. Alternatively, the non-effect of the star movement task may be explained by the cross-talk theory, in that two visual tasks minimize interference by sharing resources. But more likely, the lack of substantiation for structural interference may be accounted for by flaws in the methodological design (i.e. cueing). Nevertheless, these findings suggest that careful consideration be given to choosing the type of secondary task employed within the dual-task paradigm. In addition, it appears that healthy young adults are able to successfully allocate attentional resources between concurrent tasks with minimal interference; however, as cognition is increasingly challenged a 'breaking point' is encountered at which central processing limits are exceeded, resulting in interference.

Finally, if different task types produce varying levels of gait interference, perhaps dual-task training strategies should focus on those tasks which are most impactful on gait. For example, memorizing a phone number while walking to the phone (phonological loop) may be more of a risk than envisioning a directional route (visual-spatial sketchpad) while walking.

The final study extended on the method of the first study by incorporating a sample of healthy older adults. Between-groups analyses provided for an evaluation of the role of "age" on dual-task performance. Of particular interest was whether a manipulation of specific task properties, namely 'complexity' and 'articulation', would produce similar or dissimilar levels of gait affect across age groups. There was a general difference in overall gait performance between younger and older adults when performing under the digit span task. Consistent with previous work (Beauchet et al.,

2003; Dubost et al., 2006; Hollman, Kovash, Kubik, & Linbo, 2007) older adults experienced greater overall gait interference as compared with young adults. As demonstrated by previous work (Armieri et al., 2009), the effect of task complexity on gait parameters became most apparent under conditions of articulation. Although the pattern of effect was similar across groups, there was no significant difference between groups on any particular gait parameter. This absence of specific gait differences between groups should, however, be interpreted with caution, as this finding is almost certainly due in part to insufficient power to detect these subtle differences. Most notably, however, these findings further substantiate 'articulation' as a model of interference within both populations. Both healthy young and healthy older adults experience an increase in gait interference while simultaneously performing on a complex task that requires speaking aloud.

In combination, the present results suggest the need for modifications within future dual-task research. As well, the results hold relevance in the field of rehabilitation sciences. At the clinical level, clinicians should refrain from casual conversation with clients while simultaneously carrying out functional balance and/or gait assessments. Moreover, older adults should be made aware of the possible risks associated with walking while talking and clinicians should train older adults to successfully and safely carry on conversation while walking in an attempt to prevent future falls (Plummer-D'Amato et al., 2008).

5.1 Limitations of the Present Study

There were several notable limitations to the present study. Firstly, errors on secondary task performance were not quantified, due to the fact that task prioritization

was not of specific interest, but rather the extent to which various secondary tasks and their respective properties affected gait. If gait kinematics were considerably affected by the performance of a secondary cognitive task, it was suspected that incorrect prioritization was likely an issue – but this was not specifically relevant to the goals of the current study. Nonetheless, future employment of this methodology should accurately quantify cognitive task performance in an effort to make more definitive statements regarding strategies of prioritization (i.e. posture first and posture second hypotheses).

An additional limitation of the present study was that it neither controlled for, nor adjusted for, individual differences in cognitive abilities. Although substantive differences in this regard were not suspected to be a major issue amongst young adults, as the majority were recruited from a pool of graduate students, it is plausible that this may be a significant confound when studying individuals drawn from the general population (as was the case with the sample of healthy older adults). Future research should control for these individual differences by assessing cognition with measures of information processing speed, or general cognitive ability (*g*). Much research (Ble et al., 2005; Coppin et al., 2006) has examined executive functioning in association with dual-task performance. Specifically, lower level executive function has been shown to correlate highly with successful dual-task performance (Allali et al., 2007). It would be of interest to administer a representative measure of executive function prior to dual-task performance, in order to see whether the former encompasses any predictive validity.

5.2 Future Directions

As mentioned in the first study, future research should further examine the effect of articulation on gait - specifically, whether the effect of articulation is due to cognitive load, motoric interference, or respiration patterns. A study conducted by Conrad and Schonle (1979) illustrates the complexities inherent in understanding the articulatory effect. The above authors utilized a chest pneumograph to examine air volume changes during various tasks (i.e. spontaneous speech, reading, serial speech, arithmetic) under conditions of no articulation (i.e. thinking), subvocal articulation (motor movements), and speaking aloud. The authors found that not only were respiratory patterns dependent upon the type of task performed, but both thinking tasks and subvocal articulation produced respiratory patterns similar to that of speech production. With this in mind, careful consideration should be given to designing a methodology by which the relationship between articulation and gait can be effectively dissected.

Specific to the method employed, the digit span task may benefit from the inclusion of additional levels of complexity. In order to effectively examine the notion of a 'breaking point', as put forth in chapters three and four, digit span length should be altered to include more digits, as this would allow a more precise estimate of this breaking point. In addition, it may be beneficial for future research to examine other potential covariates of dual-tasking. It is likely that dual-task performance has multiple predictors, many of which are not yet accounted for within the literature. For instance, during the digit-rehearsal task, some individuals 'entrained' their gait with the verbal recitation of numerical digits (i.e., they timed their footfalls to coincide with each digit utterance). It is possible that individuals who are musically inclined may generate

internal cueing, which in turn affects gait cadence. To the same effect, certain types of secondary tasks may be easier for some, depending on whether their educational/ career background is relatable. For example, individuals with a background in mathematics or finances may demonstrate better dual-task performance when asked to perform on a 'digit-span' task, as their ability to work with and memorize numbers may be better developed and therefore more reflexive. By collecting relevant qualitative data on participants, new and interesting predictors of dual-task performance may come to light.

Finally, and perhaps most importantly, this paradigm should be replicated within neurologically impaired populations. O'Shea et al. (2002) postulated that individuals with Parkinson's disease may experience greater difficulty under dual-task conditions. Among these individuals, frontal lobe processes are utilized to perform the secondary task, thereby delegating gait and postural control to the defective basal ganglia. Theory suggests that cortical processes (attention) compensate for gait and postural declines in the above population; thus, transferring attentional resources to a secondary task leads to instability (O'Shea et al., 2002). Further, research among individuals with Parkinson's disease suggests that these individuals may exhibit a 'posture-second' strategy under dual-task conditions, thereby increasing their fall risk (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001). By introducing dual-task training into the typical treatment regimen for these individuals, dual-task interference may be effectively reduced under real-world conditions (e.g. crossing the street while talking). Evidence from healthy adult population has suggested that reinforcing proper prioritization 'posture-first' is effective in reducing gait and postural instability (Silsupadol, Siu, Shumway-Cook, & Woollacott, 2006).

5.3 Conclusion

Theoretically, if gait processes were indeed fully automatic, then the introduction of a secondary task should not alter gait kinematics. The results of the present studies suggest that gait clearly requires attention among both healthy older adults, and healthy young adults. Ideally, the optimal strategy for fall prevention within older adults would be to avoid simultaneous task performance entirely. Although it is not always possible to complete one task at a time during the activities of daily living, it is in the best interests of researchers and clinicians to educate older adults about the possible risks associated with performing two tasks at once. If made cognisant of the risks, it is hoped that older adults will prioritize gait over the secondary task during future dual-task endeavours, subsequently minimizing fall risk. Though at times difficult to assess, exploring the interplay between cognition and gait may help in achieving a better understanding of the mechanisms behind falls as well as help identify older adults at risk for falls.

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Appendix A

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Appendix B

Ethics Approval Forms

Western

Office of Research Ethics

The University of Western Ontario
Room 00045 Dental Sciences Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: [illegible]E **Review Level:** Expedited
Review Date: October 24, 2007
Protocol Title: The effects of cognitive secondary tasks on spatial-temporal properties of gait
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: November 8, 2007 **Expiry Date:** October 31, 2008
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent (Control Group), Letter of Information and Consent (Parkinson's Group)
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. John W. McDonald

Ethics Officer to Contact for Further Information

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Office of Research Ethics

The University of Western Ontario
Room 00045 Dental Sciences Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: 13692E **Revision Number:** 1
Review Date: April 23, 2008 **Review Level:** Expedited
Protocol Title: The effects of cognitive secondary tasks on spatial-temporal properties of gait.
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: April 23, 2008 **Expiry Date:** October 31, 2008
Documents Reviewed and Approved: Revised study methodology and study instruments. Letter of Information and Consent.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

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Chair of HSREB: Dr. John W. McDonald

Ethics Officer to Contact for Further Information

☐ Janice Sutherland	☐ Jennifer McEwen	☑ Grace Kelly	☐ Denise Grafton

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cc: ORE File
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Office of Research Ethics
The University of Western Ontario
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Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: 13692E **Revision Number:** 2
Review Date: October 29, 2008 **Review Level:** Expedited
Protocol Title: The effects of cognitive secondary tasks on spatial-temporal properties of gait.
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: October 29, 2008 **Expiry Date:** April 30, 2009
Documents Reviewed and Approved: End Date Revision
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
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Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. Joseph Gilbert

Ethics Officer to Contact for Further Information

☐ Elizabeth Wambolt ☐ Grace Kelly ☐ Denise Grafton

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cc: ORE File
LIRI

Office of Research Ethics

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Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: 13692E **Revision Number:** 3
Review Date: November 14, 2008 **Review Level:** Expedited
Protocol Title: The effects of cognitive secondary tasks on spatial-temporal properties of gait
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: November 14, 2008 **Expiry Date:** April 30, 2009
Documents Reviewed and Approved: Revised co-investigators, participant recruitment, eligibility of subjects and number of study participants. Letter of Information and Consent. Recruitment advertisement.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
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Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. Joseph Gilbert

Ethics Officer to Contact for Further Information			
[illegible]	☐ Elizabeth Wambolt	☑ Grace Kelly	☐ Denise Grafton

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