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Gait performance exhibits patterns of stride-to-stride variability. When performing a gait task with a cognitive task, it is not known whether concurrent performance affects the gait tasks' structure of variability. In this study, 16 participants performed a cognitive task (automated operation span task) and a motor task (walking on a treadmill) in single- and dual-task conditions. The purpose of this study was to establish how performance in cognitive (i.e., working memory) and motor (i.e., gait) tasks vary when the tasks are performed in isolation and concurrently.

The primary hypothesis of this study was that a decrement in gait performance would be observed when gait is performed concurrently with a working memory task (dual-task) compared to walking alone (single-task). I expected that engaging working memory while walking would lead to a corresponding decrement in gait performance by shifting gait toward maladaptive behavior (lower DFA α). The results did not support my hypothesis. Two Multivariate Analyses of Variance (MANOVAs) were used to examine performance (one for gait and one for cognition) in the single and dual-task conditions. No differences were observed in either gait or cognitive performance as a function of task condition. Conditions for gait performance were walking alone, walking while reading, and walking with cognitive task, and conditions for cognitive performance were cognitive alone and walking with cognitive task.

THE RELATIONSHIP BETWEEN WORKING

MEMORY AND GAIT PERFORMANCE

by

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CHAPTER I

INTRODUCTION

Working memory describes the ability to hold information in the mind in order to perform either verbal or nonverbal tasks, and it maintains an active awareness and management of information despite interfering distractions (Becker & Morris, 1999). It is involved in one's ability to reason, problem solve, comprehend language, and establish long-term learning (Engle, 2002). Working memory should be distinguished from earlier models of short-term memory, which simply focused on storage (Baddeley & Hitch, 1974). Working memory has a limited span in the amount of resources an individual has to allocate to competing tasks; this is referred to as working memory span (Cowan, 2001; Baddeley, 1986). Therefore, when one is required to perform concurrent tasks, an individual draws from the same resources resulting in fewer resources to devote to a single task (Beilock, 2007).

Working memory function is strongly influenced by the ability to control attention in conjunction with holding information in storage (Engle, 2002). This is because directed attention can assist an individual in avoiding distractions (Engle, 2002), whereas a lack of control in attention can limit the ability of working memory. For example, performing concurrent tasks can force an individual to divide attention between the tasks, leading to a reduced amount of attentional resources being allocated to one of the tasks. When the recollection of information is called for in such circumstances, this division of attention leads to a decreased ability to recall (Staal, 2004).

There are various models addressing working memory's organization. A commonly referenced model is Baddeley and Hitch's (1974) model, which is useful when examining the dual-task condition. The original model has three major components—the central executive that supervises information intake, the phonological loop that attends to language and sounds, and the visual-spatial sketchpad that stores visual and spatial information (Baddeley & Hitch, 1974). This model has since been updated (see Figure 2) to include another component, the episodic buffer, which describes working memory's ability to bind information from the subsystems and from long-term memory as a single episodic representation (Baddeley, 2000). It is also assumed to be important for using prior knowledge to store new information more effectively (Baddeley, 2000). Decrements in cognitive performance, such as those observed in dual tasks, may be due to a competition for limited resources (Kiefer et al., 2009). Therefore, using this model as a foundation to understanding working memory will help me further explore the relationship between cognitive and motor tasks when they are performed in isolation and concurrently.

In order to maintain the ability to manipulate information, neurons consistently fire in the delay period of working memory tasks (Arnsten, 1998). Thus, the human brain has the ability to keep these mental representations active without any additional external output. However, this process is interrupted when the task involves managing more than one source of information (Beilock, 2007). Managing different sources of information may involve binding each source together in our working memory in order to avoid confusion (Arnsten, 2009). When a task involves managing more than one source of information, the ‘normal’ thought process is interrupted (Beilock, 2007). Thus, when depending on habitual responses to guide their behavior, working memory abilities worsen due to trying to manage different sources of information.

Working memory has been linked to key learning outcomes in literacy and numeracy, and working memory impairment can affect academic and sport performance (Beilock, 2007). Poor working memory can affect one’s ability to control the information he/she attends to, and this informational control can limit the span of working memory further (Beilock, Rydell, & McConnell, 2007). In this study, the allocation of attention was determined by participants’ performance in a task involving cognitive demands while simultaneously walking. Research examining cognitive and motor tasks is a growing area of interest. Typically, these tasks are examined in isolation to control for extraneous or interacting variables. Recently, more research has been focused on the dual-task paradigm to better understand the interaction between cognitive and motor tasks. While some studies have examined impairment in only one domain as a function of dual-task (Sheridan et al., 2003; Hausdorff et al., 2005), Kiefer et al. (2009) examined performance in both the cognitive and motor domains by having participants perform three tasks: (1) walking only (motor task), (2) tapping a button in one second intervals (cognitive task), and (3) walking while tapping a button in one-second intervals (motor and cognitive task performed concurrently). The researchers adopted a dynamics framework to examine performance in both domains and found that walking performance was preserved in the dual-task condition, but cognitive performance was compromised. This finding provided support for the "posture first principle" introduced by Wollacott and Shumway-Cook (2002), which suggests that posture tasks take priority over cognitive tasks when they are performed concurrently due to the inherent physical risk of reduced motor performance (e.g. a trip or fall). This thesis was developed to further understand how cognition, and specifically working memory, interacts with gait performance. The purpose of this study was to establish how performance in cognitive (i.e., working memory) and motor (i.e., gait) tasks vary when the tasks are performed in isolation and concurrently. The main hypothesis was that a decrement in gait performance would be observed when performed concurrently with a working memory task (dual-task) compared to walking alone (single-task).

CHAPTER II

LITERATURE REVIEW

The following section summarizes the literature in the following areas: (1) relationships among working memory, attention, and cognitive performance, (2) a theory of working memory organization, (3) assessing working memory performance, (4) a theory of dual-task interference, (5) assessing gait performance, and (6) the interaction between cognitive and gait performance when performed concurrently.

Relationships Among Working Memory, Attention, and Cognitive Performance

Working memory span is not limited to memory alone but also largely involves the ability to control attention (Engle, 2002). Thus, working memory span can be enhanced by refining the ability to control attention rather than simply holding information within storage. This is because guided attention can assist an individual in avoiding distractions (Engle, 2002). On the contrary, poorer working memory can affect the ability to control which information is attended to, and this lack of control can limit the span of working memory further (Beilock, Rydell, & McConnell, 2007). Thus, dividing attention between tasks leads to a reduced amount of attentional resources able to be applied to one of the tasks being performed, leading to negative effects in encoding information into memory (Baddeley et al., 1984).

Working memory tasks have been shown to be beneficial in predicting performance on a variety of cognitive tasks that relate closely to real-world activities (Conway et al., 2005). For example, task performance involving language and listening comprehension, reading, following directions, writing, reasoning, playing bridge, writing computer programs, and learning vocabulary are able to be predicted by individuals' performance on working memory tasks (Engle, 2001).

A Theory of Working Memory Organization

Baddeley and Hitch (1974)

I used Baddeley and Hitch's (1974) model as a foundation for my research because it integrates many works on short-term and working memory to describe working memory as a complex system that is necessary to the proper functioning of cognitive processing. Their argument for distinguishing two domain-specific slave systems (phonological loop and visuo-spatial sketchpad) was created from experimental findings in dual-task research. Baddeley and Hitch created this model when they discovered that when two simultaneous tasks require the use of two *separate* perceptual domains (i.e. a verbal task and a visual task), the performance of the tasks do not suffer. However, when the two concurrent tasks require use of the *same* perceptual domain, performance declines for one of the two tasks. This model has three major components—a limited span central executive, a phonological loop, and a visual-spatial sketchpad. The central executive is responsible for the control and regulation of cognitive processes. It supervises information intake by coordinating its slave systems (phonological loop and visuo-spatial sketchpad) and shifting between tasks or retrieval strategies (Baddeley & Hitch, 1974). The phonological loop attends to language and sounds, and it remembers speech sounds in their temporal order as well as repeats the series of words on a loop to prevent decay. The visual-spatial sketchpad stores visual and spatial information. This sketchpad is involved in planning spatial movements (e.g. moving through a maze), and it can be divided into separate visual, spatial, and movement components (Baddeley & Hitch, 1974). This model has since been updated to include a fourth component (see Figure 1), the episodic buffer, which describes working memory's ability to bind information from the three major components and from long-term memory as a single episodic representation (Baddeley, 2000).

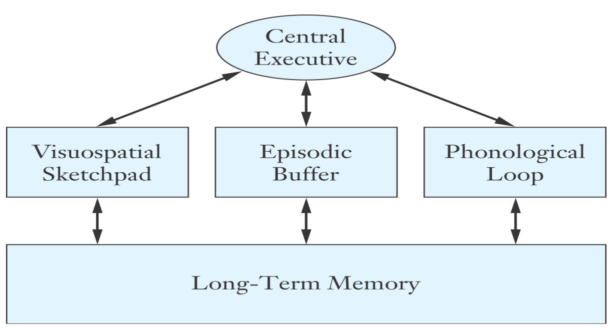

Figure 1. Baddeley (2000) Multicomponent Model of Working Memory

Assessing Working Memory Performance with WM Span Task

Operation Span

Turner and Engle (1989) proposed a task for predicting reading ability by having participants solve mathematical problems while trying to memorize sets of unrelated words as opposed to having subjects read sentences. This new task was termed the operation span task and was set up with a highly demanding processing component in order to engage the processing functions of working memory as well as to show individual differences in task performance. Thus, participants were asked to solve math problems while simultaneously remembering letters. Solving math problems was considered to have a relatively complex processing component as compared to reading tasks (e.g. reading sentences) or counting tasks (e.g. counting numbers, counting shapes) (Turner & Engle, 1989). In each math trial, subjects were asked to read aloud and solve a math problem and then read the subsequent word aloud. These operation-word strings were presented in sets of two to five items in a row. After each set, participants were asked to recall the words in order that they were presented. Engle et al. (1992) then developed the version of this task that involved a randomized presentation order for the set size (rather than having set sizes occur in numerical order). For example, the version developed by Engle et al. (1992) may have a set size of three items in a row, then five, then two whereas the original version would have a set size of two, then three, then four, then five. Engle et al.'s (1992) version is commonly used in laboratories because it eliminates strategies that come from knowing the size of the memory set (Conway et al., 2005).

Unsworth et al., (2005) created an automated version of the operation span task (AOSpan) that is mouse driven, calculates the score itself, and requires little effort on behalf of the experimenter. The automation of this task is beneficial because it analyzes response times. This timing component helps set this automated task apart from the nonautomated ones in that it collects multiple data points consisting of such things as math problem accuracy, time spent processing the math problems, and properly recalling words. Dual-task situations involving working memory look at two sources of data: one from storage and one from the processing component of the task (Conway et al., 2005). The AOSpan task is a reliable and valid indicator of working memory span that can be applied to a variety of research domains (Conway et al., 2005).

The automated version added three separate practice sections at the beginning of this task. The first section consisted of one letter at a time appearing on the screen, and participants were asked to later recall the letters in the order they were presented. The second section was the math task only. Participants were presented with math problems on the screen and asked to solve them. Then, the subsequent screen would provide the participant with a solution to the problem and ask if the solution was true or false (correct or incorrect). The third practice section combined sections one and two. First the participant would see a math problem, then be asked if a solution was true or false, and then a letter would flash on the screen for later recall. These operation-word strings would occur in set sizes ranging from three to seven, and at the end of a set participants would be asked to recall the letters in the order they were presented. After these practice sections, the test trial would begin. The test was the same format as the third practice section (i.e. math problem, true/false response, letter presentation).

The focus on quantifying working memory performance has led to several insights into how cognitive performance can be enhanced or suppressed. While this research has helped broaden our understanding of cognition, it is possible that studying cognitive processes in isolation does not help give an accurate picture of the dual-task reality humans experience on a regular basis. Since activities of daily living typically require focusing on more than one task at a time, the dual-task paradigm may be better positioned to explore cognitive processes when they are performed concurrently with another task. The next section outlines how cognitive performance is influenced when a secondary task is introduced.

A Theory of Dual-Task Interference

Limited Resources

Limited resources refer to the pools of processing resources that can be mentally divided up to use for different tasks (whether performed alone or simultaneously). When a task requires that more processing resources be devoted to it, this leaves fewer processing resources for the other task(s) at-hand (Pashler & Johnston, 1998). Thus, when performing two tasks concurrently, processing is simultaneous but occurs more slowly due to the reduced amount of available resources.

There is a rising interest in discovering the attentional mechanisms behind task performance as well as how these mechanisms differ across various tasks and skill levels (Beilock, 2007). Task performance is believed to be experienced through different learning stages varying from those at the beginning phases (i.e. novice) to those at the skilled level (i.e. expert). Novice skill is thought to be controlled by declarative knowledge held within working memory whereas expert skill is considered to be governed by procedural knowledge held within long-term memory (Anderson, 1993). Academic tasks performed under pressure, such as mathematical problems, that rely heavily on working memory will likely result in failure due to limited resources. This performance failure under pressure has also been related to motor skills that involve several decisions and thought processes occurring simultaneously, such as in golf putting (Beilock, 2007).

In situations that demand a high level of performance involving complex motor, verbal, or cognitive skills, an increase in attention is directed toward the execution of the skill. Therefore, whether it be an academic or sport setting, experts are more likely to draw from their long-term memory so automated control processes govern their performance whereas novices are more likely to use the resources in their working memory where overall span is often reduced. In this study, participants were naïve to one of the two tasks being performed, which introduced a conflict in balancing between automated control processes and the resources available to perform both tasks.

Dual-Task Research

Studies looking at perceptual capacities as distinct from memory limitations (i.e. studies looking at divided attention) allow subjects to demonstrate what they can identify without having to hold any information in memory. Thus, divided attention research tends to rely on detection or search tasks (Pashler & Johnston, 1998). In these experiments, people are asked to report the presence or absence of a pre-specified target in a search display, or choose if a target is present amongst several alternative targets. Results from these studies suggest that when the number of distractors in search displays is increased, response times generally increase too (Johnston, McCann, & Remington, 1996). Some studies focus on accuracy rather than speed of visual search performance, and results have shown that span limitations arise when processing load (the amount of information being taken in) is increased beyond a certain point (Pashler & Johnston, 1998).

When simultaneously performing two different tasks, interference generally can occur regardless of whether the tasks are compatible in stimulus-response mappings. Sufficient practice may assist individuals in avoiding task-interference (Beilock, 2007), but that has not been consistently demonstrated in the literature. However, central processing in one task can overlap with both the production of motor responses and perceptual analysis in another task. This is due to a sequence of processing stages in which a central processing task is prioritized when simultaneously operating with other tasks (Pashler & Johnston, 1998). Dual-task performance in cognitive and gait tasks was of interest in this study based on the assumption that a working memory task would require central processing (attentional resources) and would leave fewer cognitive resources to complete a gait task. Methods for assessing cognitive performance, specifically working memory, were outlined above and the next section is dedicated to discussing how gait performance can be indexed.

Assessing Gait Performance

In order to assess gait performance, it is necessary to understand the variability in gait. For successful navigation in one's environment, it is important for a human to be able to change his/her stride (i.e., to exhibit gait variability) (Rhea & Kiefer, 2013). Human gait is complex in that a healthy gait system involves input from the cerebellum, basal ganglia, motor cortex and other proprioceptive sensors in order to carefully control motor commands (Hausdorff, 2007). Further challenging the control of gait are environmental constraints such as static obstacles (e.g., a tree or lamp post) or moving obstacles (e.g., pedestrians or vehicles). To meet these challenges, gait must be flexible enough so that it can be altered when required. This flexibility can be indexed by examining gait variability.

Stride-to-stride variability in gait is commonly expressed as the standard deviation around the mean of the time between strides. Stride variability has been reported for over 100 years (Vierordt, 1881), and it was traditionally used as a metric indexing gait dysfunction. Theories examining gait control typically focused on the *amount of variability* (via the standard deviation or coefficient of variation) in gait movement. For example, functional behavior can be minimized through repeated, rigid behavior, so having some variability can help maintain functional behavior. However, in the last 20 years research has discovered that the amount of gait variability can be helpful or harmful, depending on how it is structured. Accordingly, theories have recently begun to focus on the *structure of variability*. Recent studies have revealed that variability in gait is necessary in order to adapt to external and internal factors (see Rhea & Kiefer (2013) for a review). Thus, stride-to-stride variability can be described on a continuum of adaptive to maladaptive variability. Adaptive variability describes when individuals' skeletal, muscular, and neurological systems productively work together in order to allow for functional mobility (Rhea & Kiefer, 2013). On the contrary, maladaptive variability refers to an inconsistency in coordinating these systems leading to suboptimal or limited mobility. In order to quantify the structure of gait variability, various computational methods have been created. A consensus has not been reached in terms of which method is best since each of them measures a different aspect of gait pattern, so the three most commonly used methods will be introduced.

Entropy

Entropy is a computation method that is used to index the regularity of patterns in a system's dynamics which helps describe the complexity of behavior. Approximate entropy (ApEn) quantifies the number of repetitive patterns within a data set (Pincus, 1991). Output values indicate repeatability within a signal, typically ranging in value from zero to two in which zero represents more repeatability and two represents less repeatability. As ApEn values trend away from zero, this indicates that there is more complex behavior. Thus, approximate entropy changes when the constraints of the system are changed.

Dynamic recurrence

Recurrent dynamics describe a healthy, adaptive gait pattern. A recurrence describes when the dynamics of a multidimensional state space pass through the same space, and a system with too much or too little recurrence may be functionally maladaptive. Recently, recurrence quantification analysis (RQA), an analysis based on conceptualizing recurrence plots, has been used to examine the dynamic patterns of gait. Three output variables tend to be the focus of gait literature: percent determinism (%DET), entropy (ENT), and maxline (MAXL). %DET is used as a measure of regularity of points in the recurrent plot, ENT represents the dynamic patterns in the data, and MAXL shows the total number of data points that exist in the longest diagonal line.

Although RQA describes several components of gait dynamics, little is known about how RQA variables relate to functional mobility.

Long range correlations

Detrended fluctuation analysis (DFA) indexes the dynamic patterns of gait. It is useful in analyzing the extent of repeating patterns across short and long time scales. This is commonly termed in the literature a long range correlation. This method stems from the idea that variation in DNA sequences had a particular mosaic structure and were not randomly assorted (Peng et al., 1994). To calculate DFA, there are a series of steps to follow. First, the time series is integrated by subtracting the mean from each data point using the equation:

$$y(k) = \sum_{i=1}^{k}[S(i) - S_{ave}] , \quad (1)$$

where $y(k)$ = the integrated time series, $S(i)$ = the original time series, and S_{ave}= the mean of the original time series. Next this time series is separated into boxes that consist of an equal number of data points, and a trend line is fit to the data in each box. The remaining fluctuations ($F(n)$) are then quantified using the root-mean-square method:

$$F(n) = \sqrt{\frac{1}{N}\sum_{k=1}^{N}[y(k) - y_n(k)]^2} , \quad (2)$$

Lastly, the root-mean-square value is plotted on a log-log plot and a least squares line is used to measure the slope of the data. The value of the slope describes long-range correlations and indicates the strength of those values (DFA alpha). In human stride, weaker long-range correlations range close to .5 and stronger long-range correlations have values near 1.0. This is indicative of the fact that weaker correlations represent more random behavior and stronger correlations represent more patterned behavior (Rhea & Kiefer, 2013). DFA has been used to look across multiple indices of gait performance that examined the time between two events in a stride (e.g. stride interval, stride length, step length, etc.). DFA was the analysis adopted for this thesis since it has been used extensively to understand gait performance in single and dual-task conditions.

Interaction between Cognitive and Gait Performance when Performed Concurrently

In dual-tasks involving gait and cognition, the attentional demands of controlling balance vary according to the complexity of the tasks being performed (Woollacott & Shumway-Cook, 2002). Dual-task walking and cognitive performance tends to lead to individuals prioritizing one task over the other (i.e. either walking or cognitive task). This leads to two postulates that describe what can result from the concurrent performance of a cognitive task and a walking task. One postulate is that a decline in cognitive performance would be observed when walking concurrently, which predicts that a person will reduce the resources available for the cognitive task so the walking task can be properly attended to and balance can be maintained. A second postulate is that the concurrent cognitive task would cause a decrement in gait performance, such that gait exhibits a more maladaptive pattern compared to the walking alone task. The mechanism behind this postulate is that if one is forced to do a working memory task, his/her attention is focused on that task leaving fewer resources for gait. The second postulate was adopted as my hypothesis to describe the interaction between cognitive and gait performance in this thesis.

Research involving the relationship between cognition and gait control is a relatively new and growing interest area. Some studies have suggested that changes in gait have been due to impairment of executive function and the results of dual-tasks (Sheridan et al., 2003; Hausdorff et al., 2005). Kiefer et al. (2009) used a single- and dual-task paradigm to examine gait and cognitive performance separately and concurrently. Results showed that when the tasks were performed at the same time, increased randomness of cognitive dynamics was observed (i.e., shifted toward maladaptive activity), while motor performance remained unchanged. This finding was interpreted as indicating that individuals were reorganizing their cognitive dynamics in order to complete both tasks. One explanation for this reorganization is that the tasks drew upon similar resources when performed concurrently. Specifically, the researchers looked at the timing of strides during treadmill walking (gait task) and the timing between button presses when asked to approximate one-second intervals (cognitive task). Since timing was a key feature in both tasks, it could be argued that the resources for timing may have been sufficiently taxed, causing a decrement in task performance. This supports previous research showing individuals experience difficulty in performing dual-tasks when they draw from the same resources to perform both tasks simultaneously, ultimately reducing the resources available to devote to any one task (Beilock, 2007). The methods in this thesis were such that the cognitive task was likely pulling from the same resources than those controlling the timing of gait to determine if a decrement in gait would be observed when performed concurrently.

CHAPTER III

METHODS

Participants

Twenty-one participants were recruited from the undergraduate population and Kinesiology courses at the University of North Carolina at Greensboro (UNCG) based on a power analysis that revealed that 16 participants would be necessary to find significant results. Five of the 21 original participants' data were dropped from this sample due to the AOSpan program crashing in the middle of the procedure for four of the participants and one participant's gait data was captured at 50 Hz instead of 200 Hz. Three males and 13 females (mean age: 20.25 ± 1.69 years) participated in the study, with an average height of 166.21 ± 8.55 cm, weight of 68.71 ± 13.46 cm, and walking speed of 1.51 ± .32 m/s. All procedures were approved by the UNCG Institutional Review Board and all participants signed an informed consent. The participants had no history of lower extremity injury or neuromuscular disorders that inhibited normal walking; this was a self-reported stipulation in order to participate in the study. Additionally, all participants had normal or corrected-to-normal vision.

Materials

Working Memory Task

The automated operation span task (AOSpan) was used as the working memory task. At the beginning of the task, there were three separate practice sections. The first section was intended for remembering letters, and one letter at a time was presented on the screen. The participants were then asked to recall the letters in the order they appeared. In the second section, participants were presented with math problems on the screen and asked to solve them. Then, the participant would be provided with a solution and asked if the solution was true or false (correct or incorrect). The third practice section combined the first two sections. First, a math problem was displayed on the screen asking the participant to mentally solve it, then the participant was asked if a solution was true or false, and then a letter was presented on the screen for later recall. These math-word pairings occurred in set sizes ranging from three to seven, and at the end of each set participants were asked to recall the letters in the order they were presented. The test trial began after the three practice sections. The test was the same format as the third practice section (i.e. math problem, true/false response, letter presentation).

Working memory was the dependent variable measured by the Automated Operation Span (AOSpan) task which is a computer-administered task written in E-Prime version 2.0. This version scores itself so as to prevent administrator error. A time limit was used in the AOSpan task, and this time limit was calculated using the respondent's average solve time from their third practice section and adding 2.5 standard deviations. The AOSpan task had good internal consistency (alpha=.78) and test-retest reliability (Pearson correlation coefficient: .83) (Unsworth et al., 2005) which means the task was reliable in assessing working memory. The mean lag time between the first and second testing for test-retest reliability was 13 days (Unsworth et al., 2005).

The AOSpan provides several measures including absolute working memory span, partial working memory span, speed errors, math errors, and accuracy errors. The absolute score is calculated based on the sum of scores for all perfectly recalled sets. The partial score is the number of letters recalled in the correct serial position. Math errors recorded the total number of task errors, which was then broken down into speed and accuracy errors. Speed errors occur when a subject is unable to respond to the mathematical operation within the time allowed. Accuracy errors describe when a participant answers a math problem incorrectly.

Gait Task

A treadmill (Simbex, Lebanon, NH) was used for trials involving walking, and gait performance was recorded at 200 Hz with a motion capture system (Qualysis, Gothenburg, Sweden) using markers placed on the medial aspect of the mid-thigh, the knee, and the mid-shank. The treadmill speed was set to the participants' preferred speed, and this speed was kept consistent throughout all walking conditions. The front of the treadmill was located 1.5 meters from a wall containing a 1.65 m tall x 2.95 m wide projection screen. The AOSpan task was projected onto the screen when the working memory task was employed, and participants were asked to verbally respond to the experimenter running (i.e. using the mouse to respond) the AOSpan task . Gait data from the motion capture system was reduced to knee sagittal plane angles, which were further reduced to stride interval times by determining the time between peak knee flexion of the right limb for each stride. The stride interval time series was then submitted to detrended fluctuation analysis (DFA) to examine patterns in the knee angle time series in the different conditions. The details of DFA have been published extensively elsewhere (Kiefer et al., 2009; Hausdorff, 2007) and are outlined in the Literature Review section. The output value, DFA alpha (α), was used to measure the strength of long-range correlations in the gait behavior.

Procedure

Participants were tested individually. Prior to starting any tasks, the participants were asked to complete informed consent and a short questionnaire about their demographics and history of physical activity and injuries. They were assured that their responses would be kept confidential and anonymous. This entire procedure occurred in a single session (approximately 2 hours) for the purposes of avoiding participant attrition and variations in gait between days.

Next, the participants were asked to walk on the treadmill for a one-minute familiarization period prior to beginning the experiment. Participants were asked to self-select a comfortable speed similar to one they would use while walking across campus. The treadmill speed was adjusted accordingly (see Kiefer et al., 2009; Zeni & Higginson, 2010). After the self-selected speed was chosen, the participants completed four conditions: (1) walking only (single task), (2) cognitive only (single task), (3) walking while performing the cognitive task (dual task), and (4) walking while reading (dual task). The walking alone condition was always presented first and all other conditions were counter balanced (Figure 3). The reason the walking alone condition was always presented first is because past studies have shown that gait has a carryover effect when gait patterns are altered (Rhea, Kiefer, & Leonard, 2013) (Hove et al., 2012). Thus, in order to get a true baseline, individuals needed to perform the walking alone task first. In the walking only condition, the participants walked at their self-selected pace for ten minutes. The cognitive only condition consisted of completing the AOSpan task while sitting at a computer terminal, which lasted 10 to 15 minutes, depending on the participants' speed in answering the questions. Participants were asked to sit in this trial in order to keep the procedure similar to the one used in Unsworth et al. (2005). Rather than requiring participants to respond to the AOSpan task with a mouse, participants were asked to verbally respond to the AOSpan task as the experimenter drove the mouse. This process was implemented to keep it similar to the procedure in the dual task condition (walking while performing AOSpan task). In the walking while performing the cognitive task condition, participants walked at their self-selected speed while completing the AOSpan task for approximately 15 minutes (duration of task was dependent on the speed of the participant). Participants were asked to verbally respond to the AOSpan task so the experimenter could drive the mouse. Lastly, the walking while reading condition consisted of the participants walking at their self-selected speed for ten minutes while reading a journal manuscript presented on the projection screen. The article was *On the Interplay of Emotion and Cognitive Control: Implications for Enhancing Academic Achievement* written by Sian Beilock and Gerardo Ramirez.

The walking while reading task was included to ensure that gait dynamics do not change when concurrently walking and doing a visual task (one that does not relate to working memory). If a visual task (such as reading in this case) revealed a change in gait dynamics from single task condition (walking alone) to dual-task condition (walking while reading), then the cognitive while walking task would not be necessary because there would not be a way to tell what is influencing gait performance (i.e. working memory, anything in the visual field, etc.). Participants were asked to read a journal manuscript instead of single sentences so that questions could be asked at the end of the condition to test whether participants were actually doing the reading task. Every participant took a five-minute break between conditions. The gait data collected during the practice sections of the AOSpan task (in the dual task condition) were cropped from the data set so that all gait data was measured over the course of about ten minutes per condition.

To assess working memory performance, the four output values from the AOSpan test were recorded in the single and dual-task conditions. Gait performance was evaluated by quantifying DFA α in each condition, along with the stride interval mean andstandard deviation. Lastly, follow-up questions were asked after the reading trial to ensure they were performing the desired task.

Order	**Number of Participants**	**Task 1**	**Task 2**	**Task 3**	**Task 4**
1	3	Walking Only (10 min)	Cognitive Only (15 min)	Walking + Reading (10 min)	Walking + Cognitive (15 min)
2	2	Walking Only (10 min)	Cognitive Only (15 min)	Walking + Cognitive (15 min)	Walking + Reading (10 min)
3	2	Walking Only (10 min)	Walking + Reading (10 min)	Cognitive Only (15 min)	Walking + Cognitive (15 min)
4	3	Walking Only (10 min)	Walking + Reading (10 min)	Walking + Cognitive (15 min)	Cognitive Only (15 min)
5	3	Walking Only (10 min)	Walking + Cognitive (15 min)	Cognitive Only (15 min)	Walking + Reading (10 min)
6	3	Walking Only (10 min)	Walking + Cognitive (15 min)	Walking + Reading (10 min)	Cognitive Only (15 min)

Figure 2. Procedural sequence of tasks for each participant. The 16 participants' data that were used in this study were counterbalanced to 6 possible task orders.

Statistics

Since the number of strides taken in a trial can influence DFA α, a repeated measures ANOVA was used to compare the number of strides in each gait condition (walking alone, walking while reading, and walking with cognitive). Next, a MANOVA was used to determine if task condition influenced gait performance (stride interval mean, standard deviation, or DFA α) or cognitive performance (absolute score, partial score, speed error, accuracy error, or math error). Conditions for gait performance were walking alone, walking while reading, and walking with cognitive, and conditions for cognitive performance were cognitive alone and walking with cognitive.

CHAPTER IV

RESULTS

Preliminary Analyses

Influence of number of strides taken

Prior to the main analyses, I examined the number of strides taken in each walking condition, as that describes the number of data points in each gait data set. Since the number of data points has been shown to influence the structure of variability in gait data sets (Damouras, Chang, Sejdic, & Chau, 2010), it was important to determine if a similar number of strides were taken in each condition. A repeated measures ANOVA was used to compare the number of strides in each condition, and a significant effect of condition was observed, $F(2, 30)=24.54$, $p<.01$. Follow-up Bonferroni corrected paired-sampled t-tests showed that the number of strides were not significantly different between the walking only (440.6±43.6) and walking while reading conditions (427.2±46.9), $t(15)=1.42$, $p=.18$. However, the cognitive task while walking condition (536.6±95.3) contained significantly more strides than the walking only condition, $t(15)=-4.82$, $p<.01$ and the walking while reading condition, $t(15)=-5.57$, $p<.01$. To determine if the number of strides influenced the structure of variability in the gait data sets, all data sets were truncated to the fewest strides taken by any participant in any condition (n=353), and

DFA α was run on both the original and truncated data sets (contained first 353 steps taken by each participant). A 2x3 repeated measures ANOVA was used to determine if the two types of data sets (original or truncated) influenced DFA α in any of the three conditions (walking only, walking while reading, or walking while performing the cognitive task). The data type by condition interaction was not significant, $F(2,30)=1.78$, $p=.19$, nor was the main effect for condition, $F(2,30)=1.01$, $p=.38$. However, a main effect of data type was observed, $F(1,15)=10.16$, $p<.01$, suggesting that the means of each data type were different. This suggests that truncating data to an equal number of data points did influence the DFA alpha values and should warrant future examination. However, since the main question in this thesis concerned gait performance across conditions and the data type by condition interaction was not significant, I elected to use the full dataset (non-truncated) in doing my main analyses.

Effect of task order

The order of task presentation was counterbalanced between participants. To ensure that task order did not influence cognitive or gait performance, the participants were divided into two groups. Group one performed the cognitive only condition first and the cognitive while walking condition second. Group two performed the cognitive while walking condition first, then the cognitive only condition second. The gait performance and cognitive performance metrics were compared between groups using an independent samples *t*-test, and no differences were observed ($-.14<t<.31$ and $.09<p<.93$)

indicating that there was no effect of task order. Thus, the order of tasks was removed from the subsequent analyses.

Homogeneity of data

Levene's test of equality of error variances was used to test the homogeneity of cognitive performance (absolute score, partial score, speed error, accuracy error, and math error) and gait performance (stride interval mean, standard deviation, and DFA α) in each condition. There were no differences in the variances of each metric across conditions (all $p > .05$). Thus, parametric tests were used for the main analyses.

Main Analyses

The primary hypothesis of this study was that a decrement in gait performance would be observed when performed concurrently with a working memory task (dual-task) compared to walking alone (single-task). Specifically, I expected that engaging working memory while walking would lead to a decrement in gait performance by shifting gait toward maladaptive behavior (lower DFA α). Separate MANOVAs were used to examine performance (one for gait values and one for cognitive values) from single task to dual-task condition. The independent variable was condition (single task: cognitive alone, walking alone; dual task: cognitive while walking) and the dependent variables consisted of variability in gait and variability in cognition. No differences across conditions were observed in gait performance, $F(6,86)=0.31$, $p=.93$ or cognitive performance $F(4,27)=0.82$, $p=.52$. A summary of gait performance for each participant is shown in Table 2, and a summary of cognitive performance is shown in Table 3.

Table 1
Summary of each participant's physical activity levels on a weekly basis. Participants were asked to indicate the number of times per week he/she participates in physical activity and the level of intensity they perform at consistently (ranging from recreational to intense).

Participant	Times/Week	Recreational	Moderate	Intense
1	0			
2	5			X
3	6		X	
4	3		X	
5	0			
6	7			X
7	6			X
8	5		X	
9	6		X	
10	3		X	
11	4	X		
12	5		X	
13	3		X	
14	7	X		
15	4		X	
16	6			X

Table 2
Mean, standard deviation, and DFA α of the stride interval time series for each participant

	Single Task			Dual Task					
	Walking Only			Walking + Reading			Walking + Working Memory		
Subject	M	StDev	DFA α	M	StDev	DFA α	M	StDev	DFA α
1	1.50	0.05	0.60	1.57	0.05	0.61	1.56	0.04	0.66
2	1.23	0.02	0.73	1.27	0.03	0.66	1.24	0.04	0.66
3	1.28	0.04	0.76	1.44	0.06	0.82	1.40	0.07	0.69
4	1.38	0.03	0.67	1.34	0.03	0.71	1.30	0.04	0.77
5	1.55	0.07	0.87	1.59	0.05	0.68	1.58	0.07	0.82
6	1.46	0.04	0.70	1.46	0.05	0.70	1.39	0.05	0.80
7	1.63	0.08	0.82	1.59	0.09	0.72	1.45	0.07	0.81
8	1.10	0.02	0.82	1.10	0.02	0.76	1.10	0.02	0.78
9	1.34	0.04	0.86	1.32	0.05	1.11	1.34	0.03	0.76
10	1.33	0.03	0.71	1.34	0.03	0.75	1.34	0.03	0.83
11	1.36	0.03	0.83	1.36	0.03	0.81	1.34	0.04	0.84
12	1.41	0.06	0.77	1.42	0.06	0.77	1.43	0.04	0.67
13	1.28	0.03	0.58	1.29	0.03	0.61	1.26	0.03	0.65
14	1.39	0.04	0.84	1.36	0.03	0.75	1.36	0.04	0.61
15	1.29	0.03	0.81	1.30	0.02	0.71	1.28	0.07	0.71
16	1.45	0.04	0.68	1.54	0.05	0.59	1.51	0.05	0.62
Mean	**1.37**	**0.04**	**0.75**	**1.39**	**0.04**	**0.74**	**1.36**	**0.05**	**0.73**
StDev	**0.13**	**0.02**	**0.09**	**0.13**	**0.02**	**0.12**	**0.12**	**0.02**	**0.08**

Note. No differences were observed in any of the metrics across tasks (all p>.05)

Table 3
Scores for all components of the AOSpan Task for each participant.

	Single Task				Dual Task			
	Working Memory Only				Walking + Working Memory			
Subject	Absolute	Partial	Speed error	Accuracy error	Absolute	Partial	Speed error	Accuracy error
1	31	44	0	1	22	45	1	1
2	32	59	5	0	44	61	0	3
3	10	33	0	5	11	25	0	2
4	35	61	0	3	44	62	0	0
5	9	20	0	0	57	65	0	0
6	14	35	0	0	32	48	0	3
7	0	19	0	2	32	50	1	2
8	26	47	1	0	18	44	0	0
9	44	60	1	0	25	54	0	0
10	0	23	0	1	29	51	0	0
11	9	33	1	2	22	37	1	1
12	57	67	0	0	49	60	0	1
13	7	29	0	3	8	23	0	1
14	21	38	0	3	13	43	0	1
15	10	30	0	2	14	37	1	1
16	7	43	0	3	8	36	0	2
Mean	**19.50**	**40.06**	**0.50**	**1.56**	**26.75**	**46.31**	**0.25**	**1.13**
StDev	**16.50**	**15.24**	**1.26**	**1.55**	**15.26**	**12.63**	**0.45**	**1.02**

Note. No differences were observed in any of the metrics across tasks (all p>.05)

CHAPTER V

DISCUSSION

The goal of this study was to examine the relationship between cognitive performance and gait performance when both tasks were performed concurrently. The primary hypothesis of this study was that a decrement in gait performance would be observed when performed concurrently with a working memory task (dual-task) compared to walking alone (single-task). Specifically, I expected that engaging working memory while walking would lead to a decrement in gait performance by shifting gait toward maladaptive behavior (higher standard deviation and lower DFA α). The results did not support my hypothesis.

Cognitive and motor task performance have been studied with regard to how performance can be improved or impaired, and one factor influencing task performance is working memory. Working memory relies on controlled attention to prevent distraction from the environment (Kane & Engle, 2000), as well as the ability to store information in the mind in order to perform both verbal and nonverbal tasks. Working memory is involved in one's ability to comprehend language, establish long-term learning, problem solve, and reason (Engle, 2002). The ability individuals have to perform complex cognitive activities distinguishes working memory from short-term memory, which is specifically involved in storing information (Baddeley & Hitch, 1974). Working memory tasks, such as the one used in this study (automated operation span task) require monitoring information in order to complete a goal-directed action. Thus, working memory is distinct from short term memory in that working memory refers to the structures and processes used for information manipulation and temporary storage whereas short-term memory does not require the manipulation of the organization of material held in memory.

Working memory impairment can affect sport and academic performance (Beilock, 2007). Poor working memory can affect one's ability to control and maintain the information being processed (Beilock, Rydell, & McConnell, 2007). Researchers have studied working memory to help explain intelligence, emotion regulation, autism disorders, cognitive differences for those with ADHD, and to improve teaching methods (Baddeley, 2000). Age has also been studied in relation to working memory, and working memory appears to decline with old age.

To understand how cognitive processes, such as working memory, interact with motor performance, a dual-task paradigm is often employed. Dual-task describes the act of performing two tasks simultaneously in order to compare performance in each task when performed individually (single-task). Lower performance scores in the dual-task condition can be interpreted from a limited resources perspective. That is, performance on the cognitive and/or motor task may be compromised because each task is competing for similar resources to guide the behavior. Research has shown that the simultaneous performance of movement and various cognitive tasks can lead to impaired cognitive performance (Lajoie, Teasdale, Bard, & Fleury, 1996) and reduced walking speed (Springer, Ghiladi, Simon, & Hausdorff, 2004). Furthermore, some studies have suggested that a decrement in gait performance is due to impairment of executive function from either natural causes or from dual-task conditions (Sheridan et al., 2003; Hausdorff et al., 2005).

In dual-tasks involving gait and cognition, the attentional demands of controlling balance vary according to the complexity of the tasks being performed (Woollacott & Shumway-Cook, 2002). Dual-task walking and cognitive performance tends to lead to individuals prioritizing one task over the other (i.e. either walking or cognitive task). This leads to two postulates that describe what can result from the concurrent performance of a cognitive and walking task. One postulate is that a decline in cognitive performance would be observed when walking concurrently. Thus, it is expected that an individual will prioritize resources so that the walking task can be attended to leaving fewer resources for the cognitive task. The posture-first principle (Woollacott & Shumway-Cook, 2002) supports this postulate because it posits that humans may prioritize gait performance over one's performance on a cognitive task because threats to one's walking may cause the individual physical harm (i.e. falling). Another postulate is that a decline in gait performance would be observed when performing a cognitive task concurrently. Thus, gait would exhibit a more maladaptive pattern in the concurrent task as compared to the walking-alone task. My hypothesis supported this postulate. However, the results were not supportive of this postulate.

Many of the aforementioned studies on dual-task performance typically examined a summary statistic of overall performance, such as the mean score or standard deviation of the mean score on a task. A complimentary and more microscopic way to examine performance is through a dynamics framework. This framework suggests that the manner in which a task is carried out is informative about the overall control mechanism. Thus, moment-to-moment changes in behavior *during* the task are recorded and analyzed to determine how the control process emerged and the end product of performance was obtained.

To quantify the dynamic patterns exhibited by a system, an analysis called Detrended Fluctuation Analysis (DFA) was developed (Peng et al., 1994). DFA produces an alpha (α) metric that indexes the strength of long-range correlations. DFA α in physiological systems typically range from 0.5-1.0. The middle of the continuum (0.75) represents the dynamic behavior in cognitive and motor tasks of healthy young adults, which consists of regularity with concurrent adaptive variation. This allows the system to remain stable, yet poised to adapt to challenges as needed. For example, it is desirable to have a stable gait pattern when walking, but adaptation of the gait pattern is needed when challenges such as stairs or pedestrians are imposed. Healthy young adults exhibit this type of behavior in their motor and cognitive performance which allows them to flexibly interact with their environment. However, if a constraint such as a knee injury or a cognitive stressor is imposed, behavior typically transitions toward a DFA α of either 0.5 (more random behavior) or 1.0 (more patterned behavior), depending on the context. A shift in either direction represents maladaptive behavior relative to healthy young adults. The shift toward maladaptive behavior after the imposition of a motor or cognitive constraint is a robust finding in the dynamics literature (Diniz et al., 2011; Kloos & Van Orden, 2010; Stergiou & Decker, 2011). When the shift in behavior is due to natural causes, it is typically referred to as dynamical disease (Belair, Glass, Heiden, Milton, 1995). Research has shown that more random behavior (i.e., lower DFA α values, weaker long-range correlations) are observed in the gait patterns of older adults with Parkinson's disease, Huntington's disease, and amyotrophic lateral sclerosis due to degradation in neural control (Hausdorff, 2007).

Kiefer et al. (2009) adopted a dynamics framework to further investigate the interaction between gait and cognitive performance in single- and dual-task walking and cognitive tasks. This research investigated the structure of cognitive performance variability during concurrent task performance. The researchers expected that participants' cognitive dynamics would increase in randomness when asked to perform a cognitive timing task while walking. Participants were tested individually in three conditions: temporal estimation performed alone while seated, walking performed alone, and temporal estimation and walking performed concurrently. In the temporal estimation task, participants repeatedly reproduced intervals of a fixed duration by pressing a button when they thought the one-second interval had completed. Therefore, cognitive dynamics were measured in terms of a timing mechanism used to identify variation between beats. In the walking alone task, participants walked at a self-selected pace. In the concurrent task, participants walked at the same self-selected pace while performing the temporal estimation task. The results from Kiefer et al. (2009) showed that there were no changes in standard deviation or mean for the cognitive task or the gait task. However, it was found that the timing between beats in the cognitive task became more random in the dual task as compared to the single task. Thus, this increased randomness in cognitive dynamics was interpreted as cognitive dynamics being reorganized to successfully complete task performance in dual-task conditions. The authors argued that the increased randomness of cognitive dynamics was not due to limited attentional resources due to the absence of an overall performance decrement for standard measures of either task.

The results of my thesis demonstrate results similar to the Kiefer study in that both studies report no differences in the mean, standard deviation or dynamics (DFA α) of gait performance when it was performed as a dual-task compared to a single task. Furthermore, no differences in the mean or standard deviation of cognitive performance were observed in my study, further paralleling the findings of the Kiefer study. Due to the nature of their cognitive task, Kiefer and colleagues were able to examine the dynamics of cognitive performance and only then did they observe an effect of dual-task condition. Thus, the Kiefer et al. (2009) study differed from the one in this thesis in two important ways. First, their cognitive task was conducive to a dynamic analysis, allowing for a more microscopic examination of how the cognitive task was performed on a moment-to-moment basis. Second, the cognitive task they used was a timing task which may be more closely related to motor control timing (stride interval timing). When asked to perform the gait task concurrently, the cognitive and gait task in the Kiefer et al. study may have been drawing upon similar timing resources and lead to the increased randomness of cognitive dynamics. Contrary to this, my study used the automated operation span task in which participants were asked to calculate math problems while simultaneously remembering a word. This task drew on working memory and attentional focusing resources while the gait task drew from motor resources.

Hausdorff et al (2005) provided evidence that routine walking can be considered a relatively complex task that requires higher-level cognitive input, but they found that walking was not impacted by memory or cognitive function in general. The results of my study support this notion since gait dynamics did not fluctuate in single versus dual-tasks. Woollacott and Shumway-Cook (2002) found that in dual-tasks involving gait and cognition, the attentional demands of controlling balance vary according to the complexity of the tasks being performed. In the case of the current study, it is possible that the gait task was more complex than the cognitive task subjects performed. This would support the findings of Woollacott and Shumway-Cook.

To ensure that the participants in the current study were performing the working memory task while walking, their cognitive scores in the dual task were compared to their cognitive scores when only performing the working memory task. No differences were found when comparing the cognitive scores between tasks. An accuracy criterion was included in the design of the cognitive task to ensure participants were correctly answering 85% of the math problems correctly. Since all subjects answered with at least 85% accuracy on the cognitive task in both the single and dual conditions, it is safe to assume that the subjects were doing the cognitive task. This indicates that subjects were performing the cognitive task equally when in the single or dual task condition, which does not support the notion that walking would influence summary measures (mean and standard deviation) of cognitive performance.

A third walking task was also incorporated into this study to determine if a different cognitive task (reading) influenced gait performance. Thus, participants were asked to read an article from a projector screen while concurrently walking on a treadmill. After participants completed this condition, they were asked several questions from the reading to confirm they were doing the task. These questions were based off of the first few pages of reading to assure that every participant would be able to answer the questions if they did the reading. Subjects were consistent in accurately answering the questions. Again, no differences were observed in the mean, standard deviation or dynamics of gait performance, suggesting that reading, just like working memory, has no influence on the control of gait.

It should be noted that two participants in the current study scored a 0 on their absolute score and relatively low on their partial scores (19 and 23). To determine if these two participants were affecting the data set, their data were removed and the analyses were rerun. However, the absolute and partial scores were only slightly raised (22.3 and 42.8) and no differences in the statistical analyses were observed when compared to the entire data set. Given the relatively lower cognitive scores of the participants in the current study compared to normative data, it is plausible that the participants did not have the working memory ability to do the task at a high level or they performed at a subpar level in both tasks. This is plausible considering UNCG undergraduate students tend to perform relatively lower than other schools on the operation span (Redick et al., 2013).

The results from this study did not show a difference in gait performance metrics in the single or dual task conditions. One could argue that this may be due to the participant not performing the secondary task while walking. However, since cognitive performance was not different, I can confidently say that participants were performing the cognitive task while walking. Instead, it is possible that no differences were found in gait performance metrics because the cognitive task and gait task were not drawing from the same resources. Thus, the participants may have been able to separately draw on motor resources and cognitive resources without having to compete for similar resource pools.

Limitations

One possible limitation of this study was that individuals completed all tasks in one two-hour session. This may have affected the reliability of the AOSpan task since the test-retest sample used in Unsworth et al. (2005) had a mean lag time of 13 days (ranging from 1 to 173 days). Another limitation was that subjects walked on a motorized treadmill. Even though subjects were able to self-select their pace, treadmill walking can reduce the gait variability of locomotor kinematics because it allows for fewer options in altering one's speed. Also, the gait task difficulty was minimal in that the terrain was even and uninterrupted by obstacles. However, the present study needed to be conducted using a motorized treadmill so that walking speeds could be controlled for across conditions. Another limitation is that subjects performed the AOSpan task sitting down as opposed to standing. Had the subjects been asked to stand on the treadmill while completing the task, the condition would have been more similar to the dual task condition (walking while performing the AOSpan task). However, in order to keep the procedure of this AOSpan task as similar to the original one performed in Unsworth et al. (2005), it was decided that the participants should perform that task while seated. Finally, the findings in this study may be limited in generalizability due to the small size of the sample and that the sample was predominately female. Investigations involving larger, more representative samples are needed to examine the interactions of gait task difficulty and cognitive task difficulty.

Future Directions

The results in this study raise a number of relevant questions for future research. What is the effect of dual-task inference on gait and cognitive performance during more attention-demanding gait tasks? Would gait patterns fluctuate in overground walking due to having a more complex surrounding environment? Does the automated operation span sufficiently tax working memory? Such questions will need to be addressed in future studies in order to further understand the relationship between working memory and gait. While there were no order effects found in this study, four of the 16 subjects got better on the AOSpan task in the dual-task condition. This could be an area of future direction. Research regarding these questions may help lead to a model of dual-task performance in terms of limited attentional resources. Future research should continue to pursue the relationship between dynamic patterns in gait and cognition to help clinicians and researchers provide better rehabilitation to those with impairments (either in gait or cognition). This advancement in research is dependent on identifying whether gait and cognition share the same resource pools, as well as what factors influence impairment in walking and cognitive patterns. The challenge for researchers pursuing answers to these questions is that there may not be a way to quantify or identify shared resource pools.

Conclusion

Research examining the relationship between working memory and gait is a relatively new area. Studies involving young and older adults are increasing our understanding of the role cognitive factors plan in the control of stability while walking. Using dual task paradigms to examine the effect of attentional requirements of balance control when performing a secondary task is important in better understanding stability in both healthy and impaired older adults. The results from this study did not show a difference in gait performance in the single or dual task conditions. It is possible that no differences were found in gait performance because the cognitive task and gait task were not drawing from the same resources. Since cognitive nor gait dynamics did not change from single to dual task conditions, and these results shared consistencies and inconsistencies with past research, it is apparent that more research needs to be done regarding the shared resources involved in cognitive and gait tasks.

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APPENDIX A

CONSENT FORM

Project Title: The Relationship between Working Memory and Gait Performance

Principal Investigator: Christopher K. Rhea, PhD
Student Researcher: Jordan Grubaugh

Participant's Name: ____

What this study is about?
This is a thesis research project. The goal of this study is to examine changes in walking behavior under cognitive load.

Why are you asking me?
You are being asked to participate because you are a person who demonstrates normal, healthy walking biomechanics and proper balance control. You should not participate if you have any neuromuscular injuries that cause abnormal walking biomechanics or if you do not have normal or corrected to normal vision. You must be between the ages of 18-30 to participate.

What will you ask me to do if I agree to be in the study?

You will be asked to partake in the following events (order will vary):

-You will be asked to walk on a treadmill at a self-selected pace for a duration of ten minutes.
-You will be asked to walk on a treadmill at a self-selected pace while repeating numbers you see on a screen for ten minutes
-You will be asked to complete a cognitive task on the computer for 25 minutes
-You will be asked to walk on a treadmill at a self-selected pace while simultaneously performing the cognitive task for 25 minutes

At the beginning of the session, we will place reflective markers on your lower limbs so we can record your biomechanics during the walking trials. You may ask to stop the trial at any time.

Is there any audio/video recording?
There will be no video or audio recording during the testing session.

What are the dangers to me?
The Institutional Review Board at the University of North Carolina at Greensboro has determined that participation in this study poses minimal risk to participants. There is a minimal risk that you could trip while walking on the treadmill. A spotter will be present at all times to ensure your safety.

If you have questions, want more information or have suggestions, please contact Christopher Rhea at ckrhea@uncg.edu. If you have any concerns about your rights, how you are being treated, concerns or complaints about this project or benefits or risks associated with being in this study please contact the Office of Research Compliance at UNCG toll-free at (855)-251-2351.

Are there any benefits to me for taking part in this research study?
There are no direct benefits to you for participating in this study.

Are there any benefits to society as a result of me taking part in this research?
The results of this project may inform basic and clinical science about the dyanmic nature of gait patterns under cognitive
load.

Will I get paid for being in the study? Will it cost me anything?
There are no compensations for participating in this study. There are no costs to you for participating in this study.
How will you keep my information confidential?
All information that is obtained from this study is strictly confidential unless disclosure is required by law. All consent forms will be maintained in a confidential file only accessible by the investigator and student researcher. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file separate from all data. When the study is completed and the data have been analyzed, this list will be destroyed. Your name will not be used in any report. The consent forms will be kept in a file in a locked room for three years at which time they will be destroyed by shredding. All data will be stored on the principal investigator's personal computer identified only by subject number. All data disks will be erased once all manuscripts of the data have been submitted and published for two years. A photocopy of this original consent form will be provided to you for your records.

What if I want to leave the study?
You have the right to refuse to participate or to withdraw at any time without penalty. If you choose to withdraw, it will not affect you in any way, and you may request that any of your data which has been collected be destroyed (unless it is in a de-identifiable state).

What about new information/changes in the study?
If significant new information relating to the study becomes available which may relate to your willingness to continue to participate, this information will be provided to you.

Voluntary Consent by Participant:
By signing this consent form you are agreeing that you have read, or it has been read to you, and you fully understand the contents of this document and are openly willing to take part in this study. You are also confirming that all of your questions concerning this study have been answered. By signing this form, you are agreeing that you are 18 years of age or older and are agreeing to participate.

Signature: ____
Date: ________________________

RESEARCH PARTICIPANTS NEEDED

A study examining patterns in your walking under cognitive load

Principal Investigator: Christopher K. Rhea, PhD (UNCG)
Student Researcher: Jordan Grubaugh (UNCG)

WHO CAN BE IN THIS STUDY?

FEMALES and MALES:

- 18-30 years old
- No neuromuscular conditions that affect balance or walking ability
- Normal or corrected to normal vision

WHAT DO I HAVE TO DO?

You will walk on a treadmill for short durations (10 minutes) and long durations (25 minutes). You will be asked to complete a memory task. Your walking biomechanics will be recorded using motion capture cameras. Total time commitment is approximately 1.5 hours

WHERE?

Testing takes place in the Virtual Environment for Assessment and Rehabilitation
Laboratory (VEAR Lab) in HHP Building Room 247 at UNCG.

COMPENSATION

There is no compensation for this study.

For more information and to participate, contact Jordan Grubaugh at j_grubau@uncg.edu

Questions asked the participants after the walking while reading condition:

1) How is choking under pressure described in this article?

2) What were the two mechanisms of performance failure?

3) Why is math anxiety important to study, according to this article?