Attentional requirements of walking according to the gait phase and onset of auditory stimuli

Gabriela de A. C. Abbud

A Thesis

in

The Department

of

Exercise Science

Presented in Partial Fulfillments of the Requirements
for the Degree of Master of Science at
Concordia University
Montreal, Quebec, Canada

March 2008

Your file Votre référence
ISBN: 978-0-494-40860-5
Our file Notre référence
ISBN: 978-0-494-40860-5

Abstract

Attentional requirements of walking according to the gait phase and onset of auditory stimuli

Gabriela de A. C. Abbud

The influence of an attention demanding cognitive task on each phase of gait was analyzed, using a dual-task paradigm. Electromyography (iEMG) from eight muscles from the dominant leg was collected from 23 participants (age 18-27) while walking on a treadmill at a 20% increase of their self-selected speed and while walking and performing a cognitive task. The cognitive task consisted of subtracting one (EASY) or seven (HARD) from numbers aurally presented. Reaction time (RT) and accurate responses of the cognitive task were recorded. iEMG events were selected according to stimuli onset (0-150 ms, 150-300 ms and 300-450 ms) prior to the phases of gait (double-leg, single-leg and swing). There was a decrease in iEMG amplitude of fibularis longus ($p = .013$) and vastus lateralis ($p = .065$) while walking and performing the cognitive task. When stimulus onset was considered, iEMG of medial gastrocnemius ($p = .021$) and lateral gastrocnemius ($p = .004$) were reduced during single-leg stance, when stimuli occurred between 300-450 ms prior to this phase. Participants committed more errors and had longer RT on the HARD task. RT was longer when subtracting while walking in comparison to subtracting alone. Young adults expressed dual-task cost in the motor and the cognitive tasks, suggesting that walking requires attention. There was a specific moment (300 ms after stimulus onset) during single-leg stance that dual-task cost occurred. Reasons for this interference and the implications of a reduction in iEMG while walking and performing an attention demanding cognitive task are discussed.

Acknowledgments

I could not have gotten through this period without the help of many.

Dr. DeMont and Dr. Karen Li – thank you for your supervision, support, patience and understanding. Your contribution to this work and to my growth have been incredibly important and appreciated.

Dr. Virginia Penhune – thank you for the encouragement and the discussions.

Laura Fontil, Anthony Hopley and Claudia Starnino – thank you for making the long periods of data collection and analysis a lot more fun!

Sarah Fraser – thank you for initiating the work, for the discussions and for the relevant comments.

Chris Steele – thank you for your kindness... and for all your much appreciated suggestions.

Alejandro Endo – thank you for the technical help.

To those behind the scene – thank you for providing a comfortable and enjoyable environment at home, for the moral support and friendship.

Mãe e Pai – obrigada por tudo o que vocês são, afinal, nada teria sido possível sem o apoio de vocês.

Table of Contents

List of Figures and Tables

List of Appendices

Introduction

Walking is a daily activity that, once learned, requires little effort. It is the most common method of locomotion, providing a considerable level of physical independence for an individual. Impaired mobility and gait can significantly reduce independence leading to a decrease in quality of life. The cognitive component of walking is sometimes neglected - even though it has been shown that walking requires attention. The dual-task paradigm is the most commonly used methodology to investigate cognitive influence on gait. However, results can vary considerably and the dynamic rhythmic pattern of gait is not usually taken into consideration when this paradigm is used.

The Gait Pattern

Human walking is a method of locomotion where both legs are used alternately and continuously to provide body support and propulsion (Whittle, 1991). An efficient gait implies stability of the body, while the center of mass (CoM) is progressing forward, maintaining a pattern of movement that can be adapted to the environment. The CoM is considered as the center of total mass of the body and the vertical projection of the CoM is defined as the center of pressure (CoP) (Shumway-Cook & Woollacott, 2001). Most static posturography studies use the upward projections of the CoP as an estimate of CoM, because they are similar in magnitude. However, the CoM represents a movement while the CoP represents a force (Baratto, Morasso, Re, & Spada, 2002). In this paper, CoM and CoP will be used interchangeably according to how it was used in the reference.

Walking is characterized by a cyclical pattern of movement of the entire body. In the lower limb, the cycle is defined as the time interval it takes for the same two events to occur in one leg. Usually, a cycle is considered from the moment of heel contact to the ground of one foot until the next heel contact of the same foot (Whittle, 1991). The gait cycle is divided into two main phases, stance and swing, each corresponding to approximately 60% and 40% of the total cycle respectively. The stance phase commences from heel contact with the ground and terminates when the toes push off. Approximately 20% of the stance phase is composed of double-leg stance, a period when both feet are touching the ground. The time of double-leg stance varies according to gait speed and tends to diminish as gait speed increases, until disappearing entirely during running (Rose & Gamble, 2006). The swing phase begins when the limb leaves the ground and is projected anteriorly, ending with the heel striking the ground. There is a phase lag of half a cycle between each limb, this lag accounts for the double-leg stance. Thus, one limb starts its cycle when the contralateral limb is at the midpoint of its cycle (Shumway-Cook & Woollacott, 2001).

An efficient locomotor pattern implies lower energetic cost. Transference of kinetic and gravitational energies from one phase to another is achieved by a smooth forward transition of the CoM. The proper coordination of muscles and joints of each limb contributes to this mechanism. During the swing phase, muscle activity in the swing limb is low as the leg is performing a movement similar to a pendulum (Shumway-Cook & Woollacott, 2001). Yet, proper planning of foot trajectory is required to clear toes from the ground and to decelerate the leg as the limb reaches the end of the swing phase. In order to maintain stability during the subsequent stance phase, the swing foot needs to be placed ahead and lateral to the CoP as it is moving forward (Shumway-Cook & Woollacott, 2001; Winter, 1992). At the end of the swing phase, muscle activity from knee flexors and hip extensors increase, in order to decelerate the movement. On the other hand, the muscles of the stance leg need to be active to provide stability of the body and to generate propulsion for the subsequent swing phase (Rose & Gamble, 2006). Therefore proper coordination of muscle contraction during the swing and stance phases is necessary to reduce energy cost and optimize gait.

The Motor Control of Gait

Stability is an important component of any motor task, including walking. Balance is defined as the ability to maintain the CoP within the limits of the base of support. During quiet upright stance, balance is maintained through the combination of specific balance strategies that cause the body to move like an inverted pendulum (Horak, 2006; Shumway-Cook & Woollacott, 2001). Ankle, hip and stepping strategies are used to maintain or restore the CoP within the limits of stability, thus restoring balance. The ankle strategy is composed of movements centered on the ankle joint (Shumway-Cook & Woollacott, 2001) and, as a consequence, the body moves in a cone-shape configuration with the feet as the apex of cone (Horak, 2006). When a hip strategy is used, the CoP is maintained within the base of support by large and fast torques at the hip joint. This strategy is usually used when the ankle strategy is not sufficient to restore balance or after a fast and large perturbation of the body. The step strategy consists of taking a step or hopping in order to increase or move the area of stability. It is commonly used when neither the ankle nor hip strategies are sufficient to recover balance (Shumway-Cook & Woollacott, 2001). However, during gait, dynamic equilibrium is required. Complex control of the body as a whole and of its parts must occur because there are short periods when the CoP falls out of the base of support (Winter, 1992). In the late half of the swing phase the CoP moves anteriorly to the base of support delimited by the contralateral foot, which is in the stance phase. Therefore, the heel contact to the ground, during the end of swing phase, is a critical moment for stability. If a slip or trip occurs at this point, the stance foot is not able to maintain proper balance and the swing foot has to be safely placed on the ground to restore the CoP within the limits of stability (Winter, 1992). Proper placement of the swing foot on the ground and toes clearance are crucial for a normal walking pattern, being especially important for individuals post-stroke (Goldie, Matyas, & Evans, 2001). When a mechanical perturbation of movement trajectory during step execution occurs, compensatory muscle activity is generated in order to maintain stability and recover movement trajectory (Dietz, Colombo, & Muller, 2004). Therefore it seems clear that dynamic stability achieved through online regulation of the walking pattern is a key component of gait.

The integration of peripheral information into complex motor responses is achieved through feedforward and feedback mechanisms (Kandel, Schwartz, & Jessel, 1991). Shumway-Cook and Woollacott (2001) describe feedforward responses as proactive mechanisms and feedback responses as reactive mechanisms. These motor responses are crucial for balance control during gait, providing online regulation of step execution to promote adaptability of the walking pattern. Proactive mechanisms are mostly based on visual input: changes in the environment are identified and the motor system can anticipate the responses according to the environmental changes. As an example, when stepping down stairs the tibialis anterior muscle is contracted before the foot reaches the next step, accounting for feedforward/proactive control (Kandel, 1991). In turn, reactive strategies are strongly based on all sensory systems (somatosensory, visual and vestibular) to control ongoing movement continuously. Sensory inputs from the limbs contribute to step frequency, gait rhythm, transition from stance to swing and reflex modulation during gait to adapt to each phase. Vision allows the individual to perceive the environment and align the body with reference to gravity. The vestibular system contributes to head stabilization and posture control (Shumway-Cook & Woollacott 2001). Feedback/reactive responses operate more slowly compared to feed forward/proactive response, because it relies on sensory inputs to provide corrections, thus involving a longer neuronal loop (Kandel, 1991).

During walking, the roles of the somatosensory systems vary according to the phase. Vestibular information is used differently across initial and terminal parts of step execution. Vestibular information seems to be mostly used to provide online (feedback/reactive) regulation during terminal swing and to correctly place the foot on the ground (Bent, Inglis, & McFadyen, 2004).Whereas galvanic vestibular stimulation causes no CoP deviation during initial swing, it alters CoP excursion during terminal swing (Bent, Inglis, & McFadyen, 2002). Somatosensory inputs from joints, muscles, and skin are essential for normal walking. Stimulation of $A\beta$ fibers during the swing phase causes a facilitatory muscular response from the biceps femoris muscle with a latency of approximately 80 ms. The same type of stimulation of tibialis anterior causes a reflex-reversal response, characterized by a facilitatory response during initial swing and suppressive response during terminal swing (van Wezel, van Engelen, Gabreels, Gabreels-Festen, & Duysens, 2000). During the swing phase, when the leg performs a ballistic movement, control is initially achieved by feedforward mechanisms. The influence from the somatosensory system is small during initial and mid swing, with the influence of somatosensory and vestibular systems increasing as the foot reaches the ground and accepts body weight. During the stance phase, the importance of afferent somatosensory input increases as weight is being supported on one limb. Furthermore, because the CoP does not fall within the base of support of the stance limb (Kirtley, 2005; Winter, 1992), balance is challenged and online regulation (i.e., feedback/ reactive mechanisms) needs to occur in order to maintain stability. In conclusion, in comparison to swing, stance seems to be more influenced by feedback/reactive mechanisms, based mainly on somatosensory and vestibular information, since visual afferents tend to be constant during both phases.

Sensory information needs to be integrated to allow correction and online regulation of the gait pattern. Effective navigation through the environment, which involves planning, execution, termination and adaptation of gait, requires adequate communication between spinal and supraspinal structures. The cerebellum is involved in the regulation of the gait cycle by converging peripheral information from limbs and trunk to provide correction of ongoing movements and timing (Kandel, 1991). The basal ganglia are involved in emotional, motivational, associative and cognitive functions, in addition to a range of motor functions indirectly. The basal ganglia possess a complex circuitry involving many afferent projections from sensorimotor cortex, frontal cortex and other limbic areas, hyppocampus and the amygdala; with efferent inputs to motor, premotor, and limbic cortical areas (Herrero, Barcia, & Navarro, 2002). The primary premotor and supplementary motor areas, in addition to cerebellar vermis, visual cortex and the basal ganglia have increased activation during walking (Fukuyama, Ouchi, Matsuzaki, Nagahama, Yamauchi, Ogawa et al. 1997)

It has been shown that a decerebrated cat can produce a rudimentary walk movement of alternating steps. This rhythmic pattern of movements without conscious control is achieved through the activity of the central pattern generators (Armstrong, 1988). The central pattern generator for locomotion is thought to be a pool of neurons localized in the spinal cord that can coordinate sequence and timing of muscle contraction necessary for the movement pattern to occur. In humans, the results achieved with animal models have not been replicated, and information regarding the location of the central pattern generators and the circuitry involved in such control is still lacking (for a review see MacKay-Lyon, 2002). Human walking is more complex and can not be considered simply as a reflex pattern of reciprocal activation of flexors muscles (during swing) and extensors muscles (during stance). Muscle activity from flexors and extensors from the lower limbs are not in phase. There is a delay of ankle extensors activity after heel contact to the ground when most of the activity from the extensor muscles from the opposing leg have ended (Capaday, 2002). Gait requires the integration of sensory input from somatosensory, visual and vestibular systems to generate motor responses and achieve an efficient pattern. In addition, gait requires higher level of cognitive resources to estimate, plan and perform online regulation of movement. Therefore, human walking can not be considered a stereotypical rhythmical activity such as tapping (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005)

Attention Demands of Gait

There is consistent evidence in the literature that walking demands a certain level of attention (Woollacott & Shumway-Cook, 2002). Attention becomes more important when the nervous system is being challenged with multiple tasks or when there is a disruption in its normal functioning, such as that which occurs with ageing or cerebral damage. Most of the studies demonstrating attentional influence on gait have used dual-task methodology. According to Pashler, (1994) "Overloading a system is often one of the best ways to figure out what the parts of the system are and how these parts function together. For this reason, studying dual-task interference provides an important window on basic questions about the functional architecture of the brain" (pp. 220). Dual-task experiments consist of performing two simultaneous tasks that are thought to be attentionally demanding and usually do not share the same processing resources. If at least one of the tasks requires attention, they are hypothesized to interfere with each other because the limited mental resources available have to be shared for both tasks. Therefore, when two tasks are being performed simultaneously, the performance on either or both is impaired (Pashler, 1994).

In healthy young adults, the attentional influence on gait is small unless the motor system is stressed and they are required to perform complex cognitive or motor tasks. Lajoie, Teasdale, Bard, and Fleury, (1993) showed that the performance of a secondary task of responding to an auditory stimulus decreased as the balance requirements for the motor task increased. There was an increase in reaction time to the auditory stimulus from sitting, to standing in a tandem position, to walking. In this study, walking was the most attention demanding task. However, in older adults, the effects of attentional interference tend to be more significant, resulting in a decrease in performance of either the cognitive or the motor task under relatively simple conditions (Woollacott & Shumway-Cook, 2002). This difference results from age-related neurological, physiological, spatio-temporal and musculo-skeletal changes. As individuals age, there is a reduction in the acuity of the vestibular, visual and somatosensory systems, an increased rate of brain loss, a decrease in muscle strength and aerobic capacity, joint-related dysfunction, and a reduction in gait speed and balance, among other changes (Prince, Corriveau, Hébert & Winter, 1997). Therefore, it is not surprising that older adults may require a greater level of attention while walking, expressed by either a decrease in motor or cognitive tasks performance (Melzer & Oddsson, 2004). In addition, the effects of dual-task performance tend to be greater when there is a disruption of the normal functioning of the central nervous system, such as in Parkinson's disease (O'Shea, Morris, & Iansek, 2002), after cerebral brain injury (Haggard, Cockburn, Cock, Fordham, & Wade, 2000), stroke (Regnaux, David, Daniel, Smail, Combeaud, & Bussel, 2005) or concussion (Catena, van Donkelaar, & Chou, 2007; Parker, Osternig, Lee, Donkelaar, & Chou, 2005).

On the other hand, it has been suggested that performing two tasks at once can increase the level of alertness of the individual. Older and younger adults improved their performance in an auditory reaction time task when it was performed while walking at a self-selected comfortable speed (Fraser, Li, DeMont, & Penhune, 2007). Individuals that had suffered a concussion improved gait stability parameters when performing a simple reaction time task in comparison to walking alone (Catena et al., 2007). Given the contrasting results in the literature, Huxhold, Li, Schmiedek, & Lindenberger (2006) designed a study where stimulus presentation and response mode were kept constant while other parameters such as age, attentional focus and cognitive demands were manipulated. In younger and older adults the addition of a simple cognitive task reduced CoP displacement during quiet stance; what was considered as dual-task facilitation.

However, for older adults, the positive effects of a concurrent cognitive task tended to diminish as the difficulty of this task increased. For younger adults, the same increase in difficulty of the cognitive task did not significantly affect balance. Depending on the level of difficulty of the tasks, more attentional resources may be mobilized when they are combined in comparison to when they are performed alone, resulting in better performance of either one or both tasks.

In conclusion, even though dual-task methodology has been widely used experimentally to analyze the attentional demands of walking, results can vary considerably. Dual-task facilitation, dual-task cost, or absence of interference between the motor and cognitive tasks depends mainly on the nature of both tasks (Ebersbach, Dimitrijevic, & Poewe, 1995). The effects of a concurrent task not only depend on the attentional capacity of the individual, but also on the difficulty that the tasks impose on the central nervous system. Thus, one has to be critical when making comparisons between studies and inferring results. There are many variables that need to be taken into consideration, such as the nature of the motor task (Lajoie et al., 1993; Ebersbach et al., 1995; Fraser et al., 2007; Regnaux et al., 2005), the nature of the concurrent task, that can be either motor or cognitive (Haggard et al., 2000 ; Barra, Bray, Sahni, Golding, & Gresty, 2006; Galletly & Brauer, 2005), and the characteristics of the individuals (Melzer, Benjuya, & Kaplanski, 2001; Fraser et al., 2007; Regnaux et al., 2005; Catena et al., 2007; Parker et al., 2005; O'Shea et al., 2002).

Timing of Motor Responses

Reflex postural responses from muscle stretch can be triggered approximately 70 to 100 ms after a perturbation (Kandel, 1991). The time of this response represents the summation of the sensory and motor conduction time and the time necessary for the excitation to occur in the lower limb. When balance responses are based exclusively on vestibular or visual inputs the response delay is almost double, ranging from 140 to 200 ms (Kandel, 1991). In accordance to this latency response, Norrie, Maki, Staines, and McIlroy (2002) using the dual-task methodology of maintaining balance while performing a visuomotor-tracking task, divided the control of upright quiet stance into different components. The first automatic balance reaction after the onset of perturbation from a platform took on average 144 ms (ranging from 104 ms to 179 ms). The balance reaction was defined as the first muscle contraction from the tibialis anterior or the gastrocnemius muscle (ankle strategy). In the second phase of balance recovery, which initiated on average 346 m after the perturbation, there was a pause on tracking movement during the visuomotor-tracking task. A switch of attention focus away from the visual-tracking task towards the maintenance of balance occurred, suggesting that this phase of balance recovery was more attentionally demanding. It should be highlighted that the timing of interference between a motor and a cognitive task can vary. Balance response during quiet stance may have greater latency than a dynamic condition such as walking, when fast and accurate motor adjustments need to occur.

During walking, reflexive muscle responses evoked through sural nerve stimulations have latencies between 90 (van Wezel et al., 2000) and 100 ms (Lamont & Zehr, 2006). Therefore, motor responses lower than 100 ms after the onset of a cognitive distractor should be automatic or reflexive and, therefore, minimally influenced by the stimulus itself. On the other hand, motor responses with greater latencies are likely to be centrally elicited and controlled, thus more susceptible to the influence of a cognitive task. When performing a dual-task experiment when the primary task is a dynamic condition, one should note that there could be periods of automatic motor responses and that an attentionally demanding balance reaction may be elicited several hundred milliseconds after the onset of the distractor stimulus. This is an important factor to consider when analyzing attention's influence during walking, because gait is extremely different from quiet stance. The balance requirements of each phase of gait are different and dynamic balance needs to be maintained. Furthermore, gait is a rhythmic cyclic movement. Therefore, the attentional cost of the motor task may only be exhibited in a later moment of the gait cycle, when the cognitive stimulus is being processed and balance is more demanding. In a recent study performed in our laboratory, muscle activity of the lower limb was reduced during the stance phase when an auditory stimulus occurred prior to the stance phase but not when the stimulus occurred during the stance phase (Abbud, DeMont, Fraser, Li, & Penhune, 2007). There was a delay of interference between the cognitive and motor task, probably as a result of the processing time of the stimulus and the online regulation of gait. In a subsequent study (Abbud, DeMont, Li, Fraser, Penhune, Hendry et al. 2008) we analyzed the interference of stimulus onset on muscle activity according to the phase of gait: either stance or swing. In accordance with the previous finding, muscle activity of medial hamstrings and medial gastrocnemius were reduced during stance phase when the auditory stimulus occurred prior to stance. However, muscle activity during the swing phase was not altered by the presentation of the stimulus, suggesting that there is a difference in attentional demands according to the phase of the gait cycle. Lajoie and colleagues (1993) observed an increase in reaction time to a simple auditory stimulus (responding to a tone) when it coincided with single-leg stance in comparison to double-leg stance. Regnaux and colleagues (2005) obtained different results when analyzing reaction time to an electrical stimulation delivered to the neck of participants while they were walking on a treadmill at their self-selected speed. The time taken to press a sensor was longer when the stimulus occurred during double-leg stance in comparison to when it coincided with single-leg stance. Although the sensory modality (auditory vs. somatosensory) and type of response (verbal vs. motor) involved in the tasks were different, these authors did not consider the time it could take for the secondary task to interfere with the gait pattern. Therefore, it may not be possible to draw conclusions about specific requirements of attention for the different phases of gait from these studies. Stimuli delivered during one specific phase of the gait cycle could interfere with the motor response at the next phase, which means that changes in reaction time could be a consequence of the attentional demands of the following phase.

Rationale and Objective

In summary, gait requires a certain level of attention, even for healthy young individuals, when the nervous system is challenged. Attentional demands should vary from one phase to another, because balance requirements, in addition to supraspinal and somatosensory influences on the walking pattern, vary according to the phase of gait. However, it is important to consider the time of interference between a cognitive task and the motor response, as suggested by early data from our laboratory. Motor responses as early as 100 ms after the onset of a stimulus should be automatic and; therefore minimally influenced by stimuli presentation. On the other hand, motor responses with greater latencies (~200 ms) are centrally elicited and controlled. Because centrally elicited responses require greater level of attention, they are more susceptible to cognitive interference.

This study was proposed to provide further understanding of the effect of a cognitive stimulus onset on each specific phase of the gait cycle through changes in the pattern of muscle activity. The effects of the motor task on performance of the cognitive task were analyzed through changes in reaction time (RT) and accuracy. Because muscle activity represents the output of the motor control system, it was hypothesized that muscle activity would decrease (considered as dual-task cost) from walking alone to walking and performing an attention demanding cognitive task. The reduction in muscle activity would be dependent on stimulus onset (>150 ms) in relation to the phase of gait being analyzed. In single leg stance the base of support is reduced and the CoP does not fall within this base, increasing balance requirements. Therefore it is hypothesized that this condition should be affected by a concurrent cognitive task. It was further hypothesized that dual-task costs would increase as the difficulty of the tasks increased. It was hypothesized that there would be dual-task cost in the cognitive task, characterized by an increase in RT and a decrease in accurate responses when the cognitive task was performed while walking compared to when it was performed alone.

Method

Participants

Twenty three adults (11 females and 12 males) between 18 and 30 years (*M*=23; *SD*=2.8), free of any conditions that could interfere with the motor or cognitive task, participated in this study. The number of participants was calculated based on the power and effect size of a previous study (Fraser et al., 2007). All participants were within normal limits on balance performance and neuropsychological tests. They were recruited on a volunteer basis via advertisements in the Department of Exercise Science at Concordia University and from the participant pool in the Department of Psychology. The study was approved by the Research Ethics committee of Concordia University (Appendix A) and all participants gave written informed consent (Appendix B) to participate in the study.

Material and Apparatus

Romberg Balance Test. To assess static balance, participants performed the Sharpened Romberg Balance Test (Briggs, Gossman, Birch, Drews, & Shaddeau, 1989). They were asked to stand in a tandem position (i.e., one foot in front of the other with the toes of the posterior foot touching the heel of the anterior foot) with their arms beside their bodies and their eyes closed for as long as they could, for up to 60 seconds. The examiner recorded the total time they were able to maintain this position without opening their eyes, swinging their arms or moving their feet. They performed six trials (three practice and three test trials) and their balance score was the average of the three test trials.

Star Excursion Balance test (SEBT). In order to assess dynamic balance, participants performed the SEBT. Strips of tape were placed on the floor at 45 degree angles to form a star-shaped figure (Figure 1). Participants were instructed to maintain one foot in a box in the intersection of the lines, while trying to lightly touch the tape as far as possible in all directions with the opposite foot (Gribble, 2003). The trial was discarded and repeated if they lost balance, if the reaching foot was used to support weight, or if the stable foot was lifted from the floor. Participants were free to use trunk and upper limb movements to maintain their balance, as this would allow them to develop and use their own strategy (Earl & Hertel, 2001; Gribble & Hertel, 2003). Participants performed 3 practice trails in each direction with each leg (Hertel, Miller & Denegar, 2000), with no more than 10 seconds between each trial. During the practice and testing trials, they were initially standing on the left leg as they reached with the right foot in a clockwise direction; then they stood on their right leg while reaching with the left foot in a counterclockwise direction (Gribble, 2003). All participants were exposed to the same practice and testing conditions following the same order: anterior, anteromedial, medial, posteromedial, posterior, posterolateral, lateral and anterolateral. Leg length was used to normalize the average distance reached for each participant (Gribble & Hertel, 2003). All measurements were taken by the same examiner. A composite balance score was calculated for each participant by averaging the reached distances in all directions.

Neuropsychological Tests. Neuropsychological tests were performed to obtain a general assessment of participants' cognitive status. The Stroop Test (Stroop, 1935 modified), Trail Making Test (Spreen & Strauss, 1998) and Digit Symbol Test (Weschler, 1981) were

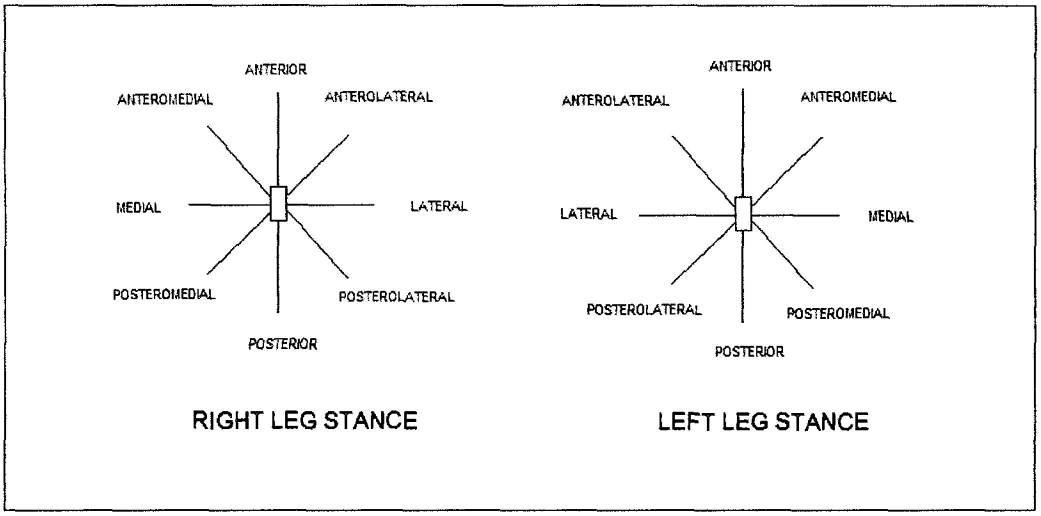


Figure 1. Reaching positions during the Star Excursion Balance Test for right and left leg stance. Participants always started the task by reaching the anterior position and then moving in a counter clockwise direction during right leg stance and in a clockwise direction during left leg stance.

used as cognitive assessment. A complete explanation of the cognitive tests and scoring methods used in this study can be found on Appendix C.

Electromyography (EMG). Surface EMG collection was carried out using Ag/AgCl conductive adhesive electrodes (Medi-Trace 133) with a bipolar electrode technique. EMG signal was sampled at 1000 Hz and amplified (gain 500) by a 27-channel amplifier (MYOPAC, RunTech Inc., Mission Viejo, CA), transmitted to a MYOPAC 16-channel receiver (RunTech Inc., Mission Viejo, CA) where it was further amplified (gain 500, total gain 1000), and A/D converted. Finally, the signal was integrated and stored in a Dell laptop computer where the signal was bandpass filtered (Butterworth) at 50 Hz (high) and 300 Hz (low) and rectified using DATAPAC2000 software (RunTech). The resulting signal was the integrated electromyography (iEMG) which was used for analysis.

Footswitches. An insole with five on-off pressure sensors was placed inside both shoes of participants (Figure 2). Based on footswitch signals it was possible to detect heel contact and toe-off, allowing identification of swing, single-leg and double-leg stance phases of gait.

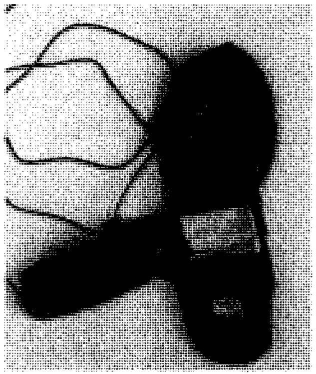


Figure 2. Footswitches with five pressure sensors (red dots) located at the base of the heel, base of the fifth metatarsal, head of the fifth metatarsal, head of the first metatarsal and first toe. Signals from the sensors were used to detect the moment of heel contact to the ground and toe-off.

Tasks

Motor (W). The motor task consisted of walking on a Biodex™ treadmill during two blocks of two minutes for the practice session and three blocks of three minutes for the test session. To challenge the nervous system, the level of difficulty of the motor task was increased by asking the participants to walk at a 20% increase of their own pre-selected, comfortable walking speed.

Cognitive (COG). In this portion of the experiment participants were instructed to complete calculations in response to aurally presented stimuli. Stimuli consisted of two-digit numbers ranging from 11 to 99, not including numbers ending with seven (e.g. 17, 27, 37...) and zero (e.g. 10, 20, 30...). Stimuli were spoken in a female voice, presented serially in a random order at ten different inter-stimulus intervals (ISIs: 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250 to 3500 ms) through wireless equipment (Evolution G2 Wireless System-Sennheiser Electronics). Participants were asked to subtract 7 (COG-HARD) or to subtract 1 (COG-EASY) verbally from the numbers they heard. Sixty stimuli were randomly arranged into four lists to be used in the four conditions: cognitive task/easy (COG-EASY), cognitive task/hard (COG-HARD), dual-task/easy (DT-EASY), dual-task/hard (DT-HARD). Two lists composed of 20 stimuli were used for the cognitive and dual-task conditions during the practice session (Appendix D contains the four lists of numbers used). Participants\` reaction time (RT) was measured using a custom-designed voice recognition program. Accuracy of the responses was recorded during testing by the experimenter and confirmed using a tape recorder.

Dual-task (DT). During this condition, participants executed the motor and cognitive tasks simultaneously. They walked on the treadmill at a 20% increase of their pre-selected speed and performed the easy and hard cognitive tasks (DT-EASY and DT-HARD). In order to avoid task prioritization caused by the instructions given by the experimenter (Verghese, Kuslansky, Holtzer, Katz, Xue, Buschke, et al. 2007) participants were instructed to pay attention to both tasks and that both tasks were equally important.

Procedure

Participants were called to attend a one-day two hour session in the Athletic Therapy Laboratory at Concordia University. They received information about the study and the tasks to be performed via telephone or electronic communication, and were asked to sign an informed consent form upon arrival. Participants answered a physical questionnaire (Appendix E) and then performed the Sharpened Romberg Balance Test (Briggs et al., 1989). Following this, participants completed the Stroop test (Stoop, 1935), Trail Making Test (Spreen & Strauss, 1998) and Digit Symbol Test (Weschler, 1981). Participants then performed the Star Excursion Balance test.

EMG was collected from the dominant leg of the participants. To determine the dominant leg, they were asked to stand against the wall and take three steps towards the examiner three times. The leg most frequently used to take the first step during the trials was considered the dominant one (Fraser et al., 2007). Eight muscles of the dominant leg were analyzed: vastus medialis (VM), vastus lateralis (VL), medial hamstrings (MH), lateral hamstrings (LH), medial gastrocnemius (MG), lateral gastrocnemius (LG), tibialis anterior (TA) and fibularis longus (FL); a reference electrode was placed over the tibia. Electrodes` placement was done according to Basmajian & Blumenstein (1989) and as described by DeMont, Lephart, Giraldo, Swanik, and Fu (1999). Before placing the electrodes, all visible hair was removed, the skin was lightly abraded with a nail file and cleaned with alcohol in order to reduce skin impedance and improve electrode adhesion. The footswitches were placed inside both shoes of participants. Prior to the experimental tasks, all eight muscle groups were tested for their maximum voluntary contraction.

After the set up of the equipment, participants were then asked to walk on the treadmill at a comfortable speed, as if they were walking on the street with a purpose, in order to determine their normal gait speed. Once their speed was determined, they were asked to re-adjust their speed according to the Borg scale of perceived exertion (Borg, 1982) targeting the number 12, representative of a level of exertion between "fairly light" and "somewhat hard". Participants were blind to their speed throughout the experiment.

After setting gait speed, participants performed a practice session in order to familiarize themselves with the tasks. The practice session had a fixed order, with three conditions: COG-HARD, W, and DT-HARD. After the practice session, they performed the test session, composed of 5 conditions: COG-EASY, COG-HARD, W, DT-EASY and DT-HARD in a counter-balanced manner (Appendix F).

Data Analysis

Motor task - iEMG.

Based on footswitch signals, markers were manually inserted to select iEMG events during the double-leg stance (DL), single-leg stance (SL) and swing phase (SW), from the dominant leg. iEMG of each phase was selected for the analysis according to the auditory stimulus onset at three different intervals: (0) when the stimulus occurred less than 150 ms prior to the gait phase, (1) when the stimulus occurred 150 to 300 ms prior to the gait phase, and (2) when it occurred from 300 to 450 ms prior to the gait phase. For each participant iEMG events were selected for SW, SL and DL according to intervals 0, 1 and 2. Because the time interval overlapped for the different phases, the same auditory stimulus could be used as a reference for one phase in interval 0 but for another phase in interval 1 (Figure 3).

The mean amplitude of iEMG during each phase was normalized to the maximum voluntary contraction, which represented the linear smoothed (10 msec) peak amplitude of the iEMG of the isometric contraction. This normalization procedure was done in order to facilitate comparison between participants. iEMG data from intervals 0,1 and 2 were collapsed for DT-EASY and DT-HARD, resulting in a value that was used for comparison to the W condition. A 3x3 repeated-measures analysis of variance of phase (DL, SL, SW) and task (W, DT-EASY, DT-HARD) was conducted to compare single vs. dual-task muscle activation regardless of the onset of the auditory stimulus (intervals). A further analysis was done in order to identify differences in muscle activity according to stimulus onset. The mean iEMG amplitude of each phase (DL, SL, SW) was matched with the three intervals (0, 1 and 2) for both levels of difficulty (EASY, HARD), resulting in a phase x onset x difficulty (3 x 3 x 2) ANOVA. Pairwise t-test comparison was carried out using Bonferroni correction to identify the direction of iEMG change.

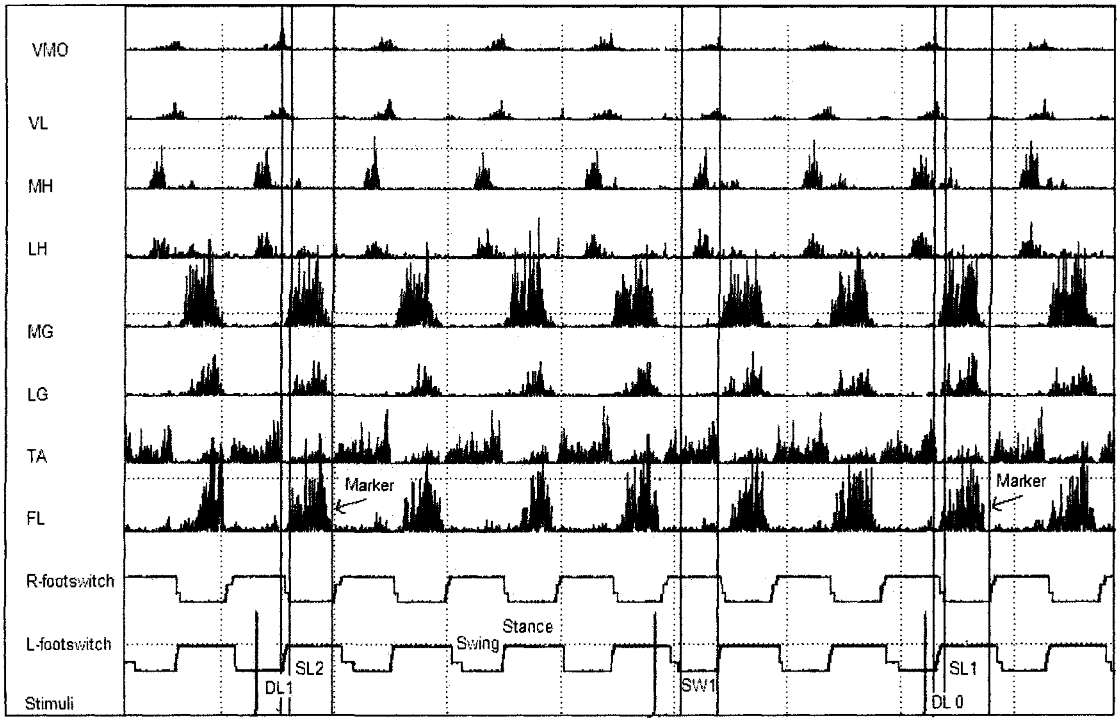


Figure 3. Footswitch signal identifying different phases of gait: swing (SW), double leg stance (DL) and single leg stance (SL). Each line represents the rectified EMG amplitude for each muscle group (Vastus Medialis-VMO, Vastus Lateralis-VL, Medial Hamstrings-MH, Lateral Hamstrings-LH, Medial Gastrocnemius-MG, Lateral Gastrocnemius-LG, Tibialis Anterior-TA and Fibularis Longus-FL). Note that the same auditory stimulus (represented by small vertical lines at the bottom) falls in interval 1 for double-leg stance (DL1) and in interval 2 for single-leg stance (SL2) for example. The long vertical lines represent the manually inserted markers identifying the iEMG to be analyzed.

Cognitive - RT and Accuracy.

Mean RT from the stimulus offset to response offset of correct responses only and percentage of correct responses were calculated during COG-E, COG-H, DT-EASY and DT-HARD conditions. A multifactorial analysis of variance was performed to identify changes in RT or in accuracy according to the task and to the level of difficulty. It resulted in a task (single and dual) x difficulty (EASY and HARD) ANOVA.

Results

In the present study it was investigated the interference between a motor and an attentionally demanding cognitive task. The motor task, walking, was analyzed through changes in iEMG, while performance in the cognitive task was analyzed through changes in RT and accuracy of the response.

On average, participants walked on the treadmill at 2.9 mph -4.67 km/h- (*SE* = 0.44 mph -0.71 km/h) at their pre-selected speed (based on the Borg scale of perceived exertion) and at 3.4 mph -5.47 km/h- (*SE* = 0.50 mph -0.80 km/h) with 20% increase. In order to identify outliers, iEMG values were converted to Z-scores and values that were above or below three standard deviations from the mean were excluded from the single-task condition, as they were considered outliers. Two participants were excluded from the entire analysis because they had a particular iEMG profile (see later discussion). From the remaining 21 participants, no outliers were found regarding balance measures and cognitive function. However participants differed in their level of physical activity: four individuals out of 21 were not active (active was defined as engaging in physical activity at least once a week). Therefore independent sample t-tests were performed in order to identify differences between individuals that were physically active and those that were not active (Table 1). Because there was no significant difference between groups in any of the scores (all p-values $> .05$), participants were considered as one group.

		Balance performance			Neuropsychological tests		
Groups		Gait speed (km/h)	SEBT (cm)	Romberg (s)	Stroop test (s)	Digit Symbol (s)	Trails A &B (s)
Active	Mean	5.71	0.85	51.61	36.29	0.68	27.71
n=17	*SE*	0.14	0.02	3.35	3.12	0.03	2.31
Non active	Mean	4.91	0.83	58.67	43.00	0.75	22.25
n=4	*SE*	0.53	0.06	1.33	6.48	0.03	10.99

Table 1. Mean and Standard Error (*SE*) for Active and Non active individuals regarding their physical and cognitive performance.

Motor Task - iEMG.

In order to evaluate dual-task cost during each phase of the gait cycle, a repeated measures analysis of variance was conducted for each muscle group. The within-subject factors were phase (DL, SL, SW) and difficulty (W, DT-EASY, DT-HARD), resulting in a 3 x 3 mixed factorial ANOVA. There was a main effect of phase for all muscle groups (Figure 4), which was expected since each muscle has its role according to the phase of gait. Pairwise t-test comparison with Bonferroni correction indicated that VMO and VL were mostly active during DL, $F(2, 40) = 35.58, p < .0, \eta^2 = .79$, $F(2, 38) = 40.89, p < .0, \eta^2 = .82$. MH and LH were mostly active during SW, $F(2, 40) = 36.04, p < .0, \eta^2 = .79$, $F(2, 40) = 52.69, p < .0, \eta^2 = .85$, when they act to decelerate the swinging limb. Ankle extensors, MG, LG and FL, had greater activity during SL, $F(2, 36) = 99.59, p < .0, \eta^2 = .92$; $F(2, 38) = 67.34, p < .0, \eta^2 = .88$ and $F(2, 38) = 25.14, p < .0, \eta^2 = .74$. TA had greater muscle activity during DL and SW, $F(2, 38) = 41.29, p < .0, \eta^2 = .82$ in comparison to SL. There was a main effect of difficulty for FL, $F(2, 38) = 8.54, p = .013, \eta^2 = .38$, and a trend for VL, $F(2, 38) = 3.20, p = .065, \eta^2 = .26$, with both muscles showing less muscle activity during DT condition (EASY and HARD did not differ) as compared to walking alone (Figure 5). There was a 4% reduction in iEMG activity during DT condition in comparison to walking alone for FL and 3% for VL. There was no interaction of phase and difficulty.

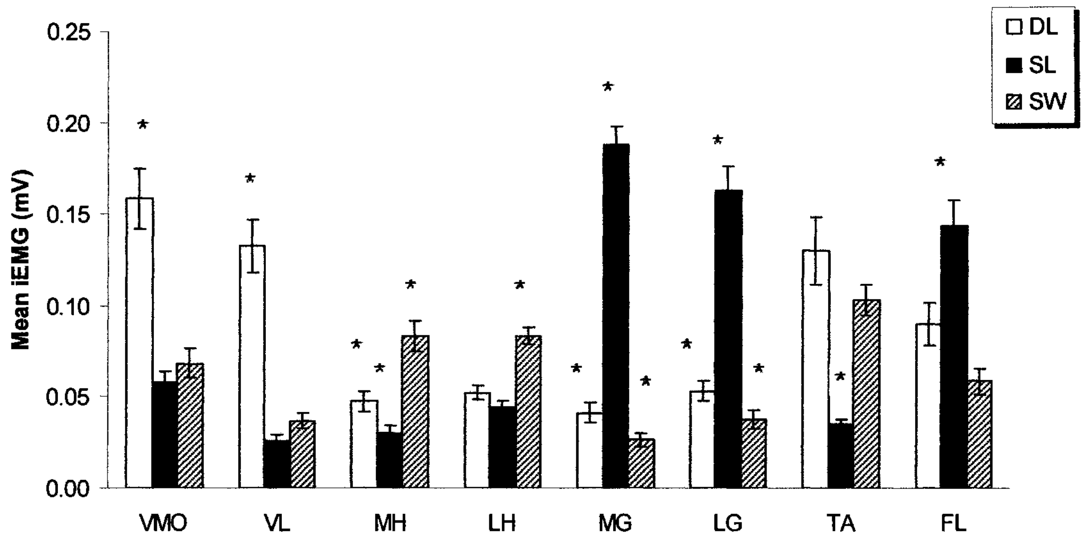


Figure 4. Main effect of phase on muscle activity for all muscle groups: vastus medialis-VMO, vastus lateralis-VL, medial hamstrings-MH, lateral hamstrings-LH, medial gastrocnemius-MG, lateral gastrocnemius-LG, tibialis anterior-TA and fibularis longus-FL. * indicates $p < .05$ in relation to the other phases.

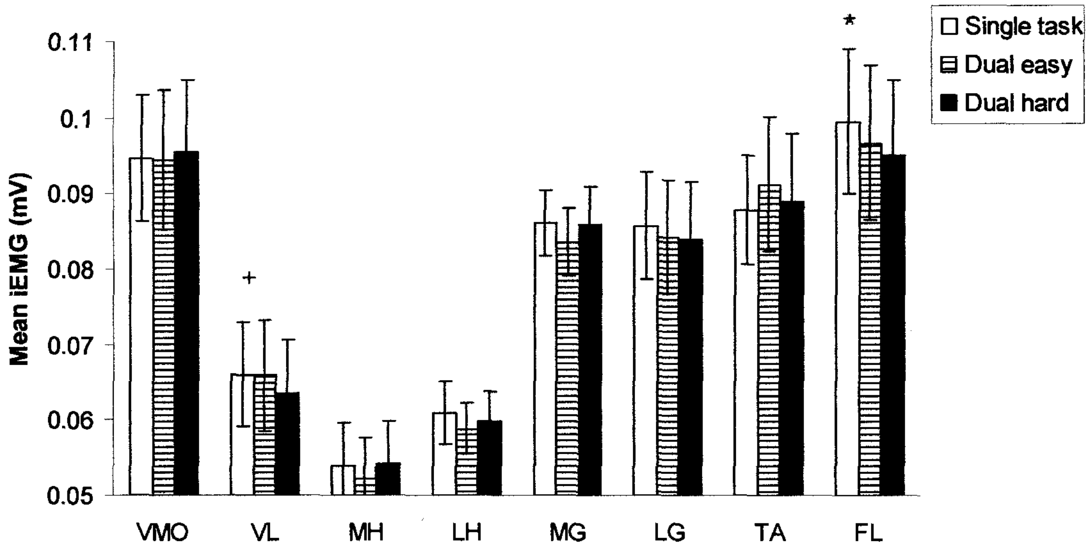


Figure 5. Main effect of difficulty on muscle activity for Fibularis Longus-FL and Vastus Lateralis-VL, during single-task (W), dual-task easy (DT-EASY) and dual-task hard (DT-HARD). * indicates $p < .05$ and $^{+}$ $p < .07$.

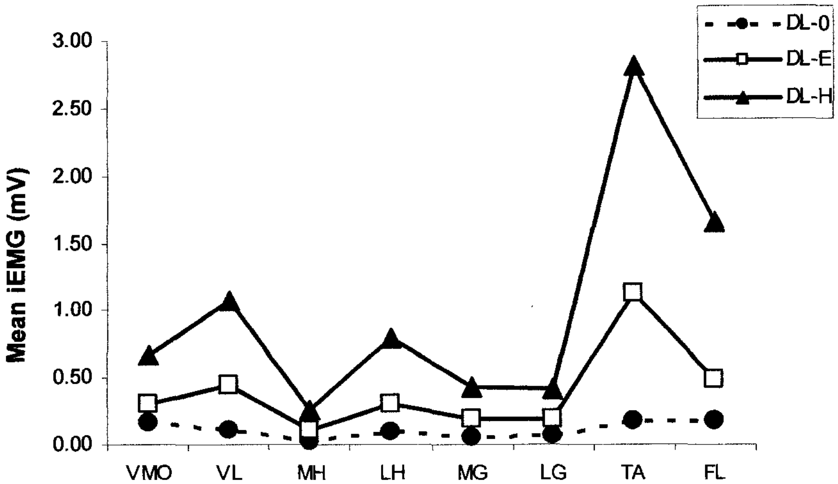
To examine the effect of stimulus onset on each phase of gait, a Phase x Onset repeated measures ANOVA was performed. Because it was hypothesized that the difficulty of the task would influence the level of muscle activity, an additional factor of difficulty was included, resulting in a Phase (DL, SL, SW) x Onset (from 0-150 ms, 150-300 ms, 300-450 ms) x Difficulty (DT-EASY, DT-HARD) analysis. Consistently, significant main effects of phase were observed for all muscle groups (Table 2). Significant interactions of Phase x Onset were observed for MG, $F(2, 40) = 3.84$, $p = .021$, $\eta^2 = .47$ and LG, $F(2, 40) = 5.91$, $p = .004$, $\eta^2 = .58$. There was a 1.6% reduction of iEMG for MG and a 1.9% reduction for LG, during SL when the stimuli came between 300 to 450 ms (Interval 2) in comparison to when the stimuli came between 0 to 150 ms prior to SL. Pairwise t-test comparison with Bonferroni correction showed that the decrease in mean iEMG was statistically significant for MG ($p = .034$). For LG there was a trend towards statistically significant reduction of iEMG during SL with stimulus onset between 300 to 450 ms ($p = .077$).

Main Effect of Phase						
Muscle group	DL Mean *(SE)*	SL Mean *(SE)*	SW Mean *(SE)*	F (2 , 40)	η^2	*power*
VMO	**.158 (.017)** *	.059 (.006)	.068 (.008)	30.25*	.76	1.0
VL	**1.39 (.015)** *	.028 (.005) *	.039 (.005) *	39.25*	.80	1.0
MH	.046 (.006) *	.030 (.005) *	**.083 (.008)** *	39.11*	.80	1.0
LH	.051 (.004)	.044 (.004)	**.083 (.005)** *	61.89*	.87	1.0
MG	.047 (.006) *	**.205 (.016)** *	.026 (.003) *	63.22*	.87	1.0
LG	.059 (.008)	**.163 (.013)** *	.060 (.022)	66.47*	.87	1.0
TA	**.134 (.019)**	.073 (.004) *	.109 (.010)	39.55*	.80	1.0
FL	.101 (.017) *	**.157 (.021)** *	.064 (.009) *	19.29*	.67	1.0

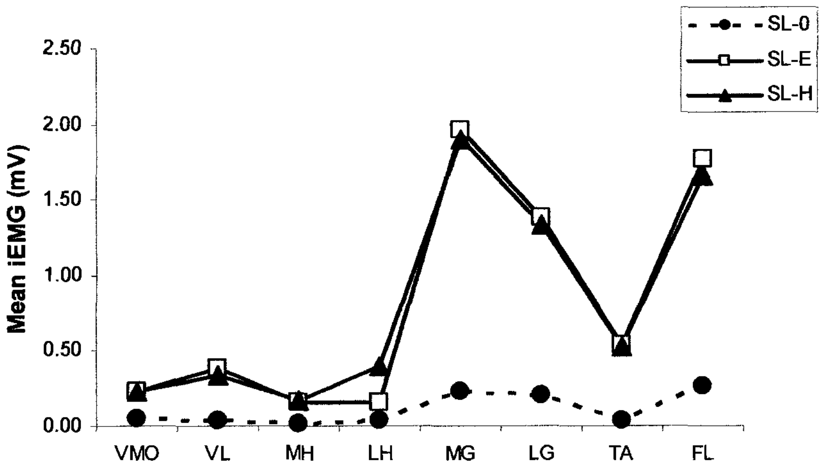
Table 2: Mean and Standard error (*SE*) of iEMG of each muscle group according to the phase of gait. Results of the ANOVA show the main effect of phase for all muscle groups. vastus medialis-VMO, vastus lateralis-VL, medial hamstrings-MH, lateral hamstrings-LH, medial gastrocnemius-MG, lateral gastrocnemius-LG, tibialis anterior-TA and fibularis longus-FL, according to double-leg stance-DL, single-leg stance-SL and swing-SW. Higher values are shown in bold. * $p < .0$.

Two participants were excluded from the entire analysis because they had a particular iEMG profile. One of them had an abnormal gait pattern while on the treadmill. This participant was not comfortable with walking on a treadmill and was the only one that made use of the support bars while walking. The iEMG profile from the other participant that was excluded from the analysis is shown in Figure 6. When walking was combined with the cognitive task, this participant expressed an increase in muscle activity for all muscle groups. The increase in muscle activity was not accompanied by a decrease in cognitive performance, suggesting that prioritization of walking was not the main reason for the increase in iEMG. Gait speed was also not a main cause of this observation, since he walked at 3.5 mph, a relatively fast speed, similar to other participants. Furthermore, the increase in iEMG was only observed when walking was combined with the cognitive task, and not while walking alone. Math calculation for this particular individual may not have been as challenge as it was for the other participants. The increase in iEMG observed in this particular case suggests that individuals may adopt different strategies under dual-task condition. The addition of a concurrent attentional task could have facilitated the mobilization of attentional resources that were efficiently divided for both tasks.

A


DL-0
DL-E
DL-H
Mean iEMG (mV)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VMO
VL
MH
LH
MG
LG
TA
FL

B


SL-0
SL-E
SL-H
Mean iEMG (mV)
2.50
2.00
1.50
1.00
0.50
0.00
VMO
VL
MH
LH
MG
LG
TA
FL

C

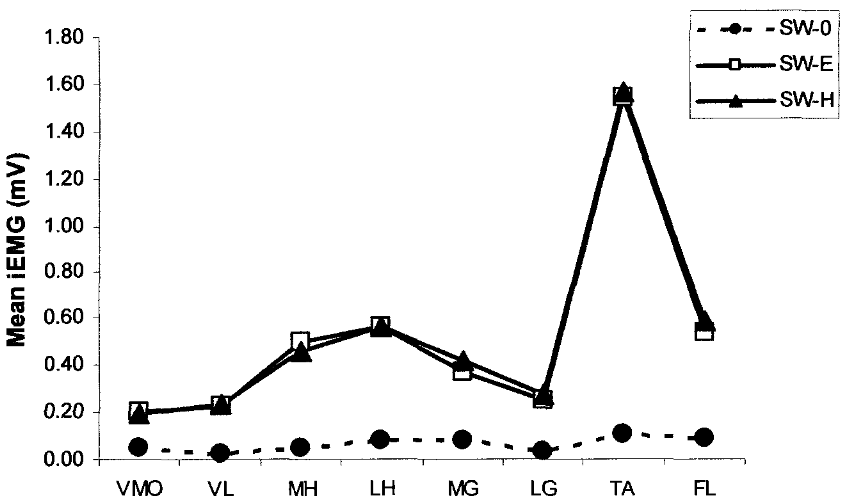

SW-0
SW-E
SW-H
Mean iEMG (mV)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
VMO
VL
MH
LH
MG
LG
TA
FL

Figure 6. Mean iEMG for all muscle groups for one individual during double-leg stance (DL-shown in A), single-leg stance (SL-shown in B) and swing (SW-shown in C). Mean iEMG values were greater during the easy (E) and hard (H) conditions in comparison to walking alone (0). Vastus medialis-VMO, vastus lateralis-VL, medial hamstrings-MH, lateral hamstrings-LH, medial gastrocnemius-MG, lateral gastrocnemius-LG, tibialis anterior-TA and fibularis longus-FL.

Cognitive task-RT and Accuracy

Cognitive performance was evaluated in terms of the percentage of correct responses (accuracy) and reaction time (RT) for the single, COG-EASY and COG-HARD conditions. In order to analyze the influences of concurrent walking and cognitive task difficulty, a task (single, dual) x difficulty (EASY, HARD) mixed-factorial ANOVA was conducted. Participants had lower percentage of correct responses, $F(1, 20) = 71.02$, $p < 0$, $\eta^2 = .78$ and took longer to respond to the stimuli, $F(1, 19) = 99.04$, $p<0$, $\eta^2 = .84$ in the COG-HARD condition in comparison to the COG-EASY condition. When comparing single-task vs. dual-task, it was found that participants had longer RT during dual-task, $F(1, 19) = 4.91$, $p = .039$, $\eta^2 = .20$. There was no interaction of task and difficulty. Results are shown in Table 3.

		Single-task (COG)		Dual-task (DT)	
		Mean	*SE*	Mean	*SE*
Accuracy (%)	EASY	100*	0.20	99*	0.45
	HARD	57*	5.14	58*	5.16
RT (ms)	EASY	1520 * +	44	1738 * +	77
	HARD	2240 * +	121	2336 * +	53

Table 3. Mean and Standard Error (*SE*) of percentage of correct responses and Reaction time (ms) of correct responses during the four different conditions: COG-EASY = Single-task easy, COG-HARD = Single-task hard, DT-EASY = Dual-task easy and DT-HARD = Dual-task hard. * Main effect of difficulty ($p < .05$), + Main effect of task ($p < .05$).

Discussion

The main purpose of this study was to identify changes in iEMG pattern according to the onset of an attentionally demanding cognitive stimulus. By using dual-task paradigm, dual-task costs in both the motor and the cognitive tasks were observed. When walking at a non-preferred speed was combined with an attention demanding cognitive task, there was a decrease in muscle activity on medial and lateral gastrocnemius, dependent of stimulus onset. Dual-task cost in the cognitive task was characterized by an increase in reaction time when the motor and the cognitive tasks were peformed simultaneously, in comparison to when the cognitive task was performed alone.

Motor task – iEMG

Walking Alone vs. Walking While Counting. Initially, changes in iEMG amplitude were investigated, according to the type of concurrent task (no concurrent task, a concurrent easy cognitive task, and a concurrent hard cognitive task) and their influence on each phase of gait. As predicted, each muscle group's activity varied according to the phase of the gait cycle. During initial heel strike, DL, it is expected that knee extensors (VMO and VL) will have a greater level of activity as a load response when weight is being supported. At the same time, TA contracts eccentrically to slowly place the foot on the ground in preparation for whole body support. During SL, the CoM of the body is carried forward by momentum, and at the end of SL, plantar flexors (MG, LG and FL) contract concentrically to generate propulsion for the SW phase. At SW, the limb performs a pendulum-like movement, while TA contracts concentrically to the clear toes from the ground. As the movement progresses, MH and LH start to act eccentrically or isometrically to decelerate the swing limb. This contributes to slow down hip flexion and knee extension and prepare for the load response (DL) during the next cycle (Rose & Gamble, 2006; Winter, 1992)

The addition of a concurrent cognitive task, independently from the stimulus onset, resulted in dual-task cost during walking, and was characterized by a decrease in muscle activity of FL and VL. This finding is in line with previous results from our and other laboratories (Fraser et al., 2007; Rankin, Woollacott, Shumway-Cook, & Brown, 2000). As a global view, internally driven movement is achieved by the proper synergy of agonists and antagonists muscles to control joints and limb position. The efficiency of muscle contraction, in addition to mechanical properties, is determined by frequency, synchronization and number of motor unit action potentials occurring in the muscle. Because surface electromyography represents the algebraic summation of motor unit action potentials occurring around the electrode site (Day & Hulliger, 2001), EMG is a good tool to understand the neural drive to the muscle during a given motor task. A decrease in muscle activation while walking and performing an attention demanding cognitive task could reflect a reduction in neural drive to the muscle. Therefore, when both tasks were performed simultaneously, the nervous system was not able to maintain the same level of output to the muscles, supporting the idea of limited attentional capacity. It is important to note that dual-task cost was obtained for young adults while walking on a stable and predictable surface, suggesting that even normal treadmill walking requires some level of attention.

Interference of Stimulus Onset. The main objective of this study was to identify changes in muscle activity dependent on stimulus onset and how it would vary according to the phase of gait. It was hypothesized that stimulus onset time would be critical in determining dual-task cost, and that the critical interval would be greater than 150 ms prior to the phase analyzed. The interaction of phase and onset observed for MG and LG confirms the initial hypothesis. There was a reduction in iEMG during SL when the stimuli came between 300 to 450 ms prior to SL. This time of onset interference is well in accordance with neurophysiological findings of latencies for monosynaptic reflexes of the lower limb and for supraspinal control of locomotion. Monosynaptic reflexes, such as the stretch reflex, are at the lowest hierarchic level of motor control. A change in muscle length in the lower limb, caused by displacement of CoM, can generate a fast burst of muscle activity to counteract body movement. During upright stance, this mechanism takes approximately 100 ms after the onset of posture perturbation (Norrie et al., 2002; Rankin et al., 2000). Stretch reflex gain, characterized by greater response with the same stimulus amplitude, is greater during standing and progressively decreases from walking to running. (Edamura, Yang, & Stein, 1991). This modulation of the stretch reflex depends on supraspinal control to increase the stretch reflex threshold (i.e., a greater stretch is required to elicit the same response) and decrease reflex response, i.e., muscle contraction (Capaday, 2002). The modulation of stretch reflex gain is an important aspect of locomotor control because if a strong contraction would occur during walking or running, movement would be stopped rather than facilitated (Edamura et al., 1991). Therefore, stretch reflex modulation is essential to shape the motor output according to the demands of the ongoing movement. Supraspinal structures may exert direct influence on α-motoneurons and on reflex modulation (through Ia afferent inhibition), but also indirectly through influence on the central pattern generators, a pool of neurons localized in the spinal cord that can coordinate sequence and timing of muscle contraction during walking. In animal models three main supraspinal regions have been suggested to influence locomotion: subthalamic locomotor region (SLR), mesencephalic locomotor region (MLR), and cerebellar locomotor region (CLR) (Armstrong, 1988). The SLR is thought to "switch-on" locomotor pattern, while the MLR can dictate the phase-dependent level of muscle activity exerted during stepping. MLR receives afferent projections from the basal ganglia, sensorimotor cortex and limbic system; and has descending projection to the ponto-medullary reticular formation, where reticulo-spinal neurons, that project to several levels of the spinal cord, make synaptic connection with α-motoneurons. The CLR also influences neurons in the reticular formation through vestibulospinal and rubrospinal tracts, exerting parallel control over phase-dependent muscle activity. Vermis and paravermal cerebellar cortex, which have connections to MLR, have increased activation according to gait speed, suggesting a pacemaker function of the cerebellum (Jahn, Deutschlander, Stephan, Kalla, Wiesmann, Strupp, et al. 2008). Afferent projections from the trunk and limbs reach the cerebellum, where they are compared to the descending motor program and used to correct the movement pattern (Amstrong, 1988; Kandel 1991). Although supraspinal control of locomotion in humans differs substantially from animals, as shown by the inability to maintain an upright posture or walk following total spine cord injury (MacKay-Lyons, 2002), similar areas of the brainstem and cerebellum seem to be involved in locomotion for both humans and cats (Jahn et al., 2008). Furthermore, cortical areas are essential to maintaining a volitional and adaptive gait pattern. Because supraspinal influence on locomotion requires the connections and coordination from different centers in the nervous system, it should require far more than 100 ms to occur. Therefore, the interference of a cognitive stimulus on gait 300 ms after its onset suggests that there are periods during walking when attention is most important. This interference may reflect the timing of influence of descending drive from locomotor centers to maintain the walking pattern. The interference of a cognitive task only during SL suggests that attentional resources are not used in the same ways across the phases of gait. SL may require greater level of cognitive resources because of its balance requirements (Lajoie et al., 1993).

Changes in iEMG amplitude-implication. An important functional implication of the interference of both tasks is the consequence of a reduction in muscle activity while walking. In this study, there was a reduction in iEMG for ankle extensor (MG and LG) during SL, when stimulus onset was taken in consideration and for FL independent of phase and stimulus onset. During single-leg stance, the activity from these muscles is crucial to generate forward acceleration of the limb and body for the swing phase. Therefore, a reduction in propulsion during SL could result in a decrease in gait speed. However, when walking on a treadmill, individuals can not vary their gait speed; therefore, to compensate the decrease in ankle extensor activity during SL, a change in stride length or cadence needs to occur to maintain belt speed. Adaptation in stride length can be achieved by either decreasing or increasing swing phase duration. A decrease in stride length is achieved by an increase in hamstrings activity to decelerate the leg and place the foot earlier on the ground, decreasing SW duration. In turn, an increase in stride length is achieved by increasing propulsive forces at the end of stance phase (possibly to increase CoM acceleration), and by increasing rectus femoris activity to maintain the leg in flexion longer so the foot can be placed later on the ground (Varraine, Bonnard, & Pailhous, 2000). In this study, muscle activity during SW was not influenced by the auditory stimuli, which means that there was no compensatory muscle activity during SW to adapt stride length. Therefore one can predict that the reduction in propulsive force from the ankle extensors during SL resulted in a shorter stride length. In order to maintain belt speed when stride length is decreased, cadence (i.e frequency of steps) has to be increased. However, it is also possible that the reduction in muscle activity during walking, consequent of dual-task interference, does not result in significant changes in gait parameters (Regnaux, Roberston, Smail, Daniel, & Bussel, 2006). If that is the case, even thought a cognitive stimulus interferes with the level of muscle activity during walking, the motor system is able to compensate and re-adjust the pattern, without further mechanical consequences. Unfortunately, a limitation of this study is that it is not possible to affirm whether changes in stride length and cadence occurred using the current method. By analysing gait kinematics, one would detect if changes in iEMG resulted in changes in stride length or cadence, or if the reduction in iEMG reflected a decrease in neuronal drive to the muscles without further consequences in gait parameters. A future study, making use of the same paradigm, should include kinematic analysis of the gait cycle.

Cognitive task - RT and Accuracy

Changes in performance in the cognitive task were analyzed through changes in RT and accuracy. It was hypothesized that participants would decrease accuracy and increase RT to the auditory stimulus when the cognitive task was performed while walking in comparison to when it was performed alone, and that dual-task costs would be more pronounced as the difficulty of the cognitive task increased. Indeed, increasing the difficulty of the cognitive task successfully challenged the nervous system, yielding more errors and longer RT when subtracting seven than when subtracting one. It is interesting to note that there was no trade-off between accuracy and speed of response, which means that participants were committing more mistakes and taking longer to respond to the stimulus.

Accuracy did not differ between single and dual-task conditions. Because accuracy is a more gross method of inferring dual-task cost, it may not be specific enough to detect changes in performance from the sample of young adults who participated in this study. On the other hand, participants took longer to respond to the stimuli during dual-task trials, regardless of the difficulty of the task. Similar results were obtained by Abernethy and colleagues (2002): there was an increase in reaction time to a simple cognitive task (i.e., pressing a button in response to a tone) when the task was performed while walking compared to when it was performed alone. However, our findings differ from those of Fraser and colleagues (2007), in which a similar paradigm was used. In the study by Fraser and colleagues, participants were asked to walk and perform a semantic judgement task simultaneously and separately. When the semantic task was performed while walking, participants took less time to judge the words, compared to when the semantic task was performed alone. However, this facilitatory effect in the cognitive task was observed while walking on a treadmill at a self-selected comfortable speed. In the present study, the increase in difficulty of both the motor and the cognitive task could explain the difference in the results, since dual-task cost in younger adults is small unless the nervous system is overloaded. By increasing the self-selected speed, participants could have been forced to walk when running would have been the preferable (more stable) locomotor pattern, thus demanding more cognitive resources to maintain the non-preferable pattern (Abernethy, Hanna, & Plooy, 2002). However, the difficulty of the cognitive task caused some discomfort to a few participants (two individuals did not want to proceeded with the experiment). In a future experiment, making use of the same paradigm, the level of difficulty of the cognitive task could be adjusted according to individual's performance in the practice session.

Dual-task – walking while counting

It is believed that if two tasks interfere with each other and they do not share the same processing resources at least one of them requires some level of attention to be executed (Pashler, 1994). In the present study young adults were asked to walk at their non-preferred gait speed and perform a relatively complex subtraction task: a condition that was expected to challenge the nervous system. However, when a dual-task paradigm is applied, dual-task cost can not be totally understood unless both tasks are analyzed in conjunction.

When a motor task is performed with a concurrent cognitive task, individuals may prioritize the motor task for safety purposes, by increasing muscle activity around the ankle joint to maintain a more stiff posture (Melzer et al., 2001; Brown, Sleik, Polych, & Gage, 2002). It has also been shown that individuals prioritize walking by making use of an external aid for walking but not for a cognitive task (Li, Lindenberger, Freund, & Baltes, 2001). However, prioritization of the motor task has been observed for older adults but not for younger adults. In our study, dual-task costs were observed in both the motor and the cognitive tasks: participants had decreased muscle activity and longer RT when the cognitive task was combined with walking. This indicates that prioritization of the motor task did not occur in this testing scenario. Interestingly, the increase in RT was observed even when participants were asked to perform a relative easy task of subtracting one (DT-EASY). This corroborates the idea that walking at a non-preferred speed is attentionally demanding for young adults.

The introduction of a cognitive task while walking had an important effect on reducing iEMG. The change in iEMG was time-dependent on stimulus presentation and independent of the difficulty of the cognitive task. This analysis of stimulus onset interference on motor performance is an innovative and relevant way of interpreting dual-task cost. It becomes especially important when considering a dynamic and rhythmic activity such as gait, when attentional load may vary during the execution of the motor task. If cognitive resources, an important component of gait, are not used evenly across and within phases, the question that arises is what determines the influence of cognitive resources on gait? If the cognitive demands of a motor task vary according to its balance requirements, based on a timing analysis, one can speculate about when during a dynamic task attention is most important and understand the cognitive demands of parts of the task.

Conclusion

This study adds to the evidence that treadmill walking in a stable and predictable environment requires attention, even for young adults accustomed to treadmill walking. More importantly, it was possible to identify a moment during single-leg stance when the dynamic and rhythmic walking pattern was more susceptible to disruption. A reduction in muscle activity 300 ms after stimulus onset may reflect the interference of stimulus processing and the supraspinal descending drive to control and maintain the stability of the walking pattern. In addition, it suggests that supraspinal control is more salient during single-leg stance of gait, probably because of its requirement of greater balance control. However, based on this study alone, it is not possible to affirm that the reduction in muscle activity resulted in significant changes in gait parameters, capable of disrupting balance. This should be further investigated using the same paradigm with motion analysis of gait. Identifying supraspinal centers involved in dual-task methodology could be a future direction in understanding the interplay between gait and cognition. Dual-task studies, using single photon emission tomography (Fukuyama et al., 1997), functional near infrared spectroscopy (Irani, Platek, Bunce, Ruocco, & Chute, 2007; Suzuki, Miyai, Ono, Oda, Konishi, Kochiyama, et al. 2004) or functional magnetic resonance imaging (fMRI) based on ankle movement to simulate gait (Dobkin, Firestine, West, Saremi, & Woods, 2004), seem to be good strategies to identify brain areas related to attentional resources during walking.

References

Abbud, G. A. C., DeMont, R. G., Fraser, S. A., Li, K. Z. H., Penhune, V. B. (2007, February) *Attentional demands of gait cycle: an EMG analysis.* Poster session presented at the 3rd Annual Conference from Center for Research in Human Development (CRDH), Montreal, Canada.

Abbud, G. A. C., DeMont, R. G., Li, K. Z. H., Fraser, S. A., Penhune, V. B., Hendry, M., & Bailey, A. (2008, February). *An EMG analysis of attentional demands of the gait cycle according to time of an auditory stimulus.* Poster session presented at the 2nd International Congress on Gait and Mental Function, Amsterdam, The Netherlands.

Abernethy, B., Hanna, A., & Plooy, A. (2002). The attentional demands of preferred and non-preferred gait patterns. *Gait and Posture, 15*(3), 256-265.

Armstrong, D. M. (1988). The supraspinal control of mammalian locomotion. *Journal of Physiology,* 405, 1-37.

Baratto, L., Morasso, P. G., Re, C., & Spada, G. (2002). A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques. *Motor Control, 6*(3), 246-270.

Barra, J., Bray, A., Sahni, V., Golding, J. F., & Gresty, M. A. (2006). Increasing cognitive load with increasing balance challenge: recipe for catastrophe. *Journal of Experimental Brain Research, 174*(4), 734-745.

Basmajian, J. V., & Blumenstein R. (1989) *Electrode placement in EMG biofeedback.* Maryland: Williams & Wilkins.

Bent, L. R., Inglis, J. T., & McFadyen, B. J. (2002). Vestibular contributions across the execution of a voluntary forward step. *Journal of Experimental Brain Research, 143*(1), 100-105.

Bent, L. R., Inglis, J. T., & McFadyen, B. J. (2004). When is vestibular information important during walking? *Journal of Neurophysiology, 92*(3), 1269-1275.

Borg, G. (1982). Ratings of perceived exertion and heart rates during short-term cycle exercise and their use in a new cycling strength test. *International Journal of Sports Medicine, 3*(3), 153-158.

Briggs, R. C., Gossman, M. R., Birch, R., Drews, J. E., & Shaddeau, S. A. (1989). Balance performance among noninstitutionalized elderly women. *Physical Therapy, 69*(9), 748-756.

Brown, L. A., Sleik, R. J., Polych, M. A., & Gage, W. H. (2002). Is the prioritization of postural control altered in conditions of postural threat in younger and older adults? *Journal of Gerontololy:Medical Sciences, 57*(12), M785-792.

Capaday, C. (2002). The special nature of human walking and its neural control. *Trends in Neuroscience, 25*(7), 370-376.

Catena, R. D., van Donkelaar, P., & Chou, L. S. (2007). Cognitive task effects on gait stability following concussion. *Journal of Experimental Brain Research, 176*(1), 23-31.

Day, S. J., & Hulliger, M. (2001). Experimental simulation of cat electromyogram: evidence for algebraic summation of motor-unit action-potential trains. *Journal of Neurophysiology, 86*(5), 2144-2158.

Demont, R. G., Lephart, S. M., Giraldo, J. L., Swanik, C. B., & Fu, F. H. (1999). Muscle Preactivity of Anterior Cruciate Ligament-Deficient and -Reconstructed Females During Functional Activities. *Journal of Athletic Training, 34*(2), 115-120.

Dietz, V., Colombo, G., & Muller, R. (2004). Single joint perturbation during gait: neuronal control of movement trajectory. *Journal of Experimental Brain Research, 158*(3), 308-316.

Dobkin, B. H., Firestine, A., West, M., Saremi, K., & Woods, R. (2004). Ankle dorsiflexion as an fMRI paradigm to assay motor control for walking during rehabilitation. *Neuroimage, 23*(1), 370-381.

Ebersbach, G., Dimitrijevic, M. R., & Poewe, W. (1995). Influence of concurrent tasks on gait: a dual-task approach. *Perceptual and Motor Skills, 81*(1), 107-113.

Edamura, M., Yang, J. F., & Stein, R. B. (1991). Factors that determine the magnitude and time course of human H-reflexes in locomotion. *Journal of Neuroscience, 11*(2), 420-427.

Earl, J.E., & Hertel, J. (2001) Lower-extremity muscle activation during the star excursion balance test. *Journal of Sports Rehabilitation 10*(2), 93-104.

Fraser, S. A., Li, K. Z., DeMont, R. G., & Penhune, V. B. (2007). Effects of balance status and age on muscle activation while walking under divided attention. *Journal of Gerontology: Psychological Sciences, 62*(3), P171-178.

Fukuyama, H., Ouchi, Y., Matsuzaki, S., Nagahama, Y., Yamauchi, H., Ogawa, M., et al. (1997). Brain functional activity during gait in normal subjects: a SPECT study. *Neuroscience Letter, 228*(3), 183-186.

Galletly, R., & Brauer, S. G. (2005). Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease? *Australian Journal of Physiotherapy, 51*(3), 175-180.

Goldie, P. A., Matyas, T. A., & Evans, O. M. (2001). Gait after stroke: initial deficit and changes in temporal patterns for each gait phase. *Achieves of Physical Medicine and Rehabilitation, 82*(8), 1057-1065.

Gribble, P. (2003) The Star Excursion Balance Test as a measurement tool. *Athletic Therapy Today, 8*(2) 46-47.

Gribble, P.A. & Hertel, J., (2003) Consideration for normalizing measures of the star excursion balance test. *Measurement in Physical Education & Exercise Science, 7*(2), 89-100.

Haggard, P., Cockburn, J., Cock, J., Fordham, C., & Wade, D. (2000). Interference between gait and cognitive tasks in a rehabilitating neurological population. *Journal of Neurology, Neurosurgery and Psychiatry, 69*(4), 479-486.

Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S., & Giladi, N. (2005). Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Journal of Experimental Brain Research, 164*(4), 541-548.

Herrero, M. T., Barcia, C., & Navarro, J. M. (2002). Functional anatomy of thalamus and basal ganglia. *Child's Nervous System, 18*(8), 386-404.

Hertel, J., Miller, S. J., Denegar, C. R. (2000). Intratester and intertester reliability during the star excursion balance test. *Journal of Sport Rehabilitation 9*(2), 104-116.

Horak, F. B. (2006). Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age and Ageing, 35 Suppl 2*, ii7-ii11.

Huxhold, O., Li, S. C., Schmiedek, F., & Lindenberger, U. (2006). Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Research Bulletin, 69*(3), 294-305.

Irani, F., Platek, S. M., Bunce, S., Ruocco, A. C., & Chute, D. (2007). Functional near infrared spectroscopy (fNIRS): an emerging neuroimaging technology with important applications for the study of brain disorders. *Clinical Neuropsychology, 21*(1), 9-37.

Jahn, K., Deutschlander, A., Stephan, T., Kalla, R., Wiesmann, M., Strupp, M., et al. (2008). Imaging human supraspinal locomotor centers in brainstem and cerebellum. *Neuroimage, 39*(2), 786-792.

Kandel, E., Schwartz, J. H., & Jessel, T. M. (1991). *Principles of Neuroscience*. 3rd Ed. New York: Elsevier.

Kirtley, C. (2005) *Clinical gait analysis: theory and practice*. Edinburgh, New York, Elsevier.

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Journal of Experimental Brain Research, 97*(1), 139-144.

Lamont, E. V., & Zehr, E. P. (2006). Task-specific modulation of cutaneous reflexes expressed at functionally relevant gait cycle phases during level and incline walking and stair climbing. *Journal of Experimental Brain Research, 173*(1), 185-192.

Li, K. Z. H., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: Age-related differences in compensatory behaviour. P*sychological Science, 12*, 230-237.

MacKay-Lyons, M. (2002). Central pattern generation of locomotion: a review of the evidence. *Physical Therapy, 82*(1), 69-83.

Melzer, I., Benjuya, N., & Kaplanski, J. (2001). Age-related changes of postural control: effect of cognitive tasks. *Gerontology, 47*(4), 189-194.

Melzer, I., & Oddsson, L. I. (2004). The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. *Journal of the American Geriatric Society, 52*(8), 1255-1262.

Norrie, R. G., Maki, B. E., Staines, W. R., & McIlroy, W. E. (2002). The time course of attention shifts following perturbation of upright stance. *Journal of Experimental Brain Research, 146*(3), 315-321.

O'Shea, S., Morris, M. E., & Iansek, R. (2002). Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

Parker, T. M., Osternig, L. R., Lee, H. J., Donkelaar, P., & Chou, L. S. (2005). The effect of divided attention on gait stability following concussion. *Clinical Biomechanics* (Bristol, Avon), 20(4), 389-395.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychological Bulletin, 116*(2), 220-244.

Prince, F., Corriveau, H., Hébert, R., & Winter D.A. (1997) Gait in the elderly. *Gait & Posture*, 5, 128-135

Rankin, J. K., Woollacott, M. H., Shumway-Cook, A., & Brown, L. A. (2000). Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. *Journal of Gerontology: Medical Sciences, 55*(3), M112-119.

Regnaux, J. P., David, D., Daniel, O., Smail, D. B., Combeaud, M., & Bussel, B. (2005). Evidence for cognitive processes involved in the control of steady state of walking in healthy subjects and after cerebral damage. *Neurorehabilitation and Neural Repair, 19*(2), 125-132.

Regnaux, J. P., Roberston, J., Smail, D. B., Daniel, O., & Bussel, B. (2006). Human treadmill walking needs attention. *Journal of Neuroengineering and Rehabilitation, 3,* 19.

Rose, J. & Gamble, J. G. (2006). *Human Walking*. 3rd Ed. Philadelphia: Lippincott Williams & Wilkins.

Shumway-Cook, A. & Woollacott, M. H. (2001). *Motor Control-Theory and Practical Applications*. 2nd Ed. Maryland: Lippicott Williams & Wilkins.

Spreen, O., & Strauss, E. (1998). *A compendium of Neuropsychological Tests: Administration, Norms, and Commentary*. New York, NY: Oxford University Press, (pp 553-547).

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643-662.

Suzuki, M., Miyai, I., Ono, T., Oda, I., Konishi, I., Kochiyama, T., et al. (2004). Prefrontal and premotor cortices are involved in adapting walking and running speed on the treadmill: an optical imaging study. *Neuroimage, 23*(3), 1020-1026.

van Wezel, B. M., van Engelen, B. G., Gabreels, F. J., Gabreels-Festen, A. A., & Duysens, J. (2000). Abeta fibers mediate cutaneous reflexes during human walking. *Journal of Neurophysiology, 83*(5), 2980-2986.

Varraine, E., Bonnard, M., & Pailhous, J. (2000). Intentional on-line adaptation of stride length in human walking. *Journal of Experimental Brain Research, 130*(2), 248-257.

Verghese, J., Kuslansky, G., Holtzer, R., Katz, M., Xue, X., Buschke, H., et al. (2007). Walking while talking: effect of task prioritization in the elderly. *Archives of Physical Medicine and Rehabilitation, 88*(1), 50-53.

Weschler, D. (1991). *Manual of the Weschler Adult Intelligence Scale-III.* New York, NY: Psychological Corporation.

Whittle, M.W. (1991). *Gait analysis: An introduction.* Stoneham, MA Butterworth-Heinemann.

Winter, D. A. (1992). Foot trajectory in human gait: a precise and multifactorial motor control task. *Physical Therapy, 72*(1), 45-53.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait and Posture, 16*(1), 1-14.

Appendix A

Ethics Committee Approval

Concordia
UNIVERSITY

CERTIFICATION OF ETHICAL ACCEPTABILITY
FOR RESEARCH INVOLVING HUMAN SUBJECTS

Name of Applicant:	Karen Li
Department:	Psychology
Agency:	None
Title of Project:	Walking while listening II: Interactions between cognition and motor control in healthy aging
Certification Number:	UH2006-077

The members of the University Human Research Ethics Committee have examined the application for a grant to support the above-named project, and consider the experimental procedures, as outlined by the applicant, to be acceptable on ethical grounds for research involving human subjects.

Dr. James Pfaus
Chair, University Human Research Ethics Committee
Date: November 23, 2006

26/03/2003

Appendix B

Consent to participant in the study

CONSENT TO PARTICIPATE IN
Walking while counting: Interaction between motor control and cognition

This is to state that I agree to participate in a program of research being conducted by Gabriela Abbud from the Exercise Science Department of Concordia University (***contact info:*** __________ under the supervision of Dr. Richard DeMont ***(contact info:*** *514-8482424 ext. 3329,* demont.conu@gmail.com*)*.

A. PURPOSE

I have been informed that the purpose of this study is to measure muscle activation patterns from leg muscles in healthy individuals during normal treadmill walking and walking while performing a counting task. This research study is an important step in determining the role of attention during walking.

B. PROCEDURES

You will be tested in one session lasting approximately two hours. All procedures will be explained to your satisfaction. You will be asked to fill out a brief questionnaire regarding activity level, previous injuries, and demographic data. Any previous leg injury within six months, or current lower extremity injury, pain syndrome, recent head injuries or neurological injuries will exclude you from participation. The electrical activity of 8 muscles around the knee will be measured via electromyography (EMG). A total of 8 pairs of adhesive sensors and 1 ground sensor will be attached to your skin after it has been cleaned, shaved (if required) and slightly abraded. You will also be fitted with a device that fits in your shoe and signals your foot contact with the ground. Once this equipment is in place, you will be asked to do three activities: walk on a treadmill, perform a counting task and walk on a treadmill while counting. The counting and walking tasks will vary in difficulty during the testing.

C. RISKS AND BENEFITS

All procedures are completely non-invasive and should be painless. There are no adverse reactions except a possible minor irritation from the tape and bandages holding the equipment in place and possible muscle fatigue. There are no direct benefits from your participation in this study.

D. CONDITIONS OF PARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is CONFIDENTIAL (i.e., the researcher will know, but will not disclose my identity)
- I understand that the data from this study may be published.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELYCONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ______________________________

SIGNATURE ______________________________

If at any time you have questions about your rights as a research participant, please contact Adela Reid, Research Ethics and Compliance Officer, Concordia University, at (514) 848-2424 x7481 or by email at areid@alcor.concordia.ca.

Appendix C

Verbal Instructions

As the participant enters the lab.

Information: Welcome to the lab. You have been invited to participate in an experiment that will involve two tasks. In the first task, you will hear a list of numbers from which you will have to subtract one or seven and tell us the result. We will record how many correct answers you have and the speed at which you answer. In the second part, you will have to walk on a treadmill while we record electromyographic signals from the muscles in your leg. We will first ask you to do these two tasks separately, and then together. I would like you to read this consent form and sign it, if you agree to participate in this study. If anything is unclear please do not hesitate to ask questions.

Once the consent form is signed, ask them if they have any questions.

Physical Questionnaire: Now I would like you to answer this questionnaire about your physical health and activity habits. If you have any questions feel free to ask me. Please answer this questionnaire as accurately as possible.
Ask the participants to put on shorts & running shoes to prepare for walking. Show them where the washroom is.

Sharpened Romberg Balance Test: Now we will do a balance test. I will measure how long you can maintain your balance in a specific position, without moving your arms and your legs, or opening your eyes. First I will demonstrate the position and then I will ask you to do it *(demonstrate while explaining).* You will place one foot in front of the other, toe to heel, with your hands at your sides. Look straight ahead with your eyes open until you feel stable, and then close your eyes. Try to maintain this position as long as you can or until I tell you to stop. I will be timing how long you can maintain this position. If you move your arms, feet, or open your eyes I will stop the timer. Keep in mind that this position is unnatural, and it will cause you to sway a little. We will do a few practices before the testing.

Let the participant practice three times. Mark down how long in seconds they were able to maintain the position for the three practice sessions (P1-P2-P3). To give the participant a break, perform the leg dominance test between the practice and test

"Those were practice, now I will ask you to do the balance test again".

Repeat the instructions before the balance test and score how long the participant is able to maintain the position (T1-T2-T3) Always ask if they need a break in between the trials.

Leg Dominance test: *Escort the participant over to the wall.* What I am going to ask you to do next is to stand with your back to this wall, with your feet together, and then take three steps towards me *(ask them perform this 3 times). Of the three trials, mark down the foot that is most often chosen for the first step (left/right).*

Neuropsychological tests: As we take a break, there are some tests that we will do. I will explain each one of them as we go on. *Administer the cognitive tests (Digit Symbol, Trial Making Test and Stroop Test).*

1-Digit Symbol

Place the digit symbol page in front of the participant and point to the coding key at the top and say: "Look at these boxes. Notice that each has a number in the upper part and a special mark in the lower part. Each number has its own mark".

Point to 1 and its mark in the key, then 2 and its mark. Then point to the seven squares located to the left of the heavy black line and say: "Now look down here where the squares have numbers in the top part but the squares at the bottom are empty. In each of the empty squares put the mark that should be there. Like this".

Point to the first sample item, then point back to the key to show its corresponding mark, and say: "Here is a 2; the 2 has this mark. So I put it in this empty square, like this".

Write in the symbol. Point to the second sample item and say: "Here is a 1; the 1 has this mark (*point*). So I put it in the square (*write down*). Now you will fill in the squares up to this heavy line".

If the participant makes an error on any of the sample items, correct the error immediately and review the use of the key. Continue to provide help if needed. Do not proceed with the subtest until the participant clearly understands the task.

"Now you know how to do them. When I tell you to start, you do the rest of them".

Point to the first square to the right of the heavy line and say: "Begin here and fill in as many squares as you can, one after the other without skipping any. Keep working until I tell you to stop. Work as quickly as you can without making any mistakes".

Sweep across the first row with your finger and say: "When you finish this line, go on with this one *(point to the first square in the second row). Bring them back to the start point and say:* "Go ahead".

If they skip any point say: "Do them in order. Don't skip any".

After 120 seconds say: "Stop!"

Scoring: *Count the number of correctly drawn symbols (not including the sample items). Do not give credit for items completed out of sequence. A response is scored as correct if it is clearly identifiable as the keyed symbol, even if it is drawn imperfectly or if it is a spontaneous correction of an incorrect symbol [Max score 133].*

Digit Symbol—Coding

1	2	3	4	5	6	7	8	9
—	⊥	⊐	∟	⊔	○	∧	×	=

Sample Items

2	1	3	7	2	4	8	2	1	3	2	1	4	2	3	5	2	3	1	4

5	6	3	1	4	1	5	4	2	7	6	3	5	7	2	8	5	4	6	3

7	2	8	1	9	5	8	4	7	3	6	2	5	1	9	2	8	3	7	4

6	5	9	4	8	3	7	2	6	1	5	4	6	3	7	9	2	8	1	7

9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

2	7	3	6	5	1	9	8	4	5	7	3	1	4	8	7	9	1	4	5

7	1	8	2	9	3	6	7	2	8	5	2	3	1	4	8	4	2	7	6

2-Trail Making- Part A

Sample A. When ready to begin the test, place the Part A sheet in front of the subject, give the subject a pencil, and say: "On this page (*point*) there are some numbers. Begin at number 1 (*point to "1"*) and draw a line from one to two, (*point to "2"*), two to three (*point to "3"),* and three to four *(point to "4"),* and so on until you reach the end (*pointing to the circle marked END*). Draw the lines as fast as you can. Do not lift the pencil from the paper. Ready! Begin!"

If the subject makes a mistake on Sample A, point it out and explain it. (e.g. "please keep the pencil on the paper and continue on to the next circle, or you started with the wrong circle. This is where you start (point to "1")).

If the subject completes the sample item correctly, and in a manner which shows that he or she knows what to do say: "Good! Let's try the next one." *Turn the page and give Test A.*

Test A. Say: "On this page there are numbers from 1 to 25. Do this the same way. Begin at number one (*point*) and draw a line from one to two (*point to 2*), two to three (*point to 3*) and three to four (*point to 4*), and so on, in order until you reach the end (*point*). Remember work as fast as you can. Ready! Begin!"

Start timing. If the subject makes an error, call it to his/her attention immediately, and have the subject proceed from the point where the mistake occurred. DO NOT STOP TIMING. Record the time in seconds, then say: "That's fine. Now we'll try another one."

Trail Making- Part B

Sample B. When ready to begin the test, place the Part A sheet in front of the subject, give the subject a pencil, and say: "On this page are some numbers and letters. Begin at number 1 (*point to "1"*) and draw a line from one to A, (*point to "A"*), A to two (*point to "2"),* and two to B *(point to "B"),* B to three (point to 3), three to C (point to C), and so on, in order until you reach the end (*pointing to the circle marked END*). Remember first you have a number (*point to "1"*) and then a letter (*point to "A"*), then a number (*point to "2")*, then a letter *(point to "B"),* and so on. Draw the lines as fast as you can. Ready? Begin".

If the subject makes a mistake on Sample A, point it out and explain it. (e.g. You skipped this circle (point to the one omitted). You should go from one (point) to A (point), A to two (point), two to B (point, B to three (point), and so on until you reach the circle marked END (point)).

After the mistake has been explained, the examiner marks out the wrong part and says: "Go on from here" *(point to the last circle completed correctly in the sequence).*

If the subject completes the sample item correctly, and in a manner which shows that he or she knows what to do say: "Good! Let's try the next one." *Turn the page over and proceed immediately to Part B and say*: "On this page are some numbers and letters. Do this the same way. Begin at number 1 (*point to "1"*) and draw a line from one to A, (*point to "A"*), A to two (*point to "2"),* and two to B *(point to "B"),* B to three (point to 3), three to C (point to C), and so on, in order until you reach the end (*pointing to the circle marked END*). Remember first you have a number (*point to "1"*) and then a letter (*point to "A"*), and so on. Do not skip around, but go from one circle to the next in the proper order. Draw the lines as fast as you can. Ready? Begin".

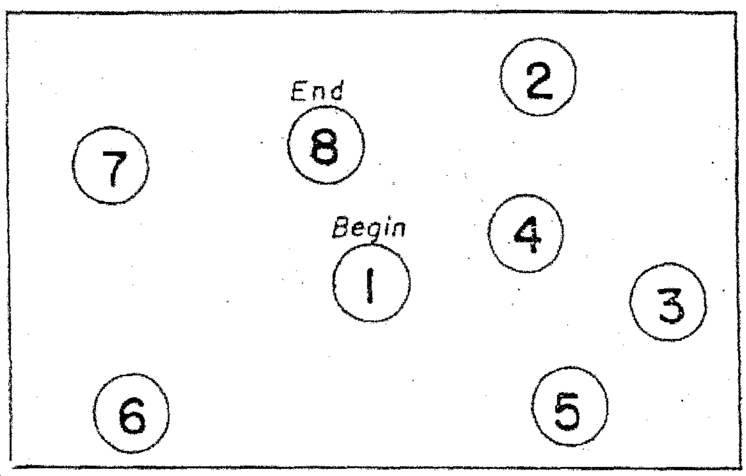
Start timing. If the subject makes an error, immediately call it to his or her attention and have the subject proceed from the point at which the mistake occurred. DO NOT STOP TIMING. If the subject completes part B without error, remove the test sheet. Record the time in seconds.

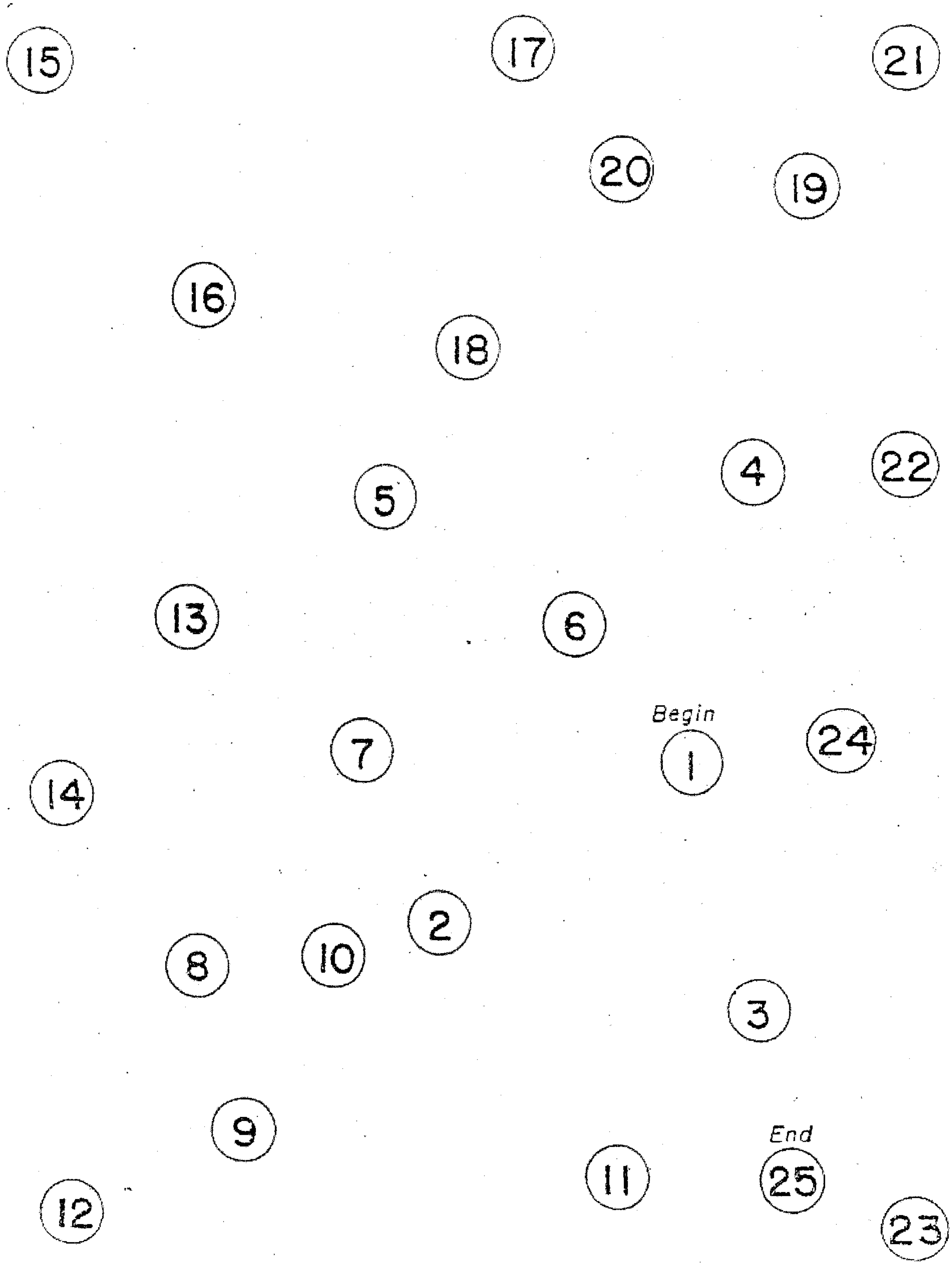
Scoring Trails: *For both forms, scoring is expressed in terms of the time in seconds required for Part A and Part B of the test. Some examiners also calculate a Trails B/Trails A ratio.*

TRAIL MAKING

Part A

SAMPLE

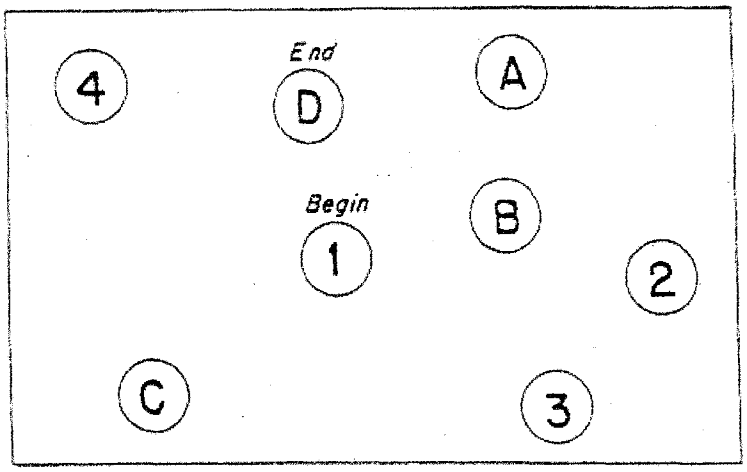


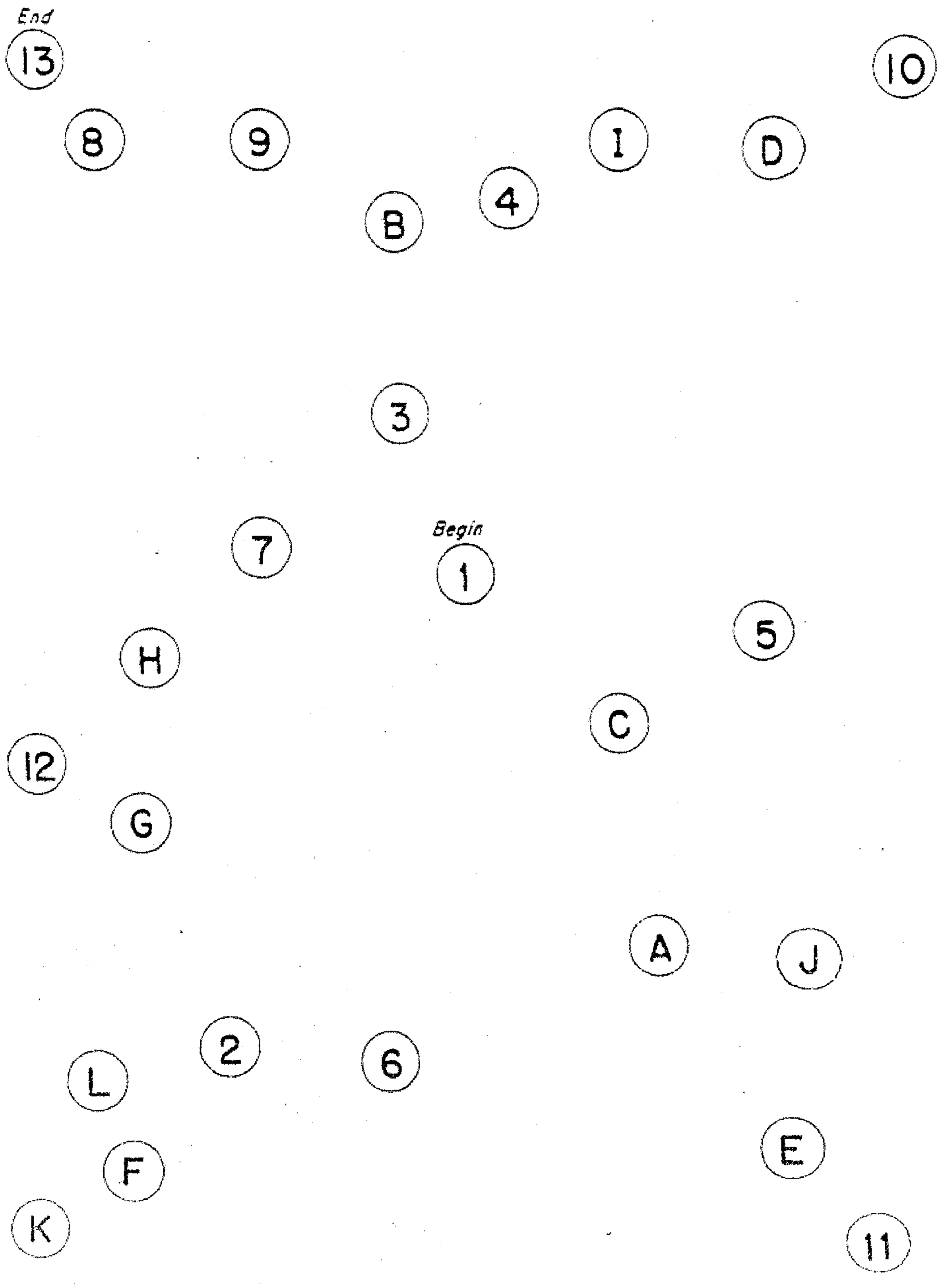

15
17
21
20
19
16
18
4
22
5
13
6
Begin
1
24
7
14
2
10
8
3
9
End
25
11
12
23

TRAIL MAKING

Part B

SAMPLE




End
13
10
8
9
I
D
4
B
3
Begin
7
1
5
H
C
12
G
A
J
2
6
L
E
F
K
11

3-Stroop Test:

Place Form C in front of the subject, flat on the desk. Do not allow the subject to move or touch the sheet during the test.

Say: "On this page there are some stars. Please read the colour of the stars as quickly as you can, starting at the top of the first column. When you finish this column, go to the top of the next column and so on" *(point to the top of the columns and indicate that the subject should read all these columns in the same manner).* "When I say begin, please read the stars out loud as quickly and as accurately as you can. If you make a mistake, just correct yourself and keep going. Do you have any questions? Ready? Begin".

Start the stopwatch and record subject's responses for 120 seconds. If the subject correctly identifies the colour, put a check next to that word in the response column. If the response is incorrect, mark an "X". If the subject gives an incorrect response and corrects it spontaneously, mark a "C" next to that word.

After 120 seconds say: "Stop!"

Place Form C-W in front of the subject. Do not allow the subject to move or touch the sheet during the test.

Say: "Here is a page with words on it. This time, I would like you to name the colour of the ink-red, blue, green or tan *(point to words printed in these colours)-* in which the word is printed. Please go as quickly as you can, going down the columns as you did before. For example, for item one, you would say "RED". If you make a mistake, just correct yourself and keep on going. When I say begin, please name the colour of the ink as quickly and as accurate as you can. Before we start, do you have any question? Ready? Begin".

Start the stopwatch and record subject's response for 120 seconds. If the subject correctly identifies the ink colour, put a check next to that word in the response column. If the response is incorrect, mark an "X". If the subject gives an incorrect response and corrects it spontaneously, mark a "C" next to that word.

After 120 seconds say: "Stop!"

Scoring: *Measure the time taken to complete Forms C and CW. The final score is the subtraction of the time taken to complete Form C from Form CW.*

Form C Modified Stimulus Sheet

★★★★	★★★	☆☆☆	★★★
★★★★★	★★★★★	★★★	☆☆☆
☆☆☆	☆☆☆	☆☆☆	★★★
★★★	★★★★	★★★★	☆☆☆
★★★★★	★★★★★	☆☆☆	★★★★
★★★★	★★★★	★★★	★★★★★
★★★★★	☆☆☆	★★★★★	★★★
★★★★	★★★★★	★★★	★★★★
★★★	☆☆☆	★★★★	★★★
★★★★	★★★★	☆☆☆	☆☆☆
☆☆☆	★★★★★	★★★	★★★★★
★★★	★★★★	★★★★★	☆☆☆
☆☆☆	★★★★★	★★★	★★★★
★★★★★	★★★	☆☆☆	★★★
★★★★	★★★★	★★★★	★★★★
☆☆☆	★★★★★	☆☆☆	★★★
★★★★★	☆☆☆	★★★★★	★★★★★
★★★	★★★	☆☆☆	★★★
☆☆☆	☆☆☆	★★★★	★★★★
★★★	★★★★★	☆☆☆	☆☆☆
☆☆☆	☆☆☆	★★★★	★★★★
★★★	★★★	★★★★★	★★★★★
★★★★★	★★★★	☆☆☆	★★★★
★★★	★★★	★★★★★	★★★
☆☆☆	★★★★★	☆☆☆	★★★★
★★★★	★★★	★★★	☆☆☆
★★★★★	☆☆☆	★★★★★	★★★★
☆☆☆	★★★★	★★★★	★★★★★

Form C-W Stimulus Sheet

BLUE	GREEN	RED	GREEN
GREEN	BLUE	GREEN	TAN
RED	RED	BLUE	RED
TAN	BLUE	TAN	TAN
GREEN	TAN	RED	BLUE
BLUE	RED	TAN	TAN
RED	GREEN	BLUE	GREEN
TAN	TAN	TAN	RED
RED	GREEN	RED	GREEN
BLUE	BLUE	BLUE	RED
RED	RED	RED	BLUE
TAN	TAN	TAN	GREEN
BLUE	GREEN	BLUE	TAN
TAN	RED	GREEN	BLUE
RED	BLUE	TAN	GREEN
BLUE	GREEN	BLUE	RED
GREEN	RED	TAN	GREEN
TAN	GREEN	BLUE	TAN
GREEN	BLUE	RED	GREEN
TAN	TAN	GREEN	BLUE
RED	GREEN	BLUE	TAN
BLUE	RED	GREEN	BLUE
RED	TAN	BLUE	GREEN
TAN	BLUE	GREEN	RED
RED	TAN	RED	BLUE
TAN	RED	GREEN	GREEN
GREEN	TAN	TAN	RED
TAN	GREEN	RED	BLUE

Star Excursion Balance test: "Now we will do another balance test. I would like you to place your left foot on the center of this box. You will have to try to maximally reach in these lines with your other foot *(here the experimenter demonstrates the foot placement and show how to reach in each of the 8 directions)*. You can not move the foot that is in the center of the lines as you reach with the other foot. When you touch as far as you can, you should not put weight on your foot and you should go back to the initial position with one foot beside the other. You will start reaching the stripe in front of you (*anterior position*) and you will move in a clockwise direction while reaching with the right foot. Once you have done it with your right foot you will perform the same task with your left foot, but this time you will be reaching in a counter clockwise direction. We will practice it a few times in each direction with both feet, so you can feel how it is like. If you put too much weight when you are trying to reach or touch any other place in between the line and the initial position or move your stable leg the trial will not be counted and you will have to reach again in that direction. There will be a person standing behind you, just in case you lose your balance. Do you have any question?"

The experimenter positions the left foot of the participant in the center of the box and instruct again the direction of the movements. Let the participant practice once in each direction standing on the left leg, then switch the leg and perform once in each direction standing on the right leg. Then repeat the left and the right leg again three times, in a way that the participant performs 3 trials in each direction with both legs. Give as much feedback as needed until the participant understands the instructions. Direct participant to the table and perform the leg length measurement.

"Ok, now that you know how to do it, you will perform the balance test again, but this time I will measure how far you can reach. You will have 3 trials in each direction for each leg. If you lose your balance, move your stable foot, or support to much weight with the reaching foot I will not consider the trial and you will have to perform it again. Are you ready?" *Make sure the participant's foot is placed properly and the person marking the distance on the tape is ready.* Start..

Mark with a chock the 3 points where the reaching foot touches the tape. At the end of the test, measure with a tape measure the 3 reached distances. The average result for each direction will be considered as the final result.

Leg Length measurement: "As we take a break, I would like to have you lay down on your back on this table. I will measure your leg length in order to normalize you reach distance". *With a tape measure, measure the distance between the ASIS to the center of the medial meleoli of the same leg. Perform the measurement for both legs.*

EMG: "Now we will place the EMG electrodes on your leg *(direct participant to the table)*. These electrodes will allow us to identify how much your muscles are contracting while you are walking on the treadmill. However, in order to get a good signal I will have to do some procedures to reduce the impedance of your skin. First, I will mark with a pen the areas where I will place the electrode. Then I will shave these areas, and abrade with a nail file and clean it with an alcohol pad. This way I make sure that dead skin and any residue of soap, lotion or oil that may be on you skin is removed. Feel free to ask any question as I go on with the procedures".

Place electrodes as explained.

MVC: "Before we go on to the treadmill I will have to test your maximum voluntary contraction. This will allow us to identify how much your muscles are able to contract so we have a baseline to compare to, when you are walking on the treadmill. For this part, I will place your legs in specific positions and will ask you to maintain that position while I try to move you from this position. I want you to try to match my resistance, enough to maintain the initial position. Do you understand?"

Start the testing for MVC.

Footswitch: "I will now place these insoles inside both of your shoes. They have sensors that will inform us when your foot is touching the ground and when it is off the ground".

Prepare the EMG transmitter box and say: "Now I am going to attach this belt around your waist. On the belt there is a box for the EMG sensors, one for the microphone, and one for the headphones".

Volume setting: "Now we will adjust the volume to your comfort. I will play a scene from a movie and I would like you to set the volume of the headphones to a comfortable volume for you. There are no words in the clip; it is simply the noise of a crowd". *Experimenter runs the movie file.*

Setting threshold: "You will hear through these earphones a list of numbers in a random order. You will have to subtract one from the number you hear and say the result out loud. I would like you to try to be as fast and as accurate as possible". *Instruct the participant to stand facing the wall, beside the treadmill and make sure the treadmill is running during this task.* "Any question? Please put on the headphones. Re-adjust them if you need to and be prepared to start when you hear a beep". *The experimenter runs the threshold filet.*

Determining gait speed: *Lead participant to the treadmill and say:* "Before we start walking on the treadmill, I would like to show you a few different ways to stop the machine or straddle the belt if you want to stop. If you feel uncomfortable at all, just say "STOP!" in a loud voice, as someone will stop the machine. You can also straddle the machine" *(the experimenter models straddling the treadmill-while it is running, pressing the emergency stop button, and how to signal the researcher if they want to stop).*

"When you are walking on the treadmill, you should walk as if you were walking on the sidewalk, looking straight ahead with your arms at your sides, but if you should need to steady yourself please grab hold of the parallel bars on either side of the track. I would like you to set your speed at a comfortable pace, as if you were walking to an appointment you have. You are not too early and not late, so you are not walking at a leisurely pace but you are not rushing either. I will increase and decrease the speed of the treadmill until it is at a pace that you feel comfortable with".

At this point, the experimenter manipulates the speed of the treadmill asking: How is that pace? Would you prefer a little faster? A little slower? Increase and decrease in increments, keeping track of the comfort/exertion level of the participant, until the participant feels that they are walking as they would be walking in the street.

Show the Borg Scale and say: "During the exercise test we want you to pay close attention to how hard you feel the exercise work rate is. This feeling should reflect your total amount of exertion and fatigue, combining all sensations and feelings of physical stress, effort, and fatigue. Don't concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try and concentrate on your total, inner feeling of exertion. Try not to underestimate or overestimate your feelings of exertion; be as accurate as you can. We would like you to aim for an exertion rate that is a 12 on this scale. Which means your exertion should be somewhere between fairly light and somewhat hard."

The experimenter again increase and decrease the speed until the participant reach the target exercise intensity. Once he/she has reached the speed and agreed that it is between fairy light and somewhat hard let them walk for a minutes to make sure they set the speed properly. Ask the participant if that is a comfortable speed and then to straddle. The experimenter stops the treadmill.

BORG SCALE

6

7 VERY, VERY LIGHT

8

9 VERY LIGHT

10

11 FAIRLY LIGHT

12

13 SOMEWHAT HARD

14

15 HARD

16

17 VERY HARD

18

19 VERY, VERY HARD

20

"Now I will ask you to step off the treadmill again".

Practice Single-task/Cognitive: "You will hear through these earphones a list of numbers in a random order. You will have to subtract seven from the number you heard and say the result. I would like you to try to be as fast and as accurate as possible". *Instruct the participant to stand facing the wall, beside the treadmill and make sure the treadmill is running during this task.* Any question? Please put on the headphones-adjust them if you need to. Be prepared to start when you hear a beep.

The experimenter runs the practice-single file.

Practice Single-task/Walk: *Be sure that the EMG experimenter is ready.* "Now I would like you to step on the treadmill. As we mentioned in the beginning, the level of difficulty will vary. You will walk on the treadmill, but at this time I will increase the speedup to an additional percentage from your original selection. You can hold the bars if you feel unsafe, straddle or say stop if you want to stop the treadmill. How is that? Now I am going to let you walk at this pace for a little while".

After 2 mins ask the participant to straddle or stop the treadmill slowly.

Practice Dual-task/Cognitive and Walk: "Ok, now that you understand both parts of the study, we are going to put them together. You are going to walk and subtract 7 from the numbers you hear as quickly and accurately as you can. Both tasks are equally important. First, I will start the treadmill and bring it to the same pace as you had before and then you will hear a beep through the earphones and you will have to walk and subtract at the same time. Do you have any question?"

The experimenter runs the practice-dual file. Once finished, have the participant straddle the treadmill again and stop it.

"That was the practice session. Now we are going to do the same thing but in a different order".

The order of tasks that the participant receives depends on the condition. Check condition order sheet to verify what order the participant will be completing.

Test Single-task/Cog: "As before, you will hear a list of numbers from which you will have to subtract seven and say the result. The only difference is that the list will be a little longer. I would like you to try to be as fast and as accurate as possible". *Instruct the participant to stand facing the wall, beside the treadmill and make sure the treadmill is running during this task.* "Any questions? Please put on the headphones-adjust them if you need to and prepared to start when you hear the beep".

For participants that are doing the easy condition first, change the instructions to subtract one from the number they hear.

The experimenter runs the cog_single_hard or cog_single_easy file according to the participant's number. Write down participant's response.

"Good! Now you will hear another list of numbers from which you will have to subtract one and say the results. Again, try to be as fast and as accurate as you can. Any questions? Please put on the headphones-adjust them if you need to and prepared to start when you hear the beep".

For participants that are doing the easy condition first, change the instructions to subtract seven from the number they hear.

Test Single-task/Walk: *Be sure that the EMG experimenter is ready.*

"Now I would like you to step on the treadmill. You will only walk and I will slowly increase the speed to the same speed that you had before. You can hold the bars if you feel unsafe, straddle or say stop if you want to stop the treadmill. How is that? Now I would like you to walk at this pace for a couple of minutes. I would like you to look straight ahead and to remain silent".

Record EMG while walking, for 2 mins. Then, ask the participant to straddle or stop the treadmill slowly.

Test Dual-task/Cognitive and Walk: "Now we are going to put them together. You are going to walk and subtract 7 from the numbers you hear as quickly and accurately as you can. Both tasks are equally important. First, I will start the treadmill and bring it to the same pace as you had before and then you will hear a beep in the earphones and you will have to walk and subtract at the same time".

For participants that are doing the easy condition first, change the instructions to subtract one from the number they hear.

The experimenter runs the Cog_dual_hard or Cog_dual_easy file according to the participant's order. Make sure the EMG experimenter is ready. Write down participant's response.

"Good! Now you will hear another list of numbers from which you will have to subtract one and say the results as quickly and accurately as you can, while you are walking on the treadmill. Both tasks are equally important. Any questions? Please put on the headphones-adjust them if you need to and prepared to start when you hear the beep".

For participants that are doing the easy condition first, change the instructions to subtract seven from the number they hear.

The experimenter runs the Cog_dual_hard or Cog_dual_easy file according to the participant's order. Make sure the EMG experimenter is ready. Write down participant's response.

"Good, that is the end of testing!"

Debriefing

Walking while counting: Interaction between motor control and cognition

The purpose of this study is to see how people manage to do two things at once and how the performance of the tasks varies according to their level of difficulty. It is believed that as the difficulty of two tasks that are carried on at the same time increases, the performance of either one or both of the tasks can decrease because we are not able to allocate attention to both tasks.

In this study, we are interested in seeing how much the math task alters your walking pattern and your muscle activity. We will compare the muscle activity from your leg when walking alone to when you were walking and performing the math task together during different phases of the walking cycle. We will also compare the accuracy and reaction time of the math task when done alone and when performed while walking. We hope that this will allow us to have a better idea of the limits of the nervous system to carry on multiple tasks and to identify more clearly when during the different phases of walking attention is most important.

Thanks you for your participation!

For further information about this study, please fell free to contact us:

Gabriela Abbud -

Dr. Richard DeMont- demont.conu@gmail.com

Suggested literature:

-Pashler H. (1994) Dual-task interference in simple tasks: data and theory. *Psychol. Bull.* 116(2):220-244.

-Woollacott M. & Shumway-Cook A. (2002) Attention and the control of posture and gait: a review of an emerging area of research. *Gait and Posture,* 16:1-14.

-Fraser SA, Li, KZ, DeMont RG, Penhune VB. (2007) Effects of balance status and age on muscle activation while walking under divided attention. *J Gerontol B Psychol Sci Soc Sci.*, 62:3, 171-178.

Personal Information

NAME	*Participant's ID:*

Age:	**Sex:**	**Time:**

Romberg Balance test:	P1 T1	P2 T2	P3 T3

SEBT

RIGHT LEG STANCE				**Leg lenght (left)**			
T1	T2	T3	T4	T5	T6	T7	T8
T1	T2	T3	T4	T5	T6	T7	T8
T1	T2	T3	T4	T5	T6	T7	T8
LEFT LEG STANCE				**Leg lenght (right)**			
T1	T2	T3	T4	T5	T6	T7	T8
T1	T2	T3	T4	T5	T6	T7	T8
T1	T2	T3	T4	T5	T6	T7	T8

Stroop:

Trails:

Digit Symbol:

Walking speed:	**with 20%:**

Cog accuracy:

Comments:

Appendix D

Complete list of stimuli

Practice Dual-Task		Parctice Single-Task	
Stimuli	ISI (ms)	Stimuli	ISI (ms)
29	3250	29	3250
85	1750	52	3500
45	2500	51	2250
31	3500	26	2750
12	2000	48	2750
49	1250	53	1500
26	2750	81	2500
51	2250	36	1250
14	3000	49	1250
52	3500	45	2500
98	1750	31	3500
32	3000	12	2000
48	2750	19	1500
53	1500	55	3250
81	2500	13	2000
22	2250	98	1750
19	1500	22	2250
55	3250	85	1750
13	2000	14	3000
36	1250	32	3000

Single-Task EASY		Single-Task HARD		Dual-Task EASY		Dual-Task HARD	
Stimuli	ISI (ms)	Stimuli	ISI (ms)	Stimuli	ISI (ms)	Stimuli	ISI (ms)
84	2250	63	3500	65	3500	65	3500
53	1250	84	2250	39	2500	34	1750
39	3500	53	1250	61	2750	42	1500
54	2750	44	3250	42	1500	15	3250
68	1500	61	2000	54	3250	21	2000
92	2250	13	1500	19	2000	66	1250
56	2000	54	2750	95	3000	41	2500
21	1250	72	3500	88	2250	82	2000
11	2250	24	2500	64	1250	43	3500
65	2500	33	2000	34	1750	62	1750
83	1500	16	3000	69	2750	95	3000
93	1250	21	1250	75	3500	38	3250
75	3000	64	1750	81	1750	33	1500
62	1500	79	2750	79	1500	22	2750
74	2000	68	1500	89	3000	84	1750
48	1250	92	2250	71	2000	18	1250
64	1750	56	2000	25	3000	24	3250
43	3500	43	3500	22	2750	39	2500
34	3250	75	3000	84	1750	88	2250
79	2750	62	1500	18	1250	89	3000
19	2250	69	2750	24	3250	64	1250
88	3250	81	2500	35	1500	69	2750
46	2750	48	1250	68	2000	75	3500
63	3500	71	2750	92	2750	81	1750
61	2000	42	1500	48	3500	79	1500
13	1500	35	3000	56	2500	56	2500
72	3500	82	1250	76	2250	71	2000
24	2500	34	3250	74	3000	78	1250
33	2000	11	2250	23	2500	25	3000
81	2500	38	2000	15	3250	68	2000
71	2750	39	3500	38	3250	92	2750
42	1500	46	2750	33	1500	48	3500
35	3000	65	2500	72	2500	72	2500
82	1250	83	1500	82	2000	76	2250
58	2250	88	3250	43	3500	35	1500
25	3000	25	3000	62	3000	74	3000
23	1750	23	1750	73	1250	23	2500
66	2750	66	2750	11	2750	94	3250
41	3500	41	3500	93	2250	91	2250
18	1750	18	1750	55	1750	63	1750
76	2500	96	3000	44	3500	16	3500
95	3250	78	2500	36	2250	13	2000
78	2500	55	1750	94	3250	53	1500
55	3250	99	1500	91	2250	86	3000
99	1500	15	3250	63	1750	73	1250
15	3250	73	3000	16	3500	11	2750
38	2000	91	1750	13	2000	93	2250

69	2750	59	3500	53	1500	58	3250
44	1750	58	2250	86	1750	61	2750
73	3000	36	2000	58	3250	46	2500
91	1750	93	1250	32	2250	59	1500
59	3500	94	2500	46	2500	96	2750
32	1250	89	2250	59	1500	32	2250
96	3000	22	3250	96	2750	83	1250
86	1750	76	2500	78	1250	99	3000
36	2000	32	1250	83	1250	54	3250
16	3000	19	2250	99	3000	19	2000
22	3250	86	1750	21	2000	55	1750
94	2500	74	2000	66	1250	44	3500
89	2250	95	3250	41	2500	36	2250

Appendix E

Physical Questionnaire

Physical Questionnaire:

Please list any injuries in the past year:

____

____

____

____

Have you had a concussion? When?

____

Have you ever been hospitalized? If yes, for what reason and when?

____

Are you currently taking any medication? Please list.

____

Are you physically active? If yes, please list your activities, frequency and intensity.

____

____

____

____

How often do you use a treadmill? What is your frequent speed?

____

Appendix F

Condition order

CONDITION ORDER: YOUNGER ADULTS

PRACTICE HAS ALWAYS THE SAME ORDER: COG-WALK-DUAL

CONDITION ORDER	PARTICIPANT #	PARTICIPANT ID	COMMENTS
1) Cog $_{easy}$ -W- Dual $_{easy}$	1		
2) Dual $_{easy}$ - Cog $_{easy}$ -W	2		
3) W- Dual $_{easy}$ - Cog $_{easy}$	3		
4) Cog $_{easy}$ -Dual $_{easy}$ -W	4		
5) Dual $_{easy}$ -W- Cog $_{easy}$	5		
6) W- Cog $_{easy}$ -Dual $_{easy}$	6		
7) Cog $_{hard}$- W- Dual $_{hard}$	7		
8) Dual $_{hard}$ - Cog $_{hard}$ -W	8		
9) W-Dual $_{hard}$ -Cog $_{hard}$	9		
10) Cog $_{hard}$ -Dual $_{hard}$-W	10		
11) Dual $_{hard}$-W-Cog $_{hard}$	11		
12) W-Cog $_{hard}$-Dual $_{hard}$	12		
13) Cog $_{easy}$ -W- Dual $_{easy}$	13		
14) Dual $_{easy}$ -Cog $_{easy}$-W	14		
15) W- Dual $_{easy}$-Cog $_{easy}$	15		
16) Cog $_{easy}$ -Dual $_{easy}$-W	16		
17) Dual $_{easy}$-W-Cog $_{easy}$	17		
18) W-Cog $_{easy}$-Dual $_{easy}$	18		
19) Cog $_{hard}$ -W- Dual $_{hard}$	19		
20) Dual $_{hard}$ - Cog $_{hard}$ -W	20		
21) W-Dual $_{hard}$ -Cog $_{hard}$	21		
22) Cog $_{hard}$-Dual $_{hard}$-W	22		
23) Dual $_{hard}$-W-Cog $_{hard}$	23		
24) W-Cog $_{hard}$-Dual $_{hard}$	24		

Note: If it is necessary to replace, choose the next # in the «participant#» and the same « condition order » of the person being replaced.