# The Interacting Effect Of Increasing Cognitive And Motor Task Demands On Performance Of Gait, Balance And Cognition In Young Adults.

by

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# ABSTRACT

The purposes of this study were to: 1) evaluate the effect of walking speed on gait, balance and cognitive task performance and 2) examine the effect of dual task (cognitive load) on gait balance and cognitive task performance. Twenty young healthy adults (24±6 years of age) were recruited and each participant walked on a motorised treadmill at two speeds(0.5m/s and 0.8m/s), first without performing cognitive tasks, then while performing three types of cognitive loaded tasks. The speed had a significant effect on average and coefficient of variation of temporal gait parameters ($P<0.001$), cognitive task performance ($P<0.001$) and center of pressure excursion ($P<0.001$). No statistically significant effect of speed was found ML trunk displacement. However, dual task (cognitive load) had significant effect on COV of temporal gait ($P<0.001$), cognition ($P<0.001$) and trunk motion ($P<0.001$). In conclusion, the speed and dual task had significant effect on locomotors rhythm, balance, and cognitive performances.

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# DEDICATION

My deepest and warmest thanks go to my husband, Dr. Shiva Shrestha, whose love and support has kept me going. I express my heartfelt gratitude and affection to my daughter and husband to whom I dedicate this thesis.

**Pramila Maharjan**

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# ABBREVIATIONS

TMT: Trail Making Test

COV: Coefficient of Variation

VRT: Verbal Reaction Time

AAI: Attention Allocation Index

GV: Gait velocity

COM: Center of Mass

COP: Center of Pressure

FSA: Foot insole pressure mapping system

DC: Direct current

2D: Two Dimensional

3D: Three Dimensional

T2: Thoracic vertebrae level two.

CANTAB: Cambridge Neuropsychological

UFOV: Useful Field of View

SW: Swing Time

ST: Stance Time

DS: Double Support

AP: Anterior-Posterior

ML: Medio- Lateral

PAL:  Paired Associate Learning test

RMS: Root Mean Squar

## INTRODUCTION

Walking is a complex process which involves the integration of sensory, cognitive, and motor processes. There are many dimensions and specific factors that attribute to safe and independent mobility outside the home. Of primary importance is the ability to confidently negotiate obstacles, different terrains, and busy environment. Sensing the state of balance during walking, along with the selection of motor strategies, which are used to maintain and quickly compensate for disturbances (stumbles), is determined by the ongoing tasks demands, environmental conditions, and cognitive loads. Sensory and cognitive processes are required to process multiple sources of spatial information in order to identify the state of balance whether instability or threats to balance exist. Once identified, appropriate timely actions can be executed to suit the task requirements and environmental conditions.

It is believed that walking, a complex motor skill is in fact tightly linked to cognitive functioning. Evidence has emerged for actual patho-physiological interaction between gait and cognition. Having a gait disorder triples the chances of developing non-Alzheimer dementia (Pettersson, Olsson, and Wahlund, 2008). Conversely, people with dementia more often have gait disorders and also sustain an increased risk of falling. A key cognitive factor in gait and balance control is executive functioning that may decline with age. Literature on the interaction of executive function and walking performance are more consistent with the conclusion that such tasks compete for limited central attention resources (Pashler, 1994, Woollacotthumway–Cook, 2002). Some notable examples are: working memory, cognitive inhibition, visual attention and useful field of view, reasoning ability, and executive functions (Corbetta & Shulman, 2002). Abilities that show greatest impairment with age are associated with performing dual-tasks in which goal-directed behaviours have to be flexibly maintained, monitored, and implemented in the face of distractions and task sets.

Age-associated changes in both speed and stability were commonly observed during performance of concurrent walking-cognitive task; i.e., the individual becomes more cautious and walks at a slower pace. It is concluded that this is partly due to a reduced ability to flexibly allocate attention between walking control and the cognitive task (Springer, Giladi, Peretz, Yoge & Hausdorff, 2006). Most previous dual-tasking gait studies have used only a single test to probe executive functions, and performance measures were restricted to body movements or variables. We will extend this prior work by examining the interaction of graded task demands and cognitive loads and to concurrently measure balance, locomotor, and cognitive performance.

## REVIEW OF LITERATURE

### OVERVIEW OF LOCOMOTION:

The initiation and termination of locomotor movements, the generation of continuous movement to progress towards a destination, maintenance of stability during progression, and adaptability to meet any changes in the demands of the environments are four components required during walking (Woollacoot & Tang, 1997). Human walking is frequently expressed as a rhythmical alternating cycle of stance and swing phases. Stance phase is further divided into double support and single support phases, according to the number of limbs in contact with the ground in particular time. The time between heel strikes reflects the internal rhythmicity of locomotion. Therefore the variability in stride interval provides insight into the organization, regulation, interaction, and consistency of the locomotor cycle, entire locomotion.

Many authors have suggested that the basic spatio-temporal parameters of gait can be used as a global measure of the success of the walking task, and, therefore, provides indication of walking stability and movement coordination (Wolfson, Whipple, Amerman, & Tobin, 1990). It has been consistently observed that older people walk more slowly than young people (Lord, Lloyd, & Li, 1996), have increased step widths, shorter step length, and increased time spent in double limb support (Ferrandez, Pailhous, & Durup, 1990; Maki, 1994).

A number of studies have also found that older subjects exhibit significantly greater variability in stride length, stride time, and step width, and this variability is associated with an increased risk of falling (Hausdorff, Edelberg, Mitchell, Goldberger, & Wei, 1997; Hausdorff, Rios, & Edelberg, 2001). A number of authors have argued that these changes observed in older people may be detrimental to stability under challenging condition.

## ANALYSIS OF TRUNK MOTION WHEN WALKING:

Many biomechanical investigations have attempted to address the issue of balance control by analysis of trunk movements (Baubly, 2000; Menz, Lord & Fitzpatrik, 2003a, 2003b, 2003c; Moe-Nilssen & Helbostad, 2005, 2004). The trunk represents 50% of the total body mass and must be sufficiently stable and coordinated with other body segment movements to enable the body to progress smoothly during gait.

A number of authors have suggested that one important event in the maintenance of stability when walking is control of lateral motion of the trunk over the supporting foot in the single support phase of gait. For example, increases in variability of lateral trunk acceleration and spatial gait parameters have been demonstrated while negotiating compliant surfaces (foam pads) as compared to solid levels surfaces. Menz, Lord, and Fitzpatrik, (2003a) observed more irregularity in vertical and anterio-posterior pelvic and head acceleration patterns. The irregularity was found more prominent in the older falling population and walking on irregular terrain. The irregular pelvis and head accelerations evident in the high-risk group suggest that these subjects may have difficulty controlling trunk motion and maintaining a stable visual field when walking, particularly on irregular terrain. But the trunk variability was less for non- moving surface walking condition ($p<0.001$). Thus, significantly greater variability in the medial-lateral direction indicates that to maintain stability, participants needed to exert greater control in the medial-lateral direction. In an experiment, Hirasaki, Cohen, Moore, and

Raphan, (2001) reported higher head acceleration in older people compared to young people while walking over ground. It was suggested that increase motion in the head makes it more difficult to maintain a stable visual field, and may therefore be associated with impaired stability while walking.

## GAIT SPEED:

Speed is an important independent variable to control and normalize when comparing spatio-temporal gait parameters, both within and between subjects and over time (Mockel, Perka, & Duda, 2003). A number of studies have demonstrated that spatio-temporal gait parameters (average values and coefficient of variation) are influenced by walking speed (Betker et al., 2006, Branch, Berthold, & Craik2001; 2003, Frenkel, Giladi, Peretz, 2005 & Jordan, Challis, Newell, 2007 ). Frenkel et al. (2005) reported association of stride time variability with walking speed but not swing time, whereas Jordan et al.(2007) found increase in mean stride length and step length with increase in speed. But the stride interval and step interval decrease with speed.

Recently, Betker, Maharjan, Szturm, and Yduvanshi (2006) conducted a study to examine the effect of over ground and treadmill walking speed with and without support on spatio-temporal parameters among healthy young adults. The spatial-temporal outcome measures were compared between over ground walking on the GAITRite carpet and treadmill walking at a speed set to the average of the GAITRite walk. Results showed that there was a 100 milli second decrease in stance time on the treadmill when compared to over ground walking at a similar speed. Conversely, there was a 300 milli second increase in the swing time for the treadmill when compared to the over ground walking. The coefficient of variation (COV) values for the temporal parameters was similar for the treadmill and over ground walking. There was a 3 to 4 cm increase in the step width on the treadmill when compared to the over ground walking; however, the COV was substantially lower on the treadmill trial. The study also found that, during treadmill walking, subjects spent more time in the swing phase than the stance phase. The spatio-temporal parameters were also compared during treadmill walking for two different speeds. The results showed substantial changes in all temporal parameters with an increase in treadmill speed, both with and without hand support ( Betker et al.,2006) .

## RELATIONSHIP BETWEEN MOBILITY AND COGNITION:

Both cognitive problems and mobility limitations are common with aging, and these impairments affect the activities of daily living and increase risk of falling and fall injuries. Research studies have shown the coexistence of gait slowing and cognitive impairment in older individuals (Hausdroff, Stern, Rakitin, 2005; Liu-Ambrose, Katarynch, Ashe, Nagamatsu and Hsu, 2009). Studies have observed a strong association between decreased executive function in older people and a variety of gait variables: walking speed, stride time variability, and fall occurrence (Ble, Volpato, Zuliani, Guralnik, & Bandilli, 2005; Coppin, Shumway-Cook, Saczynski, & Patel, 2006). The dual task paradigm has been used to investigate interference between executive function and performance of physical tasks.

Executive function is a set of cognitive abilities that is necessary to plan, monitor, and execute a sequence of goal-directed activities. Executive functions commonly observed to decline $with aging include processing speed, cognitive inhibition, and task switching. The Stroop test (Stroop, 1935) is a commonly used test to evaluate response inhibition ability in dual task. Two versions of the Stroop tests have been used: Word Stroop Test and Color Stroop Test. When the name of a color (e.g., "blue," "green," or "red") is printed in a color not denoted by the name (e.g., the word "red" printed in blue ink instead of red ink), naming the color of the word takes longer and is more prone to errors than when the color of the ink matches the name of the color. The Trail Making Test (TMT), which measures task-switching ability, has also been frequently used in dual task studies. The TMT consists of two parts (Lezak, 1995): Trail Making Test A (TMT-A) and Trial Making Test B (TMT-B). TMT-A is a simple visual scanning task that requires the subject to draw a line connecting consecutive numbers from 1 to 25. TMT-B requires the subject to draw a line connecting consecutive numbers and letters in an alternating sequence, e.g., 1-a-2-b-3-c. Other executive functions used are: arithmetic tasks (counting backwards loudly starting from 50, the plus-minus task), verbal fluency task (spelling “earthquake” backwards, backwards counting of the months and names of week days, enumerating animals’ names) along with walking to observe their relationships ( Beauchet et al.,2010; Beauchet et al.,2008)

## CORRELATION ANALYSIS BETWEEN LEVELS OF COGNITION AND WALKING PERFORMANCE:

In the last two decades, several studies have explained the association of executive function with walking performance, fall risk, and fall incidence ( Lee & Chou , 2005; Ambrose & Pang, 2007, 2006; Holtzer, Friedman, Lipton, & Katz, 2007).Holtzer et al. (2007) examined the relationship between executive function and fall incidence in older individuals. Each participant was given the Trail Making Test (TMT). The sample was divided into three groups: (a) faller (at least one fall), (b) recurrent fallers (more than two falls), and (c) non-faller. Logistic regression revealed that executive function is related to fall incidence. Participants with low TMT scores were four times more likely to fall than individuals in the normal TMT range. There was no difference found between single and recurrent fallers.

The relationship of executive function and stability measures was examined in a sample of 63 community-dwelling older adults with stroke (Ambrose & Pang, 2006, 2007). The Stroop test and Verbal Digit Span Test were used to quantify executive function. Berg Balance score, Timed-Up-Go test, and Six–Minute walk were used to measure balance performance. Pearson Product–Moment Coefficient of correlation provided the level of association between these independent variables of executive function and balance. The number of correct responses in this Stroop test in 45seconds was recorded. The study found casual and weak associations between these independent variables of executive function and balance($r=0.34$, $p<0.01$). The individuals with impaired executive function may have impaired balance and mobility.

Coppine et al. (2006) examined the association between performance on the Trail Making Test (TMT) and walking speed among a group of community-dwelling individuals without dementia. Participants were divided into groups: (a) good TMT score, (b) average TMT score, and (c) poor TMT score. Participants performed a series of walks under increasing task demands, as follows: (a) talking while walking at their usual pace, (b) picking up objects from the ground, (c) walking while carrying a light to large package, (d) walking over two obstacles, and (e) walking while wearing a weighted vest. Results indicated that the group with poor TMT scores walked at slower speeds for the majority of the conditions. The group with average and good TMT scores walked slowly during talking while walking and carrying a package task. The authors concluded that gait speed is task dependent and varies according to degree of the task's complexity, and this effect was increased in people with poor TMT scores.

Therefore, from these studies it is concluded that locomotor tasks require integrity of the neurological structures that are responsible for executive function process. Impaired executive function may impair balance via reduced attentional capacity and impaired central processing and integration.

## DUAL TASK EFFECT ON WALKING STABILITY AND GAIT PARAMETERS:

The flexible allocation of attention between walking and secondary tasks, such as talking to a companion or scanning a busy street for threats to safety, is required for efficient walking balance in a complex environment. Previous studies have suggested that falls in older adults may be caused by the reduced ability to flexibly allocate attention between two concurrent tasks. Several dual task studies examined the effect on walking stability and gait parameters. The dual task situation includes both mental and physical challenges (Woollacoott & Shumway-Cook, 2002; Sui, Shan Chou, Mayr , Donkelaar & Shumway-Cook, 2008; Dubost, Annweiler, Aminian, Najafi, Herrmann, Beauchet, 2007, 2006; Van Isersel, Kessels, Bloem, Verbeek & Olde Rikkert , 2008; Kelly, Schrager, Price, Ferrucci, and Shumway-Cook., 2008).

Sui et al. (2008) examined the effect of dual tasks on walking performance and cognitive performance. The cognitive task included auditory Stroop tests, and physical challenges included ground level walking and walking while negotiating obstacles. Participants were put into two groups: 12 healthy young adults (age=22.8±2.7) and 12 healthy older adults (74±5). Participants performed control Stroop tests in sitting. Then, they were asked to (a) walk on level ground while performing the Stroop task and (b) negotiate obstacles while performing the Stroop task. Gait velocity, stride length, step width, stride time, and toe-obstacle clearance height were quantified. The auditory Stroop test pre-recorded words “high” or “low” spoken with high and low pitch. The participants indicated the actual pitch of the voice, ignoring the actual word presented. Verbal reaction times (VRT) during the Stroop test were calculated, and only trials with correct verbal responses were included for analysis. They did not record the visual reaction time (VRT) for wrong responses. Overall, the study did not find any differences in gait parameters and toe clearance in both single and dual task conditions, suggesting that the Stroop test did not affect gait stability in either age group. In contrast, verbal reaction time (VRT) was different in both groups and conditions; for instance, VRT was longer for a dual-task condition (obstacle crossing while performing the Stroop task) in comparison to the single task condition only for older adults. But such effect was not seen in younger adults. In a subsequent experiment, an attention allocation index (AAI) was calculated to examine the ability to shift attention between the motor and cognitive task. Participants were instructed to perform the dual-task protocol with three instructional conditions: (a) focus on motor task, (b) focus on the Stroop task, and (c) focus equally on both. When both groups were asked to focus on the Stroop task, they both reduced their verbal reaction time (VRT), but the reduction was significantly more in the young adult group. Similarly, when they were asked to focus on obstacle clearance, both groups increased their gait velocity (GV); however, GV was greater in the younger group. Sui et al., (2009) suggested that disproportionate reduction in verbal reaction time and gait velocity in older adults is due to the inability to focus their attention on either the obstacles or Stroop task under different instructional sets. Attention allocation index (AAI) values in older adults were smaller than in young adults. Thus, the combination of older age and limitation in ability to switch attention appears to create a risk towards a reduced ability to switch attention between gait control and cognition. Therefore, they concluded that the ability to switch attention to different tasks is an additional factor that compromises gait control in healthy older adults.

A study conducted by Kelly, Schrager, Price, Ferrucci, and Shumway-Cook. (2008) examined the effect of verbal recital tasks (speaking the days of the week) on gait speed and medial-lateral trunk motion in a sample of healthy older adults. Participants were asked to walk at a comfortable pace within a narrow path with and without naming tasks, where the width of the path was normalized to 50% of the distance between the participant's anterior superior iliac spine. A six-camera VICON motion analysis system was used to compute position of the whole body center of mass (COM) and select spatio-temporal gait variables (stride velocity, step width, and stride time). The study observed a trend toward a decrease in mean stride velocity and step length, and increase in mean stride time with performance of the cognitive task. Similar changes in gait parameters were observed with increasing participant's age. The authors did not find any significant interacting effect of cognitive task on stride time (p=0.913), stride velocity (p=0.316), and stride length (p=0.25). The performance of a concurrent a cognitive task did not affect medial-lateral COM displacement and peak velocity (p=0.94). The result indicated that both changes in speed and stability observed during narrow base walking are age associated and the addition of a cognitive task during walking didn't affect these dependent variables.

Van Iersel, Kessels, Bloem, Verbeek & Olde Rikkert (2008) examined the effect of animal enumeration tasks and an arithmetic task on medial-lateral trunk movement and various spatial-temporal parameters during over ground walking. The addition of the cognitive tasks during walking resulted in: (a) decrease in gait velocity and (b) an increase in amplitude of medial-lateral trunk excursion and variability of both stride length and stride time. These effects were seen only during the verbal fluency (animal enumerating task), not during the arithmetic task. In addition, they also observed a decrease in the performance of the enumerating task while walking as compared to a sitting control condition. The author concluded that changes in gait velocity and trunk sway were the effect of arithmetic task. A decrease in gait velocity is a cautious strategy also seen in a number of studies that examine the effects of surface conditions on walking stability (MacLellan & Patla, 2006; Marigold & Patla, 2005; Menz et al., 2003b, 2003c). Therefore, slow walking during dual task condition would be the strategy adopted to be safe during walking.

Dubost, Annweiler, Aminian, Najafi, Herrmann, Beauchet. (2006) examined if the changes in mean stride time variability was the result of either walking speed or cognitive task. For this, 45 community-dwelling older people walked at two different speeds: normal self-selected walking and a slow speed. They performed an animal-enumerating verbal fluency task while sitting and while walking at normal speed, they also performed an animal-enumerating task. They found different coefficient of variation of stride time in normal walking, slow walking, and walking with animal enumerating conditions. When participants walked slowly, there was an increase in the mean and coefficient of variation of stride time compared to the other speeds. The result of ANOVA shows the significant effect of walking speed on mean stride time (effect size, i.e., partial Eta square=0.83, $p<0.001$) and COV stride time. The number of correct verbal responses (number of enumerating animal names) did not vary as a function of walking speed. Therefore the effect of walking speed on stride time of course was independent of animal enumerating task. The researchers concluded that stride time parameters were mainly affected by walking speed but not by animal enumerating task.

Another study evaluated the effect of cognitive task on gait speed among mild cognitive-impaired individuals (Luis, Loewntein, Acevedo, Barker, & Duara, 2003). For this, the gait velocity was recorded while walking alone, while walking and performing an animal enumerating task, and while walking and counting backwards from 100. Participants experienced a significant decrease in gait velocity while engaging in verbal recitation and backward counting conditions when compared with walking without these tasks ($p<0.001$).

In a study by Springer et al. (2006), healthy young adults, healthy older fallers, and non-fallers were asked to perform arithmetic, memory, and multiple-choice question tasks while walking at their self-paced speed; walking speed was not controlled. The results indicated that gait speed and swing time variability were reduced in all walking conditions and for all three groups. And this dual task interaction effect on swing time variability was not significant for young and non-fallers ($p=0.82$), whereas the fallers group showed a significant increase in stride time variability ($p=0.003$). The fallers made more mistakes compared to non-fallers and young adults in all three cognitive tasks while walking. The author concluded that young adults and older non-faller adults walked slowly to cope with the dual task during gait. Despite the adaptations in gait pattern, fallers were not successful at maintaining a stable walking pattern during dual tasking.

Beauchet, Dubost, Allali, Gonthie and Hermann (2005) examined the effect of verbal fluency and arithmetic task on gait changes in 16 older adults classified as transitionally frail. They reported an increase in mean stride time when they walked and performed an arithmetic or a verbal fluency task compared with when they only walked ($p < 0.001$), whereas the coefficients of variation increased significantly only when they walked and performed the arithmetic task ($p=0.005$) but not the verbal fluency task ($p=0.134$). Those findings suggest that stride time variability under a dual-task condition depends on the type of walking-associated spoken verbal task.

## EFFECT OF DUAL TASK ON WALKING STABILITY AND GAIT PARAMETERS STUDIED DURING TREADMILL WALKING

Most of the studies related to dual task effect mentioned above were conducted on over ground walking at various speeds. Therefore, speed of walking was not consistent throughout the walking course and between participants. Because walking speed depends on distance (spatial factor) and time (temporal factor) and influence of walking speed on spatial-temporal parameters, the walking speed needs to be controlled to evaluate the effect of dual task on other spatial-temporal gait parameters. A treadmill would be the important instrument to control over gait speed.

Grabiner and Troy (2005) examined the effects of performing the Stroop task on step width variability during treadmill walking in young healthy participants. They observed a significant decrease in step width variability when performing the visual Stroop tasks (18.9±4.5mm) as compared to walking only (22.4±5.5mm). The number of incorrect responses during the Stroop task was also determined and compared with standing and walking conditions. During standing, the error rate was 2.4±3.5%, whereas during the treadmill walking, error rate was about double, i.e., 5.2±4.7% ($p=0.052$). Subsequently, Dingwell, Robb, Troy and Grabiner (2008) studied the effect of an attention-demanding Stroop task on dynamic stability during treadmill walking in healthy young participants. Participants were asked to perform a visual color Stroop task while walking on a treadmill, and trunk velocity was recorded. Variability of trunk motion in all three directions did decrease during the dual-task condition. This could be explained by the fact this would help participant to stabilize their gaze on the presented words (visual display) so they could perform accurately. These findings are consistent with the results of Grabiner (2005), who observed decreased step width variability during dual-task walking using the Stroop test.

## COMPLEX CORRELATION ANALYSIS BETWEEN COGNITION AND WALKING PERFORMANCE UNDER DUAL TASK CONDITION:

The association between performance of various standard cognitive tests and gait parameters has been examine under various dual task conditions. Such association indicates that walking is a complex task that requires higher brain control of cognition. Holtzer et al. (2006) examined the association between executive function and gait velocity among older individuals while walking over ground and reciting alternate alphabet characters.  Various cognitive tests for memory (digit span test, digit symbol test) and the Trail Making Test were used to evaluate executive function ability.  Two walking conditions were used: (a) self- paced walk as controlled condition and (b) dual task condition in which participants walked at self-pace while reciting alternate letters of the alphabet (e.g., a-c-e).  Average gait velocity and coefficient of variation (CV) were used to index walking performance.  They found weak association between scores of Trail Making Tests and gait velocity variability in both control (r=0.28) and dual-task walking conditions(r=0.26).This association was even weaker in the case of scores of memory (r=0.17) in control conditions and dual task conditions

Springer et al. (2006) also examined the association of executive function test and memory tests with swing time variability during dual task conditions.  The performances of three groups were compared: (a) older people with fall history, (b) older people with no fall history, and (c) young healthy adults.  First, all participants walked at their usual speed without a cognitive task.  Three different dual task conditions were employed: (a) first dual task condition, walking at a comfortable speed and answered multiple choice questions about a story read prior to walking; (b) second task condition, walking while counting a number of predefined words, and (c) arithmetic dual task, walking and performing serial subtraction by 7s, starting from 500. The executive function and memory tests such as Stroop test and word recognition tasks were performed alone while sitting on a chair.  Among fallers, they found a weak correlation (r=0.45) between performance of Stroop test and swing time variability during usual walking condition. This relationship was modest (r= 0.61) during the dual–task (walk and perform arithmetic task) and weakest during walking and performing multiple-choice question task condition. But such correlation between executive function and variability was not observed among young adults and non-fallers (p>0.45). Memory performance was not associated to any of these conditions among all groups of participants. The nature and strength of association between executive function and swing time variability during dual task among fallers suggest further that executive function an plays important role on pathway of fall. The impairment in executive function task would reduce the ability to allocate attention in two tasks (walking while performing arithmetic task) and may lead to more risk of fall. Therefore, the observation of relationship between dual tasking and executive function would be of clinical importance to identify the problem related walking and balance.

Most of the studies that evaluated effect of dual-task, mentioned above, used a single cognitive test to probe executive function, and outcomes were restricted to gait variables. Van- Iersel et al. (2008) extended this work by examining the association between two executive functions and performance of walking during dual-task conditions. They hypothesized that in community-living elderly people, the executive functions have stronger relationship with gait and balance than with memory. The Trail Making Test and Stroop Test were conducted on these participants to evaluate executive function ability. Then, the participants walked as follows: (a) control walk at self-paced speed, (b) while performing an arithmetic task (subtracting serial 7 from 100), and (c) while naming animals. Participants verbalized their responses and were graded, recording the number of correct responses. Two angular-velocity transducers were attached to the participant's back. The primary outcomes of this study were stride length and stride time variability and magnitude of medial-lateral trunk excursion. The TMT score and Stroop test score were associated with stride length variability and trunk motion. In addition, the study found stronger association during dual-task conditions, animal naming, (r=0.87). But such dual association was absent for the arithmetic task. They did not observe the association between gait and balance parameter during the single task condition. Therefore, this study further provided additional insight to the interaction of executive function with gait and balance control during walking in community elderly individuals.

## **STATEMENT OF PROBLEMS**:

Many studies have demonstrated that cognitive demand will affect walking performance. Interpretation of the dual-task design is based primarily on the limited resource or capacity theories of attention, which postulate that changes in performance when two tasks are carried out concurrently are due to the additive demands of the two tasks on the central nervous system, which exceed the limited resources available for information processing (Woollacoott et al., 2002; Pashler, 1994; Sui et al., 2008, 2009, Grabiner et al., 2005; Springer et al.,2006; Dubost et al.,2006, 2007; Kelly et al.,2008; Dingwell et al.,2008; ). The main limitations in dual task studies can be summarized as follows.

1) Typically in many previous studies, performance on either cognitive or gait performance was considered. For instance, very few studies (Grabiner et al., 2005; Springer et al., 2006) have quantified the performance of a cognitive task in some way, i.e., number of the correct responses for the Stroop test or numbers of wrong responses

for the arithmetic tasks were recorded by tape or manually. Manual recording could be varied from therapist to therapist, and there is a chance of missing the correct record; therefore, the outcome is limited, being neither scientific nor reliable. For example, in the study by Grabiner and Troy ( 2005), young adults made more errors in the Stroop test and decreased step width variability during dual-task conditions, whereas step width variability was not affected when young adults walked and performed a verbal fluency task, e.g., reciting the days of the week (Kelly et al., 2008). From these results, two things can be inferred: (a) participants were possibly more focused on the walking task than the Stroop task, which led to more errors, or (b) the verbal fluency task is cognitively less challenging compared to the visual Stroop test. Another explanation is that when doing a visual Stroop test, viewing a display of colors, participants need to decrease movement variability (especially of the head) so as to stabilize gaze. This explanation is consistent with the results of the Dingwell et al.(2008) study, where they found a decrease in trunk motion variability during the Stroop test.

Another limitation was that the majority of dual task studies used over ground walking at self-selected speed. Therefore, walking speed was not consistent throughout the walking course and could vary among subjects. It is known that spatio-temporal gait parameters are influenced by gait speed.

Another important limitation is that only certain types of cognitive tasks can be performed while walking over ground. In such conditions, only limited cognitive tasks, i.e., verbal fluency tasks and auditory Stroop tests would be of use. It would be difficult to use a visual computerized cognitive task, which has a real environmental feeling. The current study will employ the following methods to address these limitations:

1. Using an interactive virtual environment to present various events. This will permit performance of more standardized and graded cognitive tasks related to executive function. Recent studies have used computer-based proxies to probe and evaluate visual attention, processing speed, cognitive inhibition, and other executive function. Visual attention requires both foveal and peripheral search mechanisms and the ability to select relevant information and ignore (discriminate) irrelevant information. The reliable and validated computerized neuropsychological tests, i.e., Cambridge Neuropsychological Test Automated Battery (CANTAB), have been used in studies to evaluate the executive function, spatial planning, and visual attention. The performances of these tests have been quantified in terms of: (a) number of errors made during tests, (b) motor initiation time, and (c) execution time. The motor initiation was used to estimate "thinking" time. One such test, Useful Field of View (UFOV) is an objective computer-based test of visual attention and processing speed.

2. Introducing a treadmill: An important advantage of treadmill walking is control over gait speed, which is essential when comparing most gait parameters over time and between participants, as speed can significantly influence the gait parameters. Therefore, this study uses treadmill walking to avoid the confounding effect of walking speed on temporal gait parameters. It provides us enough steps required to analyze step variance. It is estimated that 200 steps are required to calculate step kinematic variability which is significant (Owings &

Grabiner, 2003). Another important issue when testing balance and mobility limitations is safety. A treadmill with handrails and the use of overhead body support systems are effective ways to prevent falls and injuries. Treadmills can also be used in conjunction with virtual reality/environment hardware/software, an emerging and effective rehabilitation tool (You, Jang, Kim, Hallet, & Ahn, 2005). A simple method to quantify balance and mobility while performing tasks in the virtual environment would be of great value.

3. The computer-based system can also log player's performance and provide measures of cognitive outcomes, in addition to measures of balance and spatial-temporal gait parameters.

## PURPOSE, OBJECTIVES AND HYPOTHESIS;

The aim of the study is to systematically evaluate the interacting effect of increasing cognitive demand and walking speed on performance of locomotion, balance, and cognition. The first objective is to evaluate the effect of walking speed on temporal gait parameters and stability, as indexed by amplitude and variation of trunk motion and magnitude of Centre of Pressure (COP) in single support stance. The second objective is to examine differences in gait, stability, and cognitive performance under single and dual task conditions during treadmill walking.

This study addresses three hypotheses: walking speed has a significant effect on temporal gait variables, stability, and cognitive task performance; as cognitive task complexity increases, gait, stability, and cognition significantly decline; and increasing cognitive load (complexity of tasks) and walking speed has a significant interacting effect on gait measures, stability, and cognitive performance.

## MATERIALS AND METHODS

### FSA Shoe Insole:

The Insole- Foot Sensor Applicator (Vista Medicals Ltd., Picture 1.) was inserted in the footwear of the participants. The insoles consisted of an array of 128 miniature pressure sensors of one-quarter-inch square. The sampling frequency of insole was 39 Hz. The system captured the geometry and the relative arrangement of each footfall as a function of time, space, and pressure. The application software processed the raw data into footfall patterns and computed the temporal (timing) parameters, i.e., stance time, double support, and swing time.

### Electromagnetic Sensor:

The Model 800 DC magnetic TrakStar (Ascension technology, Burlington, VT, US, Picture 2.) was attached to participant's upper trunk at the T2 level and recorded trunk movement. The instrument is reliable and allows precise measurement of the 3-D spatial position and orientation of trunk. The static accuracy of the instrument is positional about 1.4 mm root mean square(RMS) and orientation with 0.5 degrees RMS. The static resolution for the position is 0.5 mm at 30.5 cm, and for orientation, 0.1 degrees at the same range. The TrakStar is capable of recording 420 measurements per second, when the sensor is within + 30.5 cm of the transmitter. It gives output as the X, Y, and Z positional coordinates and orientation angles.

## Computerized Cognitive Task:

A modified version of this test was employed in the present study in order to evaluate visual attention and processing speed, and it was used in the dual-task protocol with combined walking tasks. For this purpose, a custom video game was produced. The goal of the test game was to move a paddle (game sprite to catch falling targets) vertically top to bottom or horizontally left to right. The target objects appeared every two seconds at random locations on the monitor from center to edge. The performance of tasks was quantified majorly in terms of: (a) success rate: success rate as percentage of target objects caught, (b) motor initiation, and (c) execution time. The complexity of our cognitive tasks had been categorized in three modes (Picutre3a, b, and c):

(a) Simple mode, involving a single target object to catch a brightly colored circle moving vertically from top of monitor to bottom.

(b) Moderate mode, involving a single target, and one 3-D circle object was designated as a distracter.

(c) Complex mode involved both 2-D and 3-D objects, i.e., 2-D circle was the target, and the 3-D circles and 3-D rectangle were designated as distracters. The speed and size of distracters were decreased by one level so that distracters would not interfere with participant's performance.

## In Air Computer Mouse:

The In-Air (Gyration Inc, USA) is a commercial computer mouse that uses a biaxial gyro to detect the mouse's angular motion (Picture 4), and thus permits its rotation to control the location of the computer cursor or game sprite/avatar. The mouse was attached to a lightweight Helmet and thus allowed head control of computer cursor motion.

**Treadmill:**

A treadmill (BioDex$^{TM,}$, USA) with handrails and the use of overhead body support systems was used in this experiment. A treadmill is important to control the gait speed of the participants. Two walking speeds were used: (a) low speed of 0.5 m/s and (b) moderate speed of 0.8 m/s (Picture 5)

## METHODOLOGY:

### Participants:

Twenty healthy participants aged 20 to 30 were recruited for this study via advertising for students and staff at the University of Manitoba and Health Science Centre. Participants were excluded if they had a history of neurological disorders, e.g., cerebral palsy, stroke, spinal injury or head injury, musculoskeletal disorder (e.g. lower limb joint surgery), low-back pain, muscular dystrophy, cognitive problems, and uncorrected visual impairment. Once selected for the study, participants were subjected to other screening tests to rule out any obvious neurological or musculoskeletal disorders (see Appendix 1 for visual screening test). Other shorter tests were carried out to detect any balance problem. Regarding the musculoskeletal disorders, history was given prime importance, and screening examinations were carried out for any obvious deformity, restriction of movement, or any muscle weakness. Participants were fully informed about the procedure and informed consent. Once the participant expressed willingness to take part in the study, the investigator obtained consent and recruited the participant. Ethical approval was obtained from the Research Ethics Board (University of Manitoba).

## TEST PROTOCOL:

Prior to the experimental procedure, all participants completed a brief history questionnaire and visual test (Appendix 1) to ensure inclusion criteria, then read and signed a consent form approved by the University of Manitoba Ethics and Review Board.

Each participant wore an air-mouse mounted in a helmet. The appropriate size insole was fixed in the participant's shoe. The tri-axial sensor (TrackStar) was fixed at

T2 level with surgical tape to record trunk movement in three directions. Initially, the participants were asked to walk on a treadmill at 0.8m/s for 10 minutes and perform a two-minute practice trial of computerized cognitive tasks to accommodate and to account for learning effect. A research design strategy was used in which a baseline or control condition was taken first, followed by conditions of simple mode cognitive task (independent variable A), moderate mode cognitive task( independent variable B), and complex mode cognitive task (independent variable C).

First, a baseline control condition of three modes of cognitive task without walking was administered. The examiner instructed the participant to stand in front of the computer screen.

Next, the participants were asked to walk at two treadmill speeds, low (0.5m/s) and high (0.8m/s) without cognitive task. Finally, as the dual task condition, participants were instructed to walk on the treadmill and perform the cognitive task. The six experimental dual task conditions were:

Condition 1: Low-speed walk performing simple mode computerized cognitive task.
Condition 2: High-speed walk performing simple mode computerized cognitive task.
Condition 3: Low-speed walk performing moderate mode computerized cognitive task
Condition 4: High-speed walk performing moderate mode computerized cognitive task
Condition 5: Low-speed walk performing complex mode computerized cognitive task.
Condition 6: High-speed walk performing complex mode computerized cognitive test.

The experimental conditions (dual tasks) were grouped into blocks of 4 trials, each trial was randomly ordered within each block. The order of complexity of cognitive tasks and walking speeds were randomized in order to minimize potential training or order effect.

## DATA RECORDING AND ANALYSIS:

### Temporal Gait Parameter Analysis:

The time of each foot's contact with and off the ground was used to compute stance time, swing time, and double limb support. The sampling frequency of insole was set at 39 Hz. The system captured the geometry and the relative arrangement of each footfall as a function of time and pressure. The raw data of each trial was batched and processed using custom analysis routines written in Matlab version 7.1 (The Math Works, Natick, MA) to compute temporal parameters. The pressure threshold was set at 0.15 psi, and a minimum of five sensors were needed to justify foot contact. The maximum and minimum threshold for stance time was 3 seconds and 0.2 seconds. The initial and final five seconds data were not included for analysis. Then, the output data was exported for offline analysis to compute the following parameters:

1. **Swing Time (SW)** is the time elapsed between the toes off to heel strike of the same foot.
2. **Stance time (ST**) is the time elapsed between first heel strikes to toe off of the same foot.
3. **Double Support Time( DS)** is the time elapsed between the first heel strike of the current footfall and the toe off of the previous footfall, added to the time elapsed between the toe off of the current footfall and heel strike of the next footfall.

The average and coefficient of variation of each parameter were calculated. The variability of each parameter across multiple strides was measured by coefficient of variation (CV), defined as a percentage of the standard deviation over the mean.

**Center of Pressure (COP) Analysis:**

The measurement of COP excursion area circumscribed by COP trajectory was used to measure walking stability. Recently, Kang et al, (2008) observed the location and trajectory (COP excursion) of COP analyzed dynamic stability of older individuals. The coordinates of COP were calculated by summing the product of the pressures recorded by each transducer with its (x and y) coordinates and dividing the result by the total pressure recorded by all transducers. The final result, a set of coordinates, may be represented as a single point on the insole.

$$\textbf{COP(X,Y)=}\left[\frac{\sum (pressure * x - coordinates)}{\sum pressure}, \frac{\sum (pressure * y - coordinates)}{\sum pressure}\right]$$

a. **Path length**: It represents the total distance covered by COP (total sway path) divided by the duration of the sampled period and constitutes a good index of the amount of activity required to maintain stability (Santos , Delisle, Larivière, & Plamondon, 2008). This is the most reliable outcome parameter that measures postural stability (Lafond, Corriveau, Hebert, & Prince, 2004).

b. **Peak-to-peak excursion of COP**: The maximum and minimum value of COP excursion in x-y plane.

c. **Root Mean Square (RMS)**: The RMS indicates the magnitude of COP amplitudes. The RMS–COP is a reliable parameter to evaluate the postural steadiness (Lafond et al. 2004).

**Trunk Motion Analysis:**

The analysis of trunk movement and foot placement have been looked at to understand walking stability (Baubly, 2000; Menz, Lord, & Fitzpatrik, 2003a, 2003b, 2003c; Moe-Nilssen & Helbostad, 2005). The kinematics of trunk reflects the kinematics of legs, as the trunk measures were used to determine spatio-temporal gait parameters such as stride time, step length, and gait velocity (Zijlstra, 2004; Moe-Nilssen, 2004). The sensors were attached to the skin over the second thoracic vertebrae using surgical tape. Our analysis focuses on these upper body movements because over half of the body's mass is located above the pelvis. Thus, maintaining dynamic stability of trunk is critical for maintaining stability of the whole body (Dingwell et al., 2008). The movement of trunk in three directions (anterio- posterior, medio-lateral and ventral), x, y, and z were recorded using Trackstar. From these recordings, the following outcome parameters were computed:

a. **Path length**
b. **Peak to peak excursion**
c. **Root Mean Square**

**Cognitive Performance Analysis**:

The test game is instrumented with an assessment module that generates a logged game file to record (100 Hz) the following signals associated with actions performed by a player with respect to game play events: (a) coordinates and timing of each game event (specific task goals) and (b) coordinates of the computer mouse (game sprite) slaved to physical motion of player, in this case, head rotation. The coordinate data of each trial was batched and processed using custom analysis routines written in Matlab version 7.1 (The Math Works, Natick, MA) and exported for offline analysis.

The raw motion co-ordinates of the computer game paddle sprite contained y-axis and x-axis. The game paddle is slaved to the horizontal rotation of the head. The y-axis represents the magnitude of paddle motion (game controller); zero represents left edge (or bottom) of the computer monitor, and maximum is right edge (or top). The x-axis is time, representing the duration of the game session.

Participants played the game for 120 seconds. This includes 60 game events, each 2 seconds in duration. The starting location of the target object was presented randomly relative to the paddle, and the distance varied from medium (one-third to two-thirds of the monitor distance) to large (two- full screen).

**Index of Cognitive Performance**:

(1) **The game score:** success rate as percentage of target object caught.

**(2) The average motor initiation time:** the time from the appearance of the target to start of the paddle movement: The response times are averaged to give a more accurate picture of the overall response time of the participants. This output variable is gathered by looking at the velocity curve for each user’s movement trajectories. The maximum point of the velocity curve was considered the beginning of the movement. The sample that coincides with the maximum velocity was considered the starting sample for the movement for a given event.

**3) The average movement execution time:** 90% of the time between movement initiation and final paddle position, this variable gives an idea of the participant's game play strategy and to see whether they make controlled slow movements or really rapid sweeping actions in the hopes of contacting the target. This measure how long it takes for the participants to reach 90% of the distance to the target from the starting.

## STATISTICAL ANALYSIS:

Descriptive statistical analysis was used to describe the performance of the participants for each condition. Factor A was cognitive load (three levels), and Factor B was walking speed (two levels). The two-way repeated measures ANOVA test was applied to observe the effects of Factor A (cognitive load), Factor B (Speed), and Factor A and Factor B interaction on (a) temporal gait performance measures, (b) stability measures, and (c) cognitive task performance measures. The significance level was set at alpha level of 0.5, and a post-hoc Bonferroni correction was applied, when there was significance. For each repeated measure's ANOVA, we presented the partial Eta square as a measure of effect size, with higher value representing the strong effect of independent variables.

## RESULTS:

The main objective of this study was to evaluate the interaction effect of increasing cognitive demand and walking speed on temporal gait parameters, stability, and cognitive task performance. Typical plots of movement trajectory (paddle slaved to head rotation) of a single subject during walking (two speeds) and performing cognitive tasks (three loads) are shown in Figure 3. The left panel of Figure 3 shows the comparison of the baseline performances of three cognitive tasks. The middle panel represents the cognitive task profiles while walking at low speed, whereas the right panel shows the cognitive performance while walking at high speed.

For the baseline condition, the movement trajectories were remarkably changed in all cognitive demanding tasks. The movement trajectory during simple cognitive task performance exhibits a regular pattern with onset period and plateau, indicating that participants took a short time to move the paddle from the appearance of the target (response time) and took a longer time to complete the task (execution time). The trajectories' patterns were irregular and dispersed with a plateau at their maximum and at their off period, indicating longer response time and shorter execution time for moderate and complex cognitive task. In both speeds, all movement trajectories exhibited irregular and dispersed pattern. The response time increased and the execution time decreases as walking speed increased. The pattern of trajectories represents the quality of head movement. The regular pattern shows the effective plan of head movement initiation and execution.

Typical plots of anterior-posterior (AP) and medial-lateral (ML) of center of pressure (COP) of a single subject is presented in Figure 4. COP traces are offset to a common baseline value of zero for display purpose. The signal represents the rhythmical cyclic anterior-posterior and medial-lateral distribution of COP for each stride taken on the treadmill. The left panel represents the AP and ML COP excursion pattern during baseline walking (without cognitive task), the middle panel shows the COP excursion pattern during low speed, and the right panel represents during high-speed treadmill walking. For baseline condition, there wasn't a visible difference in signal intensity and cyclic pattern in COP trajectories. However, during low speed, typical ML COP pattern was absent, which remains significant. For various cognitive demanding task conditions, the AP COP trajectories were evident. When cognitive demand increased, the AP COP signal was prominent. The intensity increased as the cognitive task demand increased, indicating participants were careful placing their step on treadmill. Such effect was not seen in ML COP.

Figure 5 represents the rhythmical cyclic forward-backward and left-right motion of the trunk for each stride taken on the treadmill. The signal intensity was consistently high in the linear AP and ML trunk movement. The AP peak-to-peak amplitude decreased with cognitive load. The high signal intensity and decrease in peak to peak amplitude indicates the less trunk sway.

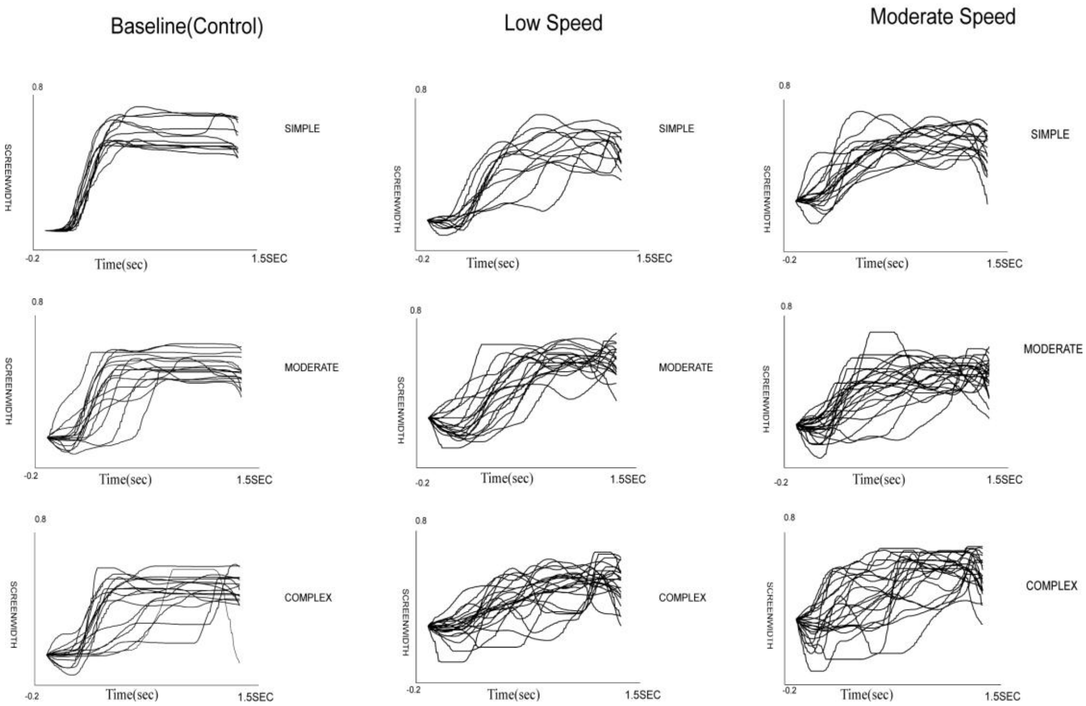

Figure 3: represents the raw data for a single subject. Left panel represents cognitive task performance movement at baseline condition (standing and performing three loads of cognitive tasks). Middle panel is the performance during dual task condition ( low speed walking and performing simple, moderate, complex cognitive tasks). Right panel is for moderate speed. The X-axis presents the time when target disappears (at 1sec). The Y-axis represents the screen width.

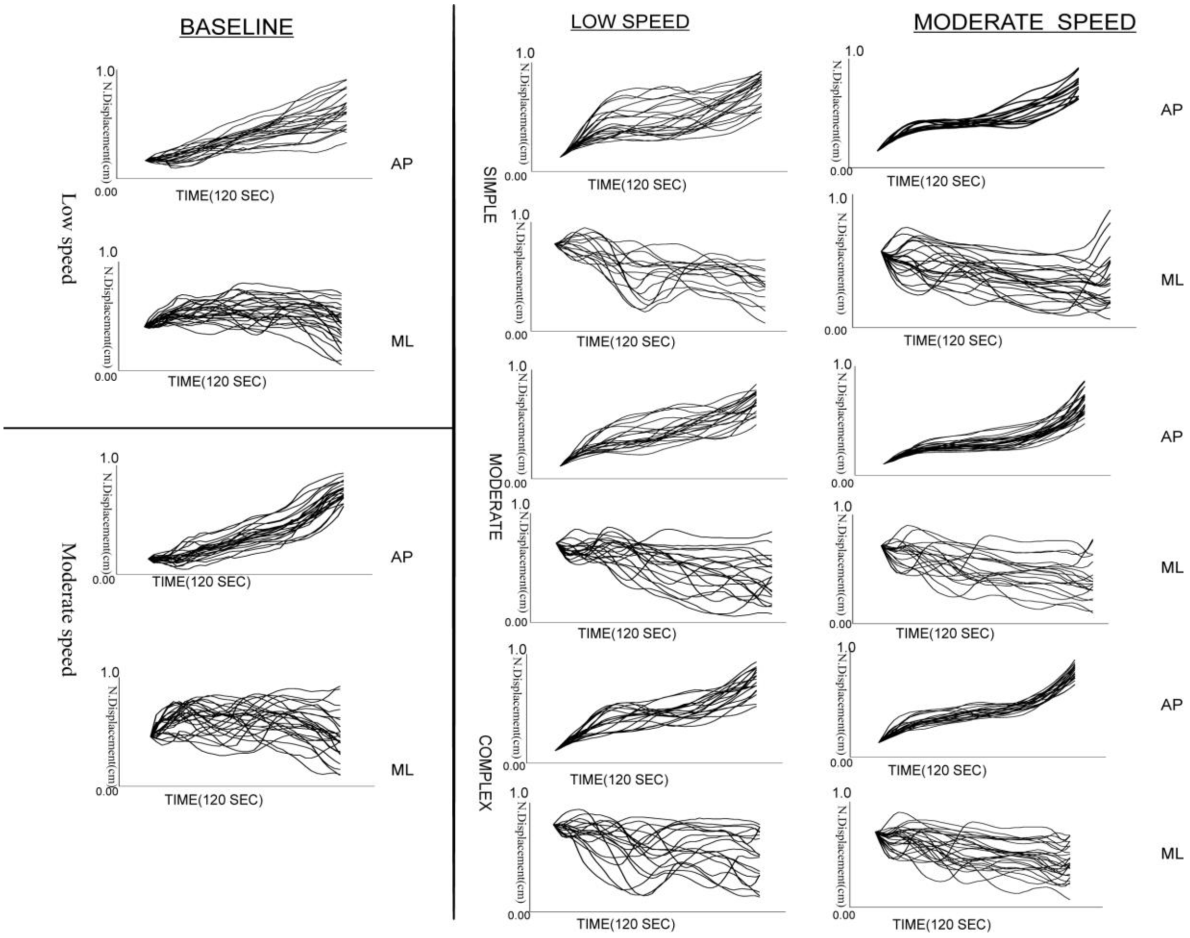

Figure 4: Graph represents the AP and ML Centre of Pressure trajectories for baseline conditions (walking in low and moderate speed) and various dual task conditions (performing three types of cognitive tasks in two walking speed).The x-axis represents time duration (120 second) and y-axis represents the COP displacement in anterior-posterior and medial-lateral direction.

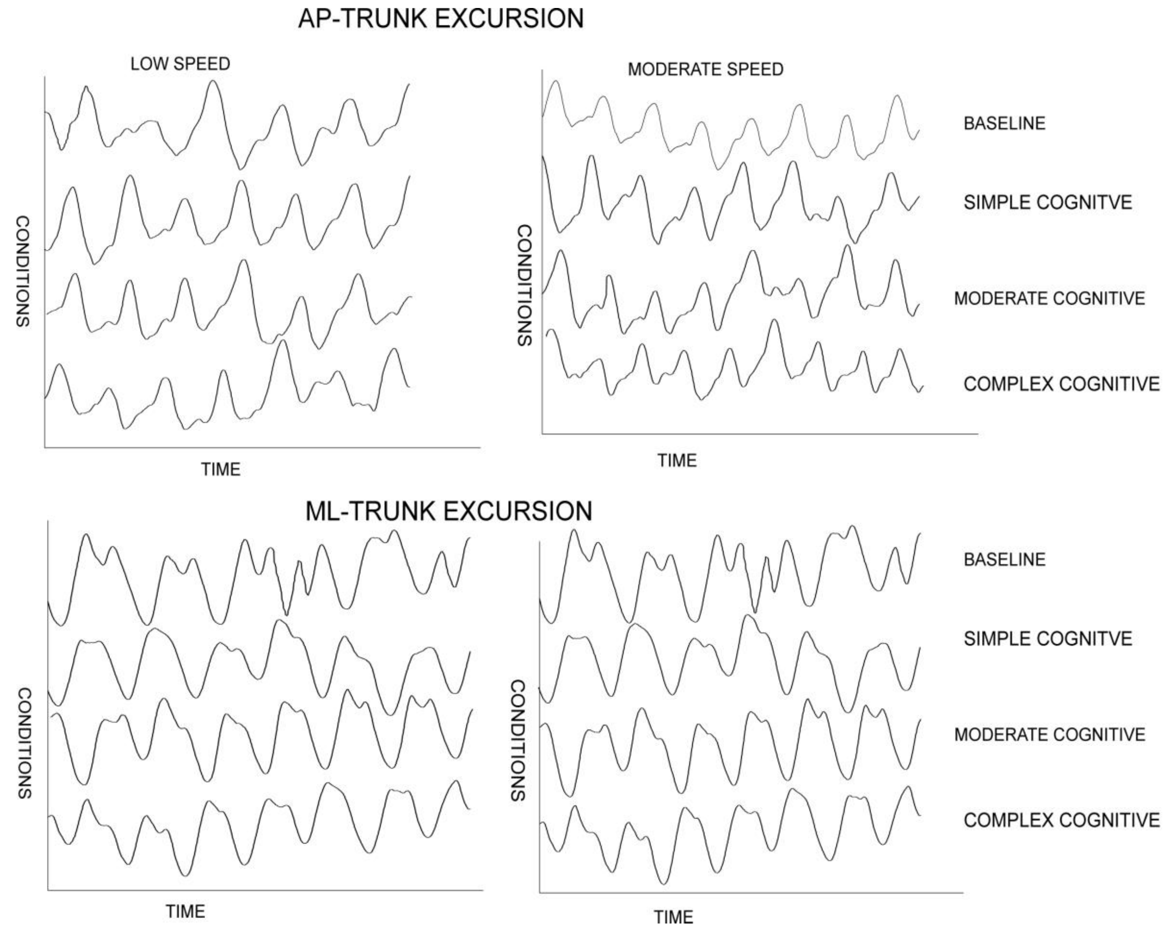

Figure 5: Graph represents the AP and ML trunk motion trajectories for baseline conditions (walking in low and moderate speed) and various dual task conditions (performing three types of cognitive tasks in two walking speeds). The x- axis represents time duration and y- axis represents the trunk motion excursion in anterio-posterior and medio-lateral direction**.**

## UNIVARIATE ANALYSIS:

The effect of two independent variables, i.e., walking speed (2 levels) and cognitive task demands (3 levels) on temporal gait parameters (double support, stance time, swing time), stability (trunk sway amplitude and COP excursion), and their interaction was studied using two–way repeated measures of analysis of variance (ANOVA – 2 x 2 designs).

## TEMPORAL GAIT VARIABLE:

Group means and SEM's for double support time (DS), stance time (SN), and swing time (SW) for baseline treadmill walking at two speeds (walking without cognitive tasks) and treadmill walking (two speeds) with cognitive tasks (three cognitive loads) are presented in figure 6. The summary of statistical result is presented in Table 1.

A statistically significant effect of speed was found on average and coefficient of variation of double limb support time (DLs) (p=<0.001, p=0.018). As presented in Figure 8, the average of double limb support time (DLs) and COV of DLs decreased as a function of walking speed.

No statistically significant effect of cognitive load was found on average DLs but COV of DLs was significant (p=0.008). As presented in Figure 8, the coefficient of variation (COV) of double limb support increased as function of cognitive task demand. There was no significant interaction of speed and cognitive demand on double support time.

A statistically significant effect of speed was found on average and COV of swing time (SW) ($p<0.001$, $p<0.001$). The average and COV of SW time decreased as the speed increased. The cognitive load did not affect average and COV of SW time. There was no significant interaction of speed and cognitive demand on swing time.

A statistically significant effect of speed was found on average and COV of stance (SN) time. As presented in Figure 8, the average and COV of SN time decreased as a function of speed ($P<0.001$, $P<0.001$). The COV of stance time was significantly affected by cognitive load. There was no significant interaction of speed and cognitive demand on stance time.

## COGNITIVE PERFORMANCE VARIABLES:

Group means and SEMs for success rate, execution time, and response time between baseline condition (cognitive task while standing) and dual task condition (walking at both speeds and three cognitive loads) are presented in figure 7. Both walking speed and cognitive demands had significant influence on success rate ($p<0.001$), response time ($p<0.001$), and execution time ($P<0.001$). Results of the statistical analysis are presented in Table 2.

As presented in Figure 7, there was a decrease in success rate as a function of speed and also as a function of cognitive load. The success rate was 40.6 catches/2min at baseline walking, 35.8catches/ 2min for low-speed walking, compared to 35 catches/ 2min at high-speed walking. The average success rate for simple mode cognitive task was 45.6 catches/ 2min, for moderate mode was 36.01 catches/ 2min, and 31.01catches/min for complex mode cognitive task. There was no significant interaction of speed and cognitive demand on success rate.

As presented in Figure 7, there was an increase in response time as a function of speed and as a function of cognitive demand. The response time was 1.06 s. for base line condition, 1.20s for low speed, and 1.27s for high speed. The response time was 1.08 s for simple mode cognitive task, 1.16 s for moderate mode cognitive task, and 1.29s for complex mode cognitive task. There was no significant interaction of speed and cognitive demand on response time.

As presented in Figure 7, the execution time increased as a function of speed but decreased as a function of cognitive load. The execution time was 1.0s for simple mode, 0. 78s for moderate mode cognitive task condition, and 0.4s for complex mode cognitive task. There was no significant interaction of speed and cognitive demand on execution time.

**TRUNK SWAY VARIABLES:**

Group means and SEMs for mean velocity, peak-to-peak amplitude, and root mean square (RMS) of trunk displacement in linear ML and AP including rotational ML and AP are shown in Figure 8. Statistical results are shown in Table 3.

No statistical significant effect of speed was found on linear and rotational AP and ML trunk motion. A statistically significant effect of cognition load was found on ML and AP mean trial velocity (path length excursion) ($p=0.01$, and $p= 0.04$). The cognitive load also affected AP peak-to-peak amplitude ($p=0.019$). The mean trial velocity and peak-to-peak amplitude decreased as the cognitive load increased during dual task performance. There was no significant interaction of speed and cognitive load on trunk movement.

## CENTER OF PRESSURE (COP) VARIABLES:

Group mean and SEMs for mean velocity, peak-to-peak and root mean square (RMS) of COP excursion in AP and ML direction are shown in fig 9. The statistical results are presented in Table 4. The result showed the significant effect of speed on mean trial velocity, peak-to-peak amplitude and RMS of COP. All parameters of COP in the ML direction increased as the function of walking speed ($p<0.001$, $p=0.010$, $p=0.016$). The cognitive load did not significantly affect COP parameters except for AP-RMS ($p<0.001$). There was no significant interaction of speed and cognitive load on COP parameters.

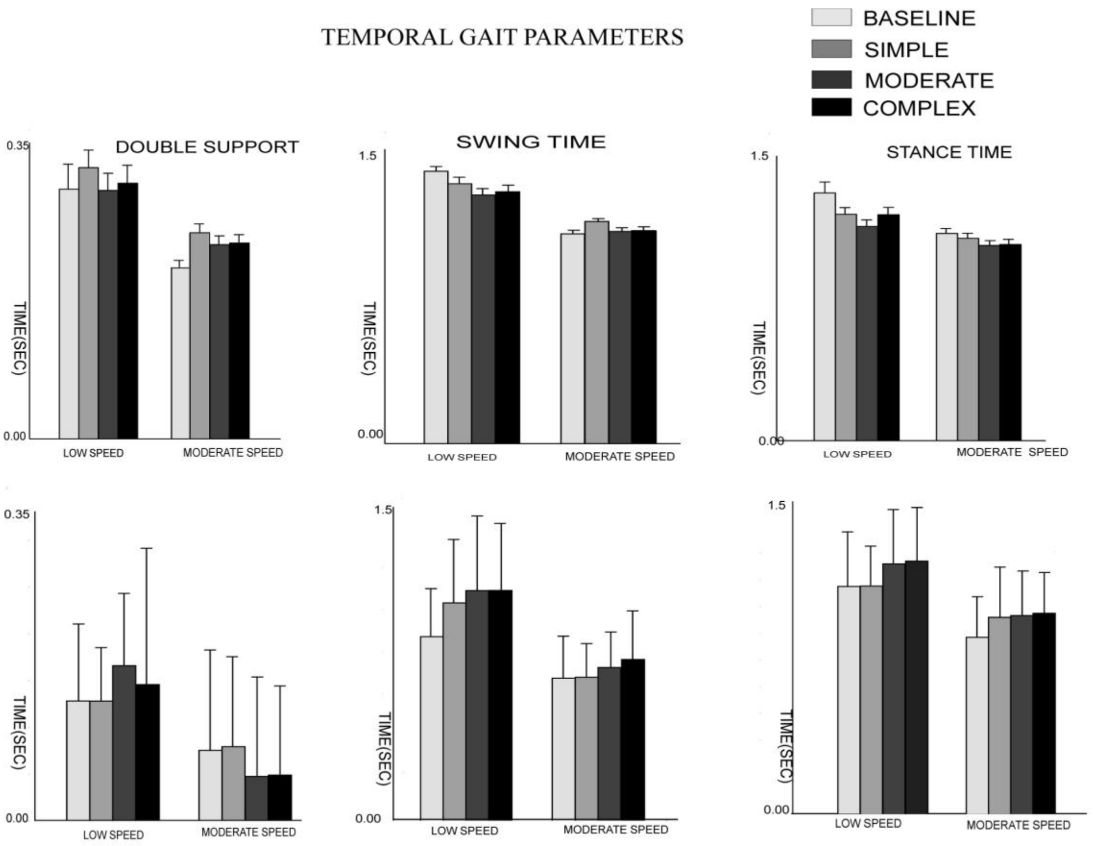

Figure 6: Top panel presents the group means and SEM of temporal gait parameters for low speed and moderate speed at baseline( only walking) conditions and various cognitive load conditions (simple, moderate, and complex). Bottom panel represents the group coefficient of variation and SEM for same conditions.

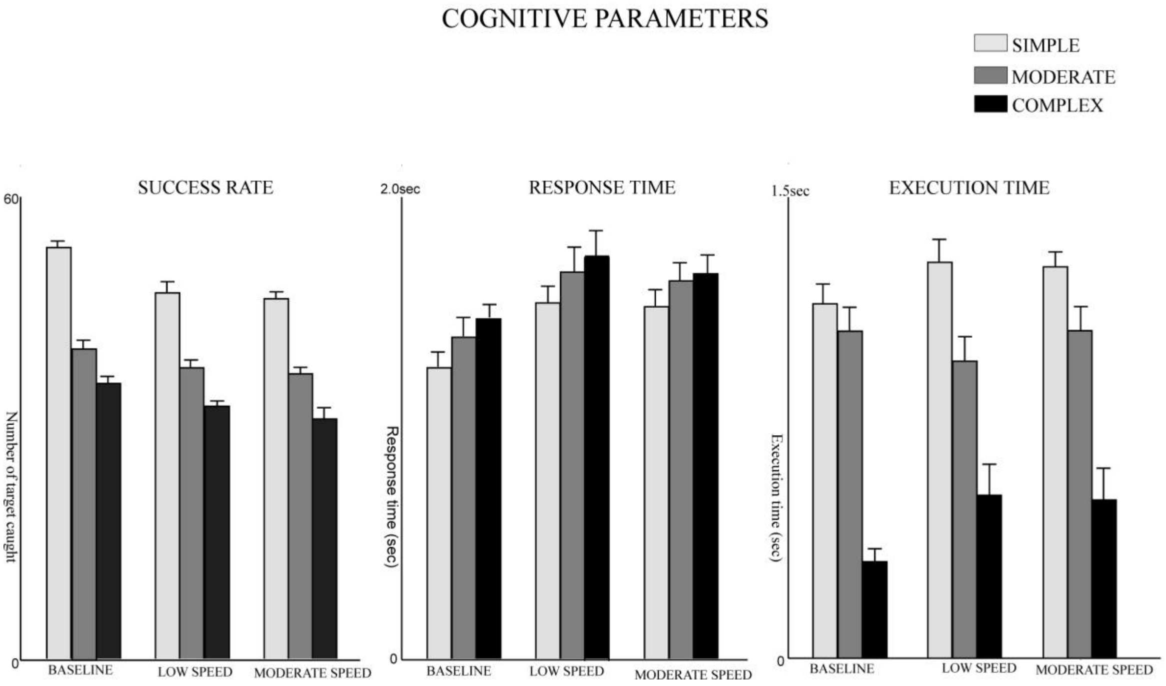

Figure 7: Group means and SEM of Success Rate, Response Time and Execution Time for cognitive tasks (three loads) are presented at baseline, low-speed, and moderate-speed condition.

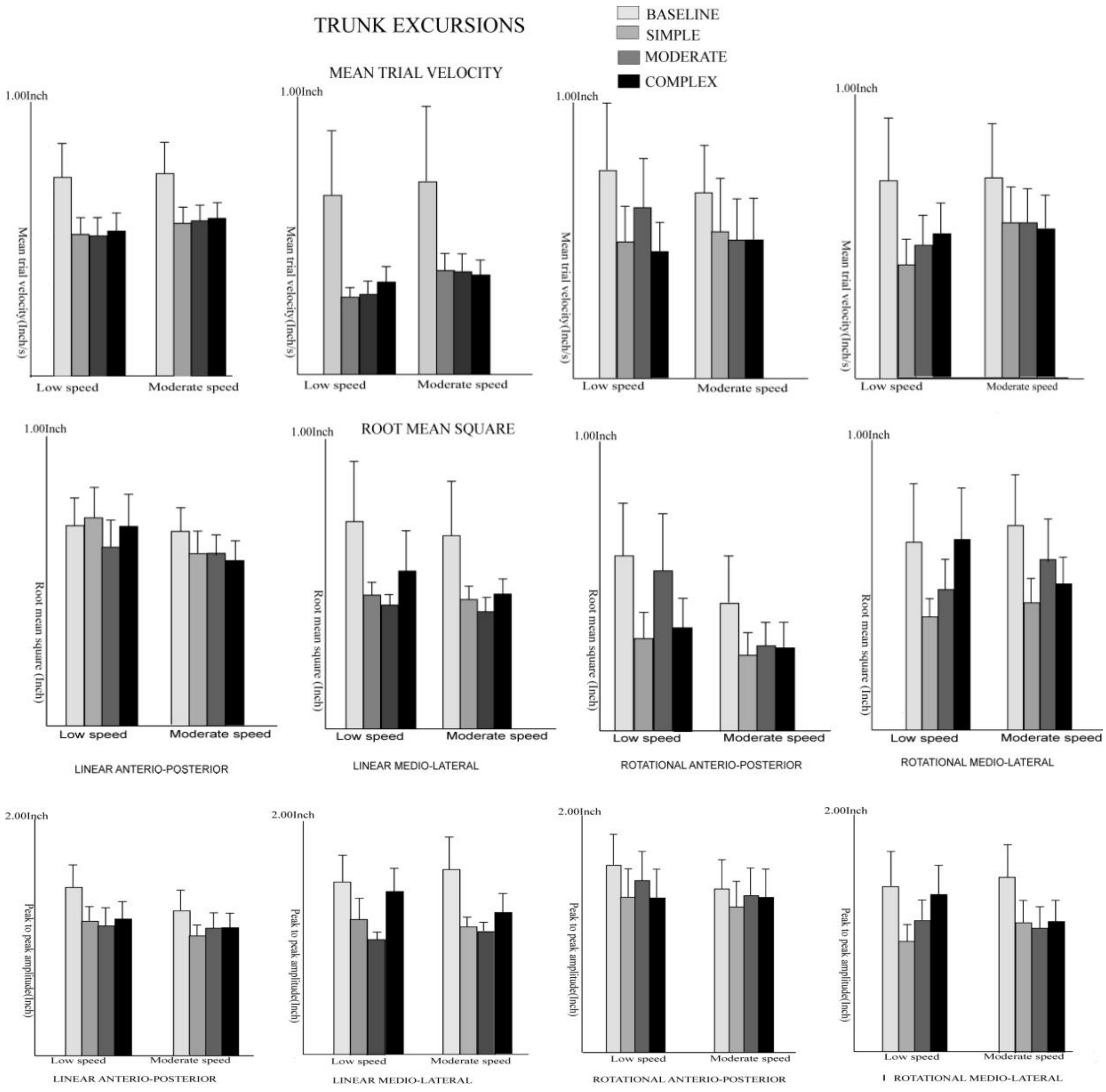

Figure 8: Presents the group mean and SEM of the Mean Trial Velocity, Root Mean Square and peak to peak amplitude of Linear and rotational anterio-posterior and medio-lateral trunk movement for the baseline and different conditions.

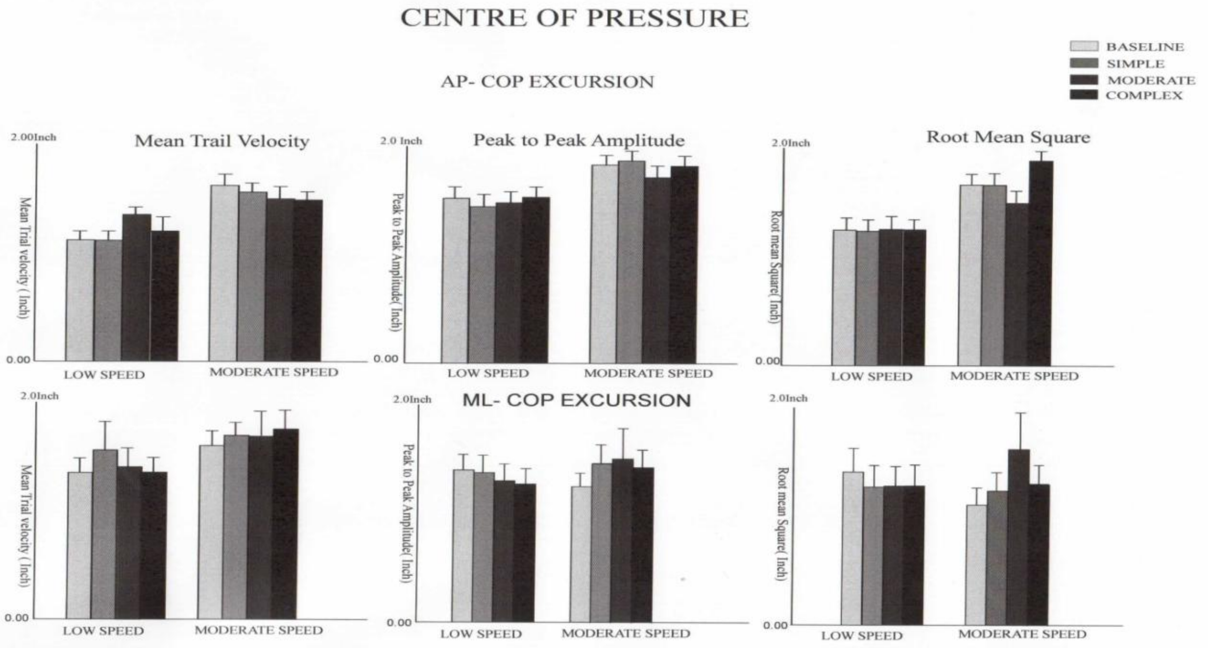

Fig9: graph represents the group mean and SEM of COP of Mean Trial velocity, Root Mean square and Peak to Peak amplitude for AP and ML-COP excursion for baseline walking ( low speed and high speed) and dual task conditions( walking with Simple, Moderate and Complex cognitive tasks at two speeds).

**Table 1. Effect of speed and cognitive load on average and coefficient of Variation of temporal gait parameters.**

| | SPEED LEVEL | | COGNITIVE LEVEL | | INTERACTION | |
|---|---|---|---|---|---|---|
| | **MEAN** | **COV** | **MEAN** | **COV** | **MEAN** | **COV** |
| **DOUBLE SUPPORT** | **SIGNIFICANT**<br>$P<0.001$<br>$F_{2,18}$=46.42(,18)<br>$n_P{}^2$ =0.336 | **SIGNIFICANT**<br>$P=0.018$<br>$F_{2,18}$=4.094<br>$n_P{}^2$ =0.081 | **N.S.** | **SIGNIFICANT**<br>$P=0.008$<br>$F_{3,17}$=5.11<br>$n_P{}^2$ =0.101 | **N.S.** | **N.S.** |
| **SWING TIME** | **SIGNIFICANT**<br>$P<0.001$<br>$F_{2,17}$= 19.567<br>$n_P{}^2$ =0.172 | **SIGNIFICANT**<br>$P<0.001$<br>$F_{2,18}$= 70.328<br>$n_P{}^2$ = 0.433 | **SIGNIFICANT**<br>$P<0.025$<br>$F_{3,17}$= 3.837<br>$n_P{}^2$ =0.075 | **N.S.** | **N.S.** | **N.S.** |
| **STANCE TIME** | **SIGNIFICANT**<br>$P<0.001$<br>$F_{2,18}$= 53.55<br>$n_P{}^2$ =0.36 | **SIGNIFICANT**<br>$P <0.001$<br>$F_{2,18}$=132.54<br>$n_P{}^2$ =0.590 | **N.S.** | **SIGNIFICANT**<br>$P <0.03$<br>$F_{2,18}$=3.54<br>$n_P{}^2$ =0.071 | **N.S.** | **N.S.** |

COV: coefficient of variation N.S.: not significant

Repeated Measures ANOVA to study the effect of walking speed and cognitive load on dependent variables of gait. The significance level was set at alpha (α) = 0.05.

**Table 2. Effect of speed and cognitive load on cognitive task performance.**

| | SPEED | COGNITIVE LEVEL | INTERACTION |
|---|---|---|---|
| **SUCCESS RATE(SCORE)** | **SIGNIFICANT**<br>P<0.001<br>$F_{2,18}$= 16.493<br>$n_P^2$ =0.38 | **SIGNIFICANT**<br>**P<0.001**<br>$F_{2,18}$= 524.54<br>$n_P^2$ =0.90 | **N.S.** |
| **RESPONSE TIME** | **SIGNIFICANT**<br>P=0.001<br>$F_{2,18}$= 7.93<br>$n_P^2$ =0.224 | **SIGNIFICANT**<br>**P=0.001**<br>$F_{2,18}$= 12.28<br>$n_P^2$ =0.18 | **N.S.** |
| **EXECUTION TIME** | **SIGNIFICANT**<br>**P=0.09**<br>$F_{2,18}$=2.50<br>$n_P^2$ =0.08 | **SIGNIFICANT**<br>**P<0.001**<br>$F_{2,18}$= 171.735<br>$n_P^2$ =0.75 | **N.S.** |

N.S.: not significant

Repeated Measures ANOVA to study the effect of walking speed and cognitive load on cognitive task performance. The significance level was set at alpha (α) = 0.05.

**Table 3. Effect of speed and cognitive load on trunk motion.**

| VARIABLES | SPEED | | | | COGNITIVE LEVEL | | | | INTERACTION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Co-ordinate** | **ML (x)** | **AP (Y)** | **Rot-ML** | **Rot-AP** | **ML(x)** | **AP(Y)** | **Rot-ML** | **Rot-AP** | **ML (x)** | **AP (Y)** | **Rot-ML** | **Rot AP** |
| **Mean trial velocity** | **N.S** | **N.S** | **N.S.** | **N.S.** | **Significant**<br>P=0.039<br>$F_{2,18}$=3.47<br>$n_P^2$ =0.118 | **Significant**<br>**P= 0.04**<br>$F_{2,18}$=3.433<br>$n_P^2$ =0.119 | **N.S.** | **N.S.** | **N.S** | **N.S** | **N.S.** | **N.S.** |
| **Root Mean Square** | **N.S** | | **N.S.** | **N.S.** | **N.S.** | **N.S.** | **N.S.** | **N.S.** | **N.S** | **N.S** | **N.S.** | **N.S.** |
| **Peak to Peak** | **N.S** | **N.S** | **N.S.** | **N.S.** | N.S. | **Significant**<br>**P= 0.019**<br>$F_{2,18}$=4.37<br>$n_P^2$ =0.146 | **N.S.** | **N.S.** | **N.S** | **N.S** | **N.S.** | **N.S.** |

AP: Anterior-posterior ML: Medial- Lateral, N.S.: not significant

Repeated Measures ANOVA to study the effect of walking speed and cognitive load on trunk displacement in linear anterior-posterior (AP), medial-lateral (ML), and rotational AP and ML. The significance level was set at alpha (α) = 0.05

## Table 4. Effect of speed and cognitive load on center of pressure excursion

| **VARIABLES** | SPEED | | COGNITIVE LEVEL | | INTERACTION | |
|---|---|---|---|---|---|---|
| **CO-ORDINATES** | **AP** | **ML** | **AP** | **ML** | **AP** | **ML** |
| **MEAN TRIAL VELOCITY** | **Significant,**<br>P= <0.001<br>$F_{2,38}$= 13.16<br>$n_P^2$ =0.113 | **Significant**<br>**P<0.001**<br>$F_{2,38}$=18.90<br>$n_P^2$ =0.189 | **N.S.** | **N.S.** | **N.S.** | **N.S.** |
| **RMS** | **N.S.** | **Significant**<br>P=0.010<br>$F_{2,38}$=7.020,<br>$n_P^2$ =0.078 | **Significant**<br>**P=0.019**<br>$F_{3,37}$ =4.13<br>$n_P^2$ =0.07 | **N.S.** | **N.S.** | **N.S.** |
| **PEAK TO PEAK** | **N.S.** | **Significant**<br>P=0.016<br>$F_{2,38}$=5.39<br>$n_P^2$ =0.06 | **N.S.** | **N.S.** | **N.S.** | **N.S.** |

AP: Anterior-posterior ML: Medial- Lateral, N.S.: not significant, RMS- Root Mean Square.

Repeated measures ANOVA to study the effect of speed and cognitive load on average Center of pressure (COP) variables. There was no interacting effect. The significance level was set at alpha (α) = 0.05

## **DISCUSSION**:

This study evaluates the effects and interactions of increasing physical demands (walking speed) and increasing cognitive load on (a) temporal gait parameters, (b) stability measures, and (c) cognitive performance measures. For this purpose, each participant was asked to perform a series of cognitive activities on a computer while walking in a treadmill. The cognitive demands of the game activities and walking speed were varied. Both physical task difficulty (walking speed) and cognitive load affected the gait performance, stability measures, and cognitive performance, and there was no evidence for an interaction between physical task load and cognitive load.

### Aim 1: Effect of walking speed on temporal gait parameters

Our study has examined the effect of gait speed on temporal gait parameters. For each outcome variable of interest, we have reported average and coefficient of variation of double limb support time, swing time, and stance time.

### 1.1. Effect of speed on average temporal gait parameters:

This study reported a decrease in average double limb support time, swing time, and stance time with increasing walking speed from 0.5m/s to 0.8m/s. A similar study by Betker et al. (2006) also observed a decrease in average double-support time, swing time, and stance time decreased as treadmill speed increased. Hence, speed is an important independent variable to be controlled and normalised before comparing average value of temporal gait parameters both within and between the subjects over time

### 1.2. Effect of speed on coefficient of variation of temporal gait parameters:

Our study also found a significant effect of speed on coefficient of variation of the temporal gait parameters. The coefficient of variation of double limb support time, swing time, and stance time all decreased with increased treadmill speed. This result is consistent with results of Jordan et al. (2007) who observed a decrease in stride time variability with increased over ground walking speed. Similar results have also been reported by Lili et al. (2005). In this study, spatio-temporal variability was significantly decreased with increased over-ground walking speed. Hence, speed is an important independent variable to be controlled in studies that are designed to examine effects of secondary cognitive tasks on temporal or spatial gait parameters, i.e., dual-task walking studies. Measures of variability are also important parameters that provide a perspective on the consistency of the locomotor rhythm and as a measure of stability (Dingwell et al., 2008; Kang et al., 2006). Many dual task studies have used video-based motion analysis methods or a GAITRite carpet. Both have short walkways of a few meters for steady-state gait. They obtain a few steps for each trial and require multiple trials to accumulate a reasonable size sample of the temporal gait parameters. This is another crucial issue and should be used to compute variance when enough samples obtained (30-40 consecutive steps in steady state). The treadmill walking used in the present study, during the 2-minute walk, we have recorded more than 45 consecutive steps which provide a real picture of walking performance.

## 2. Effect of walking speed on stability measures:

### 2.1. Effect of walking speed on trunk motion:

The trunk represents over 50% of the body's total mass and must be sufficiently stabilised to enable the body to smoothly progress forward during gait. The control of the position and motion of the trunk (head and arms) relative to moving base of support (i.e., transition from stance to swing) is a main contributor to overall stability during walking. However, there is limited information about how trunk control is influenced by walking speed. We hypothesised that an increase in walking speed would result in an increase in trunk motion. However, our result did not show any significant effect of speed on trunk motion. In contrast to this finding, Kavanagh. (2009) found a significant effect of gait speed on trunk motion. The study was conducted on healthy young adults, where participants walked at different speeds on a 30-meter walkway. Trunk motion increased with gait speed in medio-lateral and anterio-posterior directions. The difference in these findings might be explained by the difference in walking speeds or also may reflect a consequence of treadmill walking. In our study, the difference between slow speed (0.5m/s) and fast speed (0.8m/s) was relatively small, whereas, in the Kavanagh study it was much greater (0.93m/s and 1.79m/s)..

### 2.2. Effect of walking speed on Center of Pressure:

As with trunk control, there is limited information of the effects of walking speed on excursion and variation of the COP trajectory. Our findings show significant increase in COP path length, peak-to-peak excursion, and root mean square in medio-lateral direction with increasing speed. This indicates that when speed was increased our participants felt the threat of instability.

## 3. Effect of walking speed on cognitive performance measures:

### 3.1. Success rate:

The present results demonstrate a significant decrease in success rate in performing the cognitive tasks as walking speed increased.  This is not consistent with the findings of Dubost et al. (2006), who used a covariance analysis to examine the effect of walking speed on performance of a verbal response task in a population of older adults.  They did not find any significant effect of speed on performance of verbal response task.  Our visual tracking tasks (target-only and with distracters) are quite different from the verbal enumerating animal task.  The type and complexity of the cognitive tasks could  provide a substantial difference in the added attention load during walking and thus on cognitive performance.  A limitation of the study by Dubost et al. (2006) is that a short walkway of 12 meters was used.  Thus there would only be a few steps taken at steady state for each trial, and this limited time period could also influence how many animal names were verbalized.  In contrast to this design, our system is capable of recording 60 responses within 2 minutes of the task and thus provides a much greater number of continuous events to quantify success rate.  Other studies have also observed a significant effect of physical demands during standing on performance of visual discrimination task.  Cognitive performance decreased when standing balance was challenged by using a sway-referenced platform (Redfern, Jennings, Mendelson, & Nebesl, 2009) or when the support surface was moving, i.e., experiments performed on a ship at dock versus at rough sea (Yu, Yank, Villard, & Stoffregen, 2010).

### 3.2 Response time:

Many previous studies have used reaction time to index cognitive performance during walking for example, performing an auditory Stroop test (Kelly et al., 2010; Sui et al., 2008; Sparrow et al., 2002; Faulkner et al., 2006). These studies consistently demonstrated that participants had longer response times to initiate the cognitive task when physical demands were increased, such as (standing versus walking). Similar to these findings, participants in the present study took significantly longer times to initiate movements to specified targets during treadmill walking at a speed of 0.8 m/s compared to 0.5 m/s.

### 3.3 Movement Execution time:

There is limited research that examines effect of speed on this aspect of cognition. Our study demonstrated an inverse relationship between physical demands and movement execution time. As physical demands increased, more attention was directed towards the coordination of the walking tasks which could decrease resources to perform the cognitive tasks. And together with the fact that movement initiation (response time) took longer than needed to make a faster execution of task resulted shorter movement execution time.

From observation of the parsed movement trajectories, seen in Figure 3, there was a consistent increase in variance of players' actions as walking speed increased, indicating poor cognitive performance. This was also true when comparing plots of the control trials performed in standing to the walking trials.

## Aim 2: Effect of Dual -Tasks:

Independent of walking speed, the second aim of this study was to the evaluate effect of cognitive load on temporal gait measures, stability measures, and cognitive performance measures. The study found no effect of cognitive load on average temporal gait variables, but the coefficient of variation of the temporal gait parameters increased as the cognitive load added. In addition trunk motion decreased during walking while performing the cognitive tasks. Most of the COP parameters were not affected by cognitive load except for the RMS of the AP direction, which was decreased.

### 1. Effect of dual task on average temporal gait parameters

The most common and consistent finding of over ground dual-tasks studies comparing walking alone to walking plus performing secondary cognitive tasks has been the reduction of gait speed as the effect of cognitive task (Nadkarni et al., 2010; Beuchet et al., 2002; Springer et al., 2006). A recent systemic review and meta-analysis (Al-Yahya et al., 2010) on dual tasks on the over ground walking showed that the effect of different cognitive loads was prominent in gait speed. Consistent with these findings, a number of studies have observed a cautious gait strategy of reduced gait speed when negotiating obstacles or irregular terrains where threats to balance were not visible (Schrager, Kelly, Price, Ferrucci, & Shumway-Cook, 2008) so of importance is that gait speed decreases with increasing age. Studies have also reported an increase in average stride time, double limb support time during over ground dual task conditions (Nadkarni et al., 2010; Beucheaut et al., 2010). In the same studies, speed also decreased in the dual task condition compared to the walk only condition. Therefore, temporal gait variables should also change due to speed. As discussed above in Section 1, this would confound any effects of added cognitive load in temporal gait parameters. The confounding nature of gait speed can be controlled by using a motorised treadmill. However, the moving treadmill belt forces the participants to move their legs forward to maintain step rhythmicity. It should be noted that average stride time would not change while walking on a constant-speed treadmill belt. However, it is possible that average stance time, swing times, and, more importantly, double support times could change under conditions of added cognitive loads. Interestingly, we did not find any significant effect of cognitive load on average double support and average stance time. Average swing time decreased when cognitive load was increased. In contrast to our result, Sparrow et al. (2008) reported an increase in average step time for both older and young adults during treadmill walking and performing visual reaction time task. In visual reaction task time, immediately after the stimuli were presented, the participants pressed the button in their hand. The opposite finding could be due to the higher treadmill walking speed (ranging from 1.25m/s to 1.53m/s) in their study in comparison to our walking speed (ranging from 0.5m/s to 0.8m/s).

### 1.1. Effect on coefficient of variation of temporal gait parameters:

A number of studies have reported a significant increase in variability of stride time, swing time, and double support time when the participant was performing a secondary cognitive task (Al-Yahya et al., 2010; Plummer et al., 2010; Sparrow et al., 2008; Beauchet et al., 2005; Dubost et al., 2006, 2008; Allali et al., 2007; Nadkarni et al., 2010; Springer et al., 2006). These studies suggested that attention interference was the cause of increased variability of temporal gait variables. According to these studies, when two tasks were performed at the same time, a significant portion of attention was diverted towards cognitive tasks that likely jeopardized the walking rhythm. The variability in stride time observed in dual task has empirically been interpreted as a failure in the automatic stepping process controlled by brain regions (Nutt et al., 1993), due to shared attentional capacity between cortical gait control and cognitive task. There were two limitations of these studies: first, gait speed was not controlled in these studies. It has been shown that, during over ground walking, gait speed influences the level of stride time variability (Swearingen, 2001; Danion, 2003). As discussed in section 1, our temporal variability increased as treadmill walking speed increased.

Second, these studies used a relatively short walkway of less than 15 meters. Thus, only 3 to 5 steps of steady-state walking could be obtained for each trial (i.e., minus initiation and termination). To calculate variability of temporal gait, at least 20 consecutive steps are required (Lindeman et al., 2007); however, these over ground studies only recorded 3 to 5 steps to calculate the variability. In order to increase the sample of steps, multiple passes were necessary. In the present study, a treadmill was used with controlled speed and walking durations of 2 minutes, or in the order of 45 consecutive steps. We observed an increase in variability of stance time, swing time, and double limb support time during dual task walking, and this variability increased as a function of increased cognitive load. This indicates that, when demands on cognitive tasks were increased, our participants focus more attention on the computerised cognitive task performance than on walking performance.

## 2. Effect on stability measures:

### 2.1. Effect on trunk motion:

In the present study, we found a significant decrease in path length, peak-to-peak excursion of trunk motion in anterior-posterior and path length of medio-lateral trunk motion between walking only condition compared to walk plus cognitive tasks conditions. The trunk excursion was reduced in greater magnitude in the complex cognitive tasks, i.e., two distracters followed by one distracter, and without any distractor. A similar finding has been reported by Dingwell et al. (2008). Trunk motions decreased when participants performed a visual Stroop test during treadmill walking. During the dual task condition, participants were presented with four words, each a different color. A large projection screen placed directly in front of the treadmill was used for this purpose. Participants were asked to verbally identified the color of the word (i.e., ignore the meaning of the word). The authors suggested that the reduction in trunk motion during the dual-tasks condition was due to increased gaze stability required to see and identify the displayed words and colours, thus to minimize head motion. This would be achieved by reducing magnitude of trunk motion. A similar result was also observed in the study by Grabiner and Troy (2005); young adults were asked to perform a visual Stroop task (i.e., using a display monitor in front of the treadmill) while walking on a treadmill. They observed decreased step width variability in the dual-task condition as compared to the walking only condition. While engaged in cognitive tasks that require visual tracking of small targets or reading, gaze stability is an important factor for clarity of the visual image and also to minimize the feeling of dizziness. During the visual tracking, the display provides an external spatial frame of reference that could be used to limit changes in body (trunk) position in space during the treadmill walking. Together these findings demonstrate that continuous walking is possible at the same time that clients can comfortably view a computer display, a convenient method to engage clients in different types and levels of cognitive demands. In contrast to our studies, Van Iserel et al. (2008) and Kang et al. (2010) have reported an increase in trunk motion while performing verbal fluency tasks such as backwards counting, serial subtraction, and arithmetic problem. Velocity transducers were used for recording the trunk excursion during over ground walking. The increase in trunk motion in these studies might be due to the type of secondary task selected in those studies. It is very interesting to note that when a secondary task is verbal then trunk motion does increase for dual-tasks condition compared to walk alone. However, the trunk motion decreased for dual task condition when secondary task is non-verbal (visual). This likely speaks to the power of gaze stability requirements, i.e., if the head moves randomly while walking, then vision will be degraded significantly but like most of our other parameters, there is a decrease in performance when a second tasks is added.

### 2.2. Effect on COP measures:

An increase of COP peak to peak excursion, path length and RMS are considered to reflect a reduction in task stability (Pinsault & Vuillerme, 2009). The main find of the present study was that most COP parameters examined were not affected by presence of secondary cognitive tasks. The one notable exception was a significant decrease in RMS of AP COP displacement when walking was combined with a secondary cognitive task. These findings are consistent with the findings of Stins et al. (2010). The COP was measured in two force platforms placed in walkway. Similarly, Stins et al. (2010) also found reduction of RMS of AP COP displacement when young adults stood on a force plate and were asked to count backwards by seven. In contrast, Kanga et al. (2010) reported an increase in RMS of AP COP displacement in older participants when they performed a secondary serial subtraction task. Our study would suggest that, with increasing level of difficulty of cognitive task, the body prioritizes the attention to control of stability.

### 3. Effect on cognitive task performance:

The present study demonstrated that all cognitive performance parameters were profoundly affected during dual-tasks conditions (i.e., standing versus walking). Success rate in performance of cognitive tasks such as the visual Stroop test has been used in other dual task studies (Grabiner et al., 2006; Dingwell et al., 2008). Similar to the present study, they observed a significant decrease in the number of incorrect answers during treadmill walking compared to sitting condition. The reduction of success rate when a cognitive task was combined with a more demanding physical tasks such as walking could be due to a shift in focus of attention away from information-processing required to perform the cognitive tasks to processing of spatial information related to walking stability and control of the locomotor rhythm on a moving treadmill. This is consistent with the findings of Huffman, Horslen, Carpenter, and Adkin (2009) who observed a reduction in ability to track more than one moving target while walking. She suggested that dynamically updating a representation of objects changing locations in space and keeping track of one's own changing location in space could share the same spatial processing resources (Huffman et al., 2009). Recent studies using arm pointing movements to target choice selection tasks demonstrated that analysis of the timing and duration of trajectories reflects the temporal evolution of cognitive processing involved in motor planning (Song et al., 2009; Chapman et al., 2010). In a similar fashion, in the present study, the average movement response time and movement execution time of the parsed contextual player movement trajectories would also represent planning and execution aspects of cognitive performance (Figure 2). Song et al. (2008) examined the efficiency of movement correction when target selection is required among multiple distracters. A single target (color coded) was first presented without any distracters, then with 2 or more distracters. Participants were instructed to reach and touch targets of same or odd colours with their finger as quickly as possible. The target colors were randomly changed between red and green color. Highly curved trajectories were observed when participants initiated pointing movements toward a distracter before a correction is made to the target object, whereas the straight trajectories were observed for the single target task. They observed significant longer movement response times when distracters were present compared to single target conditions. Consistent with these results, the present findings also demonstrate a significant increase in movement response time for two distracter tasks than one distracter and without distracter tasks. However, in the present study, the opposite was observed for movement execution time; shorter for two distracter versus one distracter versus no distracter. As secondary task demand increased, more attention was directed towards the performance of cognitive tasks, which could decrease resources to coordinate the walking movement. And together with the fact that movement initiation (response time) took longer than needed to make a faster execution of task resulted in shorter movement execution time.

**Aim 3: Interaction between cognitive load and walking speed**:

The third aim of this study was to examine the interacting effect of increasing cognitive load and walking speed on temporal parameters, stability measures, and cognitive performance measures. The analysis did not reveal any significant interaction effect of speed and cognitive load. Therefore, this study rejects our third hypothesis that there would be significant interaction between increasing cognitive load and walking speed on temporal parameters, stability measures, and cognitive performance measures.

## CONCLUSION

This study revealed that both walking speed and cognitive load affect locomotors rhythm, stability, and cognitive performance. No significant interaction between walking speed and cognitive load was observed. Firstly, we found that both average and variability of temporal gait parameters decrease as a function of increasing gait speed. However, cognitive load resulted in an increase in double support time and stance time variability. This indicates that when cognitive task is demanding, the participants diverted their attention to perform the cognitive task and ignored the walking task. This resulted in increased temporal gait variability (more unstable). The anterior- posterior and medio-lateral center of pressure decreased when walking at high speed in compare to low speed. The cognitive load had no significant effect on COP in AP and ML direction with one exception, a reduction in RMS COP with added cognitive load. Interestingly, trunk motion decreased as a function of cognitive load, and this likely relates to the need to maintain stable gaze of the displayed visual information. This finding is also consistent with the decrease in COP excursion when a secondary cognitive task is added during walking. When cognitive demand increased, the AP COP signal was prominent indicating participant was careful in placing the foot on treadmill.

## CLINICAL SIGNIFICANCE:

Independent and safe mobility is a major concern among the elderly and individuals with neurological disorders. The everyday environment requires safe and efficient locomotion while attending to information in addition to the primary gait task, such as oncoming vehicles, pedestrians, and other potentially hazardous distractions. Gait is a complex task requiring many sensory and cognitive systems demands (Sheridan & Hausdroff, 2007) and must be tested under these conditions. The usage of dual task methodology to assess the interplay between gait and cognition among different populations had interested researchers over the last few decades. Extensive work had been done to understand the relative cognitive demand of gait control. However, the observed dual task-related gait changes were systematically related to variation in methodological, which conflicts with the conclusion drawn from previous studies. This study aimed at extending the current literature in dual task studies. A better understanding of dual task-related gait changes in different populations requires standardizing research methodologies. Most of the dual task studies have used serial subtraction and verbal fluency tasks during dual task studies, which lack ecological validity; furthermore, the concurrent tasks used were rarely performed with a functional environment. Studies have identified changes in certain gait parameters as independent predictors of fall risk. Such gait changes are often too discrete to be detected by clinical observation alone. The dual task paradigm, walking while simultaneously performing a second cognitive task, had been used to assess the effects of divided attention on motor performance and gait control. Objective quantification of such clinically relevant gait changes is necessary to determine fall risk. Early detection of gait disorders and fall risk permit early intervention and fall prevention. Therefore, better understanding of the interaction between gait and cognitive function would benefit both researchers and professionals to plan appropriate interventional trials, inform clinical decision-making and therapeutic value.

**STRENGTH:**

1. Typically in many previous studies, performance on only one of the two tasks was considered. For instance, very few studies (Grabiner et al, 2005; Springler et al., 2006) have quantified the performance of a cognitive task in some way, i.e., number of correct responses for the Stroop test or numbers of wrong responses for the arithmetic tasks were recorded by tape or manually.

2. There are advantages of providing gait evaluation over longer periods of time versus the limitation of a one-time visit to a motion laboratory or stop-and-start walking on a fixed length carpet. Treadmill walking offers a simple, unobtrusive method to obtain a larger sample number and permit quantification of average and stride-to-stride variation of spatio-temporal gait parameter; e.g., over 40 steps are required to calculate step kinematic variability which is significant (Owings & Grabiner, 2003).

3. An important advantage of treadmill walking versus over ground is control over gait speed, which is essential when comparing most gait parameters over time and between participants, as speed can significantly influence gait patterns. The majority of dual task studies used over ground walking at self-selected speed.

Therefore, walking speed was not consistent throughout the walking course and could vary among subjects.

4. Treadmills can also be used in conjunction with computer monitors to display other information. Another important limitation is that only certain types of cognitive tasks can be performed while walking over ground. In such conditions, only limited cognitive tasks, i.e., verbal fluency tasks and auditory Stroop tests would be of use. It would be difficult to use a visual computerized cognitive task while over ground walking; a tasks-specific intervention has been shown to be an effective therapy in rehabilitation training for many populations.

5. Treadmills can also be used in conjunction with virtual reality/environment hardware/software, an emerging and effective rehabilitation tool (You et al., 2005). A simple method to quantify balance and mobility while performing tasks in the virtual environment would be of great value. This will permit performance of more standardized and graded cognitive tasks related to executive function.

6. The computer-based system can also log a player's performance and provide measures of cognitive outcomes, in addition to measures of balance and spatio-temporal gait parameters

## LIMITATIONS AND FUTURE IMPLICATIONS:

1. Our study recorded gait parameter limited to only temporal gait parameters; the measurement of spatial gait parameters such as step length and step width would add robustness in analyzing the gait. Hence, future study should use instruments that could record spatial gait parameters as well.

2. It is impossible to generalize our results because we limited our study to healthy young adults. Future study should be conducted on a large sample of older and other pathological problem populations.
3. It would be interesting to observe the temporal asymmetry of step timing of right and left leg, as a study had reported a longer step time in left leg than in right leg (Sparrow et al., 2008).
4. Frequency analysis in future studies may enable us to view temporal gait instabilities and the effect of cognitive load during dual tasking.
5. The treadmill walking speed of 0.5m/s and 0.8 m/s were used in this study. Since many of us in a day-to-day life walk faster than these speeds, it would be beneficial to look at the effect of higher speed on gait, stability, and cognitive tasks.
6. The motorized treadmill imposed its self-speed because of a moving belt that would eventually normalize the locomotor rhythm. Therefore, further studies should be done on over ground walking to see how above findings change when walking speed is self-imposed by participants.
7. In this study, the entire walking trial or 2 minutes was analyzed, but it would be beneficial to see the effect of cognitive load on different phases of gait: (a) the initial double support phase: the time prior to taking the step, where both feet are planted and adjustments are being made for preparation of swing limb unloading, (b) the single support phase: the time from toe-off of the swing leg until the heel strike of the swing leg, and (c) the final double support phase, where both feet are again planted after having taken a step.

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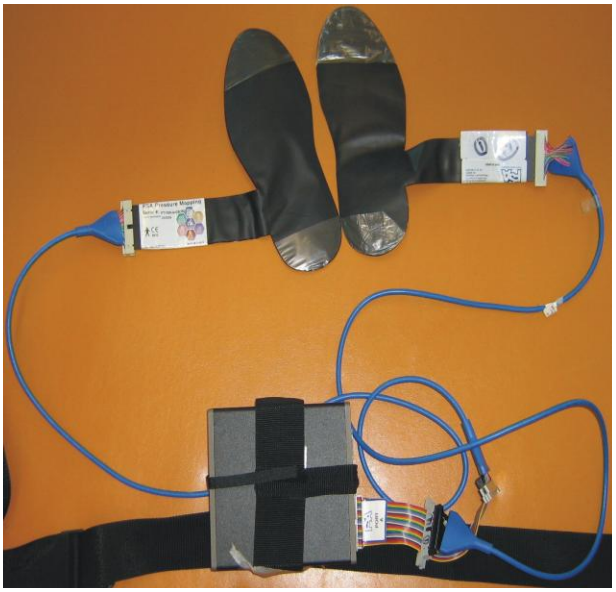
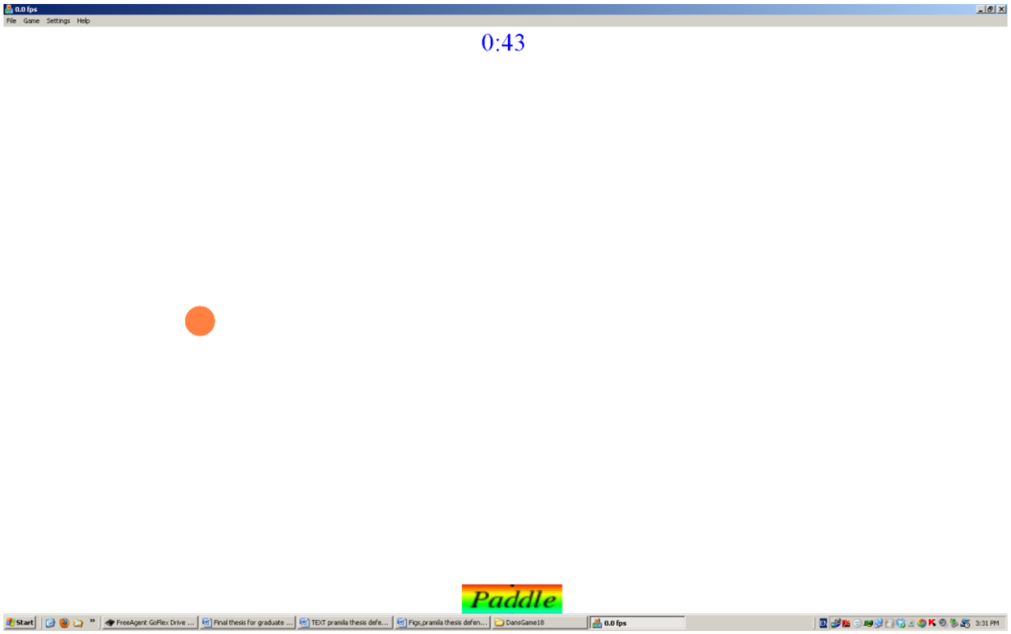
# APPENDICES

Picture 1.  Medium size Insole.

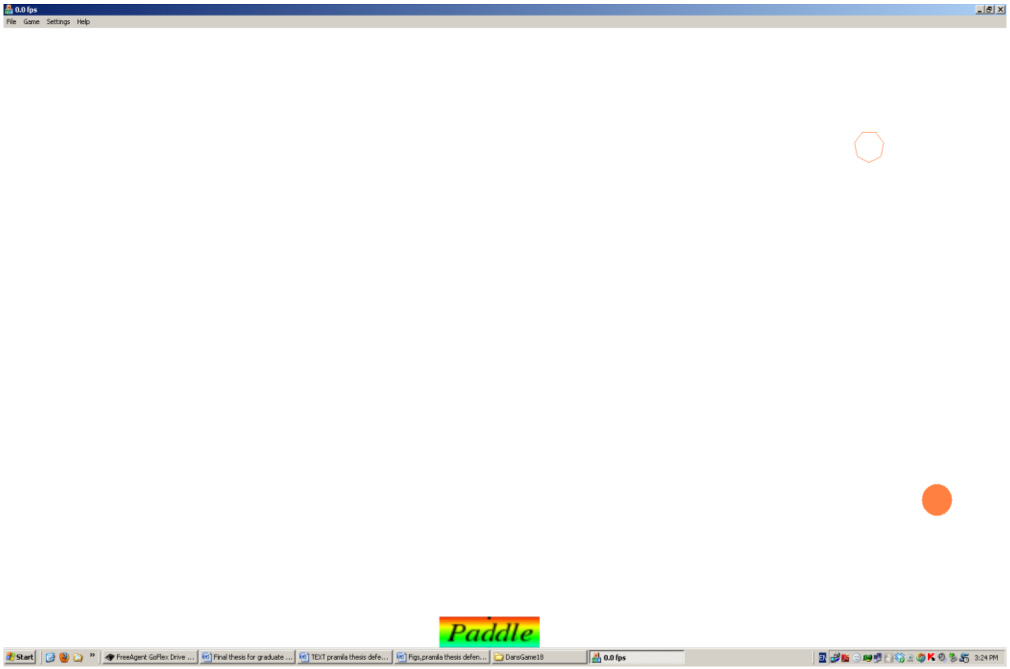


Picture 2.  Electro Magnetic sensor attached to T2 level

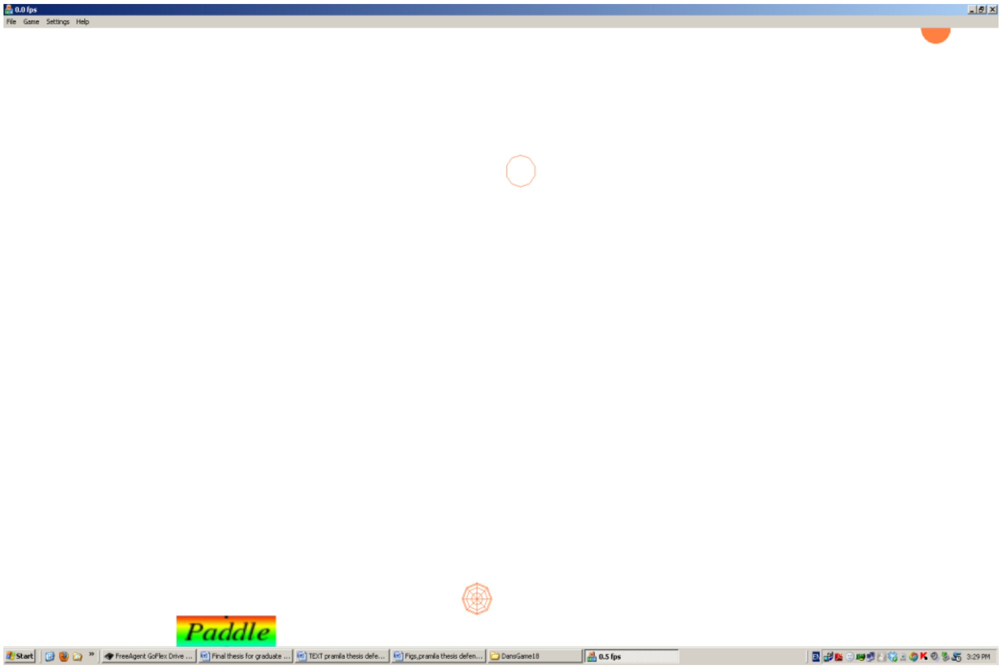
Picture 3.  Cognitive tasks



a.   Simple cognitive task



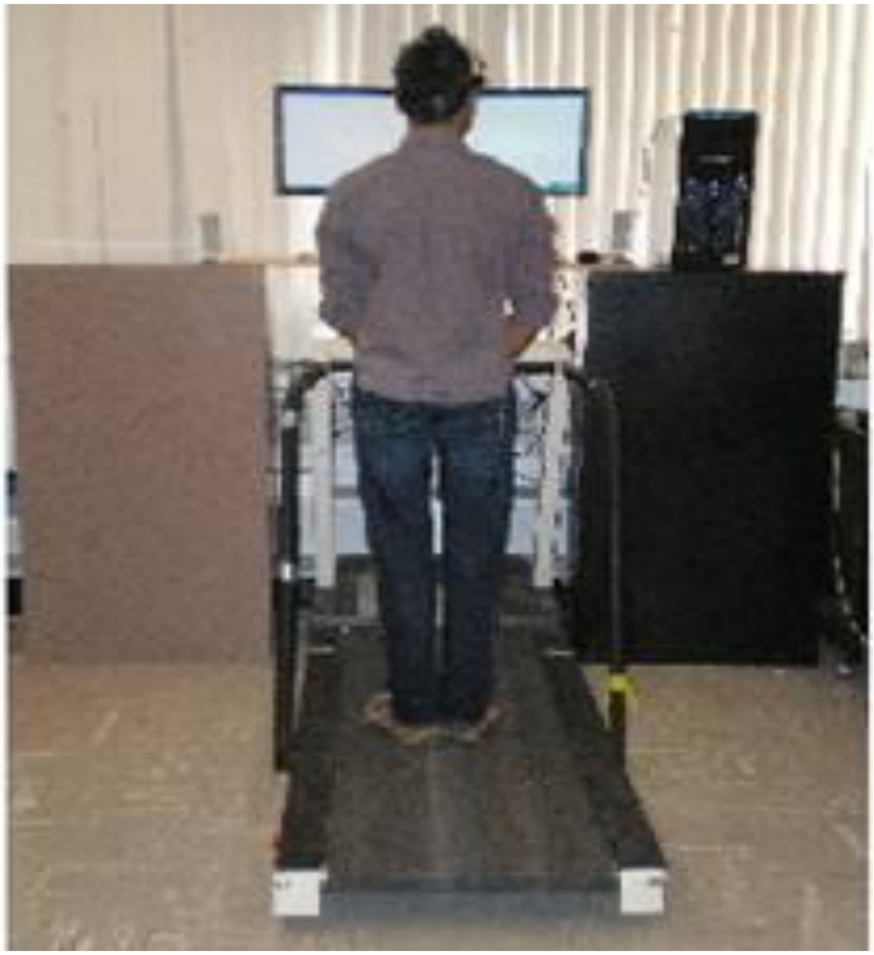
b.   Moderate cognitive task

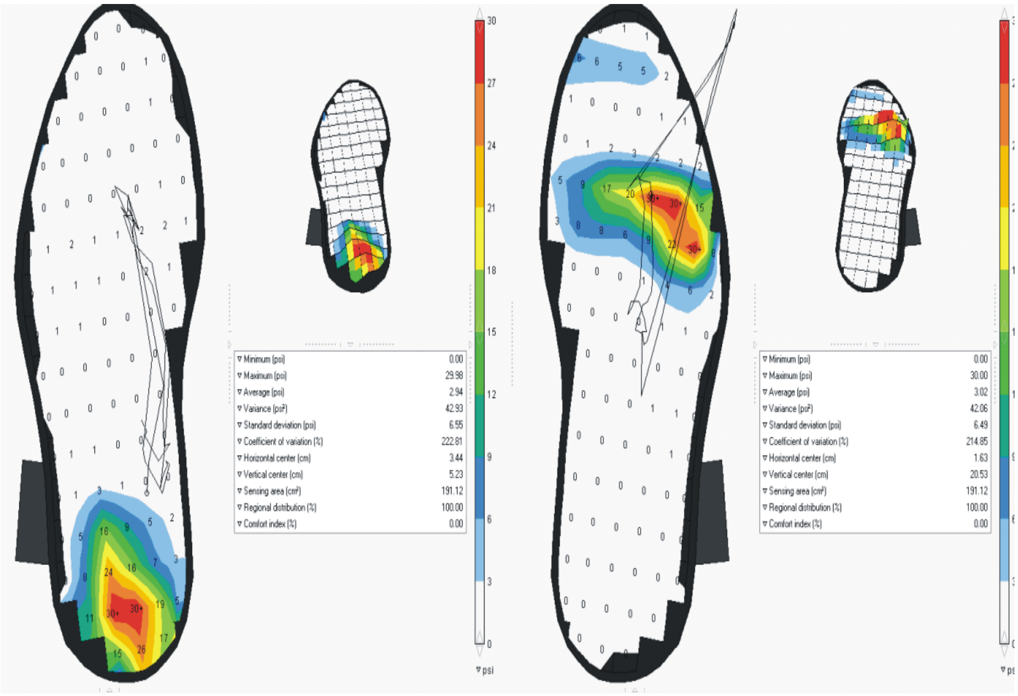


c. Complex Cognitive task

Picture 4. Gyration Air –mouse fitted in helmet.

Picture 5.  Experimental set up





| | |
|---|---|
| ▿ Minimum (psi) | 0.00 |
| ▿ Maximum (psi) | 29.98 |
| ▿ Average (psi) | 2.94 |
| ▿ Variance (psi²) | 42.93 |
| ▿ Standard deviation (psi) | 6.55 |
| ▿ Coefficient of variation (%) | 222.81 |
| ▿ Horizontal center (cm) | 3.44 |
| ▿ Vertical center (cm) | 5.23 |
| ▿ Sensing area (cm²) | 191.12 |
| ▿ Regional distribution (%) | 100.00 |
| ▿ Comfort index (%) | 0.00 |

| | |
|---|---|
| ▿ Minimum (psi) | 0.00 |
| ▿ Maximum (psi) | 30.00 |
| ▿ Average (psi) | 3.02 |
| ▿ Variance (psi²) | 42.06 |
| ▿ Standard deviation (psi) | 6.49 |
| ▿ Coefficient of variation (%) | 214.85 |
| ▿ Horizontal center (cm) | 1.63 |
| ▿ Vertical center (cm) | 20.53 |
| ▿ Sensing area (cm²) | 191.12 |
| ▿ Regional distribution (%) | 100.00 |
| ▿ Comfort index (%) | 0.00 |

Figure 1: Upper part of figure represents the FSA recording of right and left foot. The black line represents the Center of pressure trajectories. The lower part of figure represents the scattered diagram of right and left feet placement.

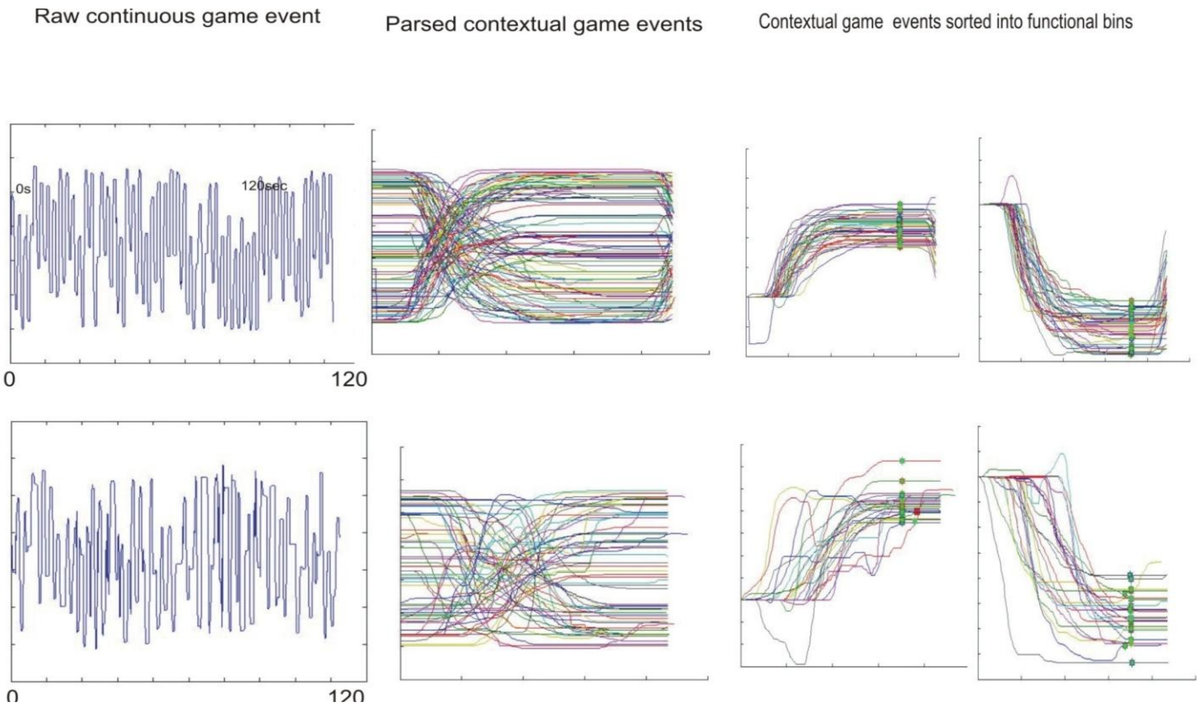


Figure 2: Represents the raw data for a single subject. Left panel represents cognitive task performance movement at baseline condition (standing and performing three loads of cognitive tasks). Middle panel is the performance during dual task condition (low-speed walking and performing simple, moderate, complex cognitive tasks). Right panel is for moderate speed. The X-axis presents the time when target disappears (at 1 sec). The Y-axis represents the screen width.

# Appendix 1

Winnipeg is the capital of Manitoba. It has long been one of the most multicultural communities in Canada. Mount Everest is situated in Nepal. It attracts most of well-experienced mountaineers as well as novice climbers

45 X AP % ABC 19 @ & BEQ#

Jumping, jugging, running, walking and skipping,

BALLON, CAKE, CANDLE, PLATE, GLASS.SUN, WINTER

# Appendix 2