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Examining The Role Of Attention In Steering Using A Dual Task Paradigm

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EXAMINING THE ROLE OF ATTENTION IN STEERING USING A DUAL TASK PARADIGM

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2014

DEDICATION

I dedicate this dissertation to my mother. You are the strongest woman I know! I cannot imagine getting through this hardest journey without your love and support.

EXAMINING THE ROLE OF ATTENTION IN STEERING USING A DUAL
TASK PARADIGM

by

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ABSTRACT

Changing the direction of locomotion, often referred to as “steering”, is an integral component of human locomotion. Steering requires maintaining dynamic balance while translating and rotating the body in the new travel direction. Given the level of sensation thought to be involved in sub serving goal directed modifications in steering, it is highly likely that steering control may require attention. Since attention resources decline with increasing age, we may see the influence of age on steering performance when attention resources are limited. Therefore, this study sought to investigate the role of attention in steering using a dual task paradigm in healthy young and healthy older adults. Twenty-five healthy young adults and nineteen healthy older adults completed the experimental protocol that involved baseline and dual task conditions. In the baseline condition, the participants walked and turned 90° at a comfortable pace. In the dual task condition, the participants walked and turned 90° while reciting serial 7 subtractions. We measured the time taken to turn, and the turn onsets of the eyes, head, trunk and pelvis in the baseline and dual task conditions. One-way ANOVA and Multivariate analyses ascertained the effects of age on the time taken to turn, and the turn onsets of the eyes, head, trunk and pelvis in the baseline and dual task conditions. The results of the study indicated a significant impact of age on steering performance under dual task conditions. In healthy young adults, the dual task condition increased the time taken to turn, but it did not affect the turn onsets of the eyes, head, trunk and pelvis. In older adults however, the dual task condition not only increased the time taken to turn, but it also altered the turn onsets of various body segments. These results provided evidence that steering performance varied with age, under dual task conditions. This is an important finding as turning in activities of daily living are rarely done in isolation of a secondary motor or cognitive task. Disruption of steering performance could place older adults at risk of disruptions to turning movements, resulting in a loss of balance and/or falling. Future research should focus on studying the level of variance in steering due to

dual tasking that might infer details about the nature of motor control during turning in older adults.

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CHAPTER 1: INTRODUCTION, SPECIFIC AIMS, AND STUDY RATIONALE

1.1 Introduction and back ground of the study

An important component of human locomotion is the ability to adapt to the environment. Redirecting walking direction is a commonly performed activity that allows an individual to go around obstacles, turn corners, and avoid collisions. In fact, turning to change direction makes up 35-45% of the steps taken during activities of daily living (Glaister, 2007). Whilst turning, also referred to as “steering”, is involved in a substantial number of walking activities, most research on gait involves only straight paths walking and not turning (Glaister, 2007). Therefore, there is a disconnection between the movements made during daily life and those studied in research.

Steering requires planning in the previous step that necessitates slowing the acceleration of the center of mass (COM) in the sagittal plane, controlling its motion in medial-lateral direction, and accelerating it in the new travel direction (Patla, Prentice, Robinson, & Neufeld, 1991). It requires maintaining dynamic stability while translating and rotating the body towards the new travel direction (Patla et al., 1991; Patla, Adkin, & Ballard, 1999). To maintain dynamic balance during steering, the Central Nervous System (CNS) either uses the top-down strategy or the bottom-up strategy. Both these strategies involve two functional principles that vary the level of stability achieved. The functional principles are the frame of reference on which balance control is based and the number of degrees of freedom to use for the various joints in the body. The top-down strategy uses the gravitational vector as the frame of reference and increases the degrees of freedom of various joints in the body. The top-down strategy involves descending temporal organization of body segment reorientation that is mainly based on visual and vestibular information obtained from early head reorientation. In this strategy a clear head followed by the trunk and feet is observed. Conversely the bottom up strategy uses the

supporting surface on which the person is standing as the frame of reference and decreases the degrees of freedom of various joints in the body. The bottom up strategy involves ascending organization of body segment reorientation based on proprioceptive and cutaneous information obtained from the lower body. In this strategy the body's segments tend to move together in an 'en bloc' fashion, where the trunk and head move together as a single unit. The bottom up strategy is considered to be less stable because it reduces the degrees of freedom of various joints of the body, making the body less flexible to adaptation (Assaiante & Amblard, 1995). Steering is an organized behavior that involves inhibition of movement in one direction and generation of movement in another without stopping and, planning. Therefore, execution of a complicated locomotor task like steering may require attention. However, there is no clear evidence that explains the role of attention in steering in humans.

Most of the previous literature on steering implies that it is an automatic process initiated by anticipatory eye movement (Berthoz & Viaud-Delmon, 1999; Courtine & Schieppati, 2003; Reed-Jones, Hollands, Reed-Jones, & Vallis, 2009; Reed-Jones, Reed-Jones, Hollands, & Vallis, 2009). Initial studies on steering that did not use eye tracking technology demonstrate the presence of a steering synergy that was initiated by head reorientation (Patla et al., 1999; Grasso, Prevost, Ivanenko, & Berthoz, 1998; Vallis, Patla, & Adkin, 2001). This concept of head initiation prior to other body segment reorientation has provided support for several hypotheses, that redirecting the visual system to the new travel direction provides information regarding the environment and travel path which is critical for steering control. Later research studies conducted based on this hypothesis and using eye tracking technology have further provided evidence that steering is a robust pre-programmed motor synergy that is triggered by eye movement (Reed-Jones et al., 2009a; Reed-Jones et al., 2009b; Ambati, Murray, Saucedo,

Powell & Reed-Jones, 2013). The results of these studies confirm that steering in locomotion is triggered by anticipatory eye movement followed by an articulated top-down body segment reorientation. That is eye reorientation followed by head and trunk reorientation in that sequence. In the studies where the eye movement was constrained, healthy young participants demonstrated an “en bloc” movement strategy, in which all the body segments reoriented together (Reed-Jones et al., 2009b; Ambati et al., 2013). En bloc turning involves minimizing the degrees of freedom of body joints making them rigid, thereby reducing the stability of the body (Assaiante & Amblard, 1995; Bernstein, 1967). En bloc turning is observed in older adults who are at risk of falling while steering (Paquette, Fuller, Adkin, & Vallis, 2008). The collective results of these studies suggest that steering is an automatic activity initiated by anticipatory eye reorientation. However it has also been demonstrated that steering is a goal oriented activity that requires planning (Patla et al., 1991). Steering involves decelerating the center of mass of the body in the sagittal plane and controlling it in the medial-lateral direction to maintain dynamic postural stability and the acceleration of the body towards the new direction of travel, in advance (Patla et al., 1991; Patla et al., 1999). Turns embedded in locomotion (steering) are of two types: the ‘step turn’, involves turning away from the stance limb (i.e. going to the left with the left limb while the right foot is on the ground); and the ‘spin turn’, involves moving toward the stance limb (i.e. going to the left with the right limb while the left foot is on the ground) (Hase & Stein, 1999). Step turns are more stable than spin turns and require lower biomechanical costs (Taylor, Dabnichki, & Strike, 2005). Planning proper foot placement (step turn) before turning in the previous step (Patla et al., 1991) increases dynamic stability and also reduces energy expenditure (Patla et al., 1991; Taylor et al., 2005). Apart from planning the steps necessary to execute steering, it is also important to ensure that these actions have taken a proper course and

manipulate those steps if necessary to successfully change the direction of locomotion. For example, in a steering study when the participant's head was fixated to the trunk using a spinal board, the trunk moved earlier to facilitate head reorientation prior to execution of the turn (Hollands, Sorensen, & Patla, 2001). Thus the central nervous system (CNS) is capable of modifying the sequence of body segment reorientation based on the movement situation involved.

Goal setting, planning the actions needed to accomplish a task such as steering and ensuring that the actions have taken a proper course, requires mental flexibility and utilization of feedback. These elements are controlled by the psychological construct Executive Function (EF) which is composed of inter-related higher cognitive skills (Lezak, 1995; Anderson, Jacobs, & Anderson, 2008; Hunter & Sparrow, 2012). Several neuropsychological models were developed to conceptualize Executive Function as an overall control system composed of these inter-related cognitive skills (Stuss, Shallice, Alexander, & Picton, 1995; Anderson, 2002). For example, the Executive Control System is a conceptual framework that describes executive function as an overall control system composed of four domains: attention control, mental flexibility, goal setting, and information processing (Anderson, 2002). Given the level of planning, monitoring and manipulation of actions thought to be involved in sub-serving goal directed modifications to the steering synergy, it is highly likely that steering control requires a significant amount of attention control. Attention control processes may be considered as important subordinate skills of Executive Function (EF) or may be considered as the executive system in itself (Anderson, Jacobs, & Anderson, 2008), because attention control is involved in the regulation and monitoring of the rest of the cognitive domains forming Executive Function like mental flexibility, goal setting and information processing (Anderson, 2002).

Although we may explain the role of attention in steering using theoretical models of executive function, there is no existing research examining the role of attention in steering control, creating a major gap in the literature. Hence, there is a need for evidence covering the importance of attention in steering. Attention deficits are commonly observed in older adults, and this group has been reported to be at risk of falling while steering (Milham, Erickson, Banich, Kramer, Webb, & Wszalek, 2002; Cumming, & Klineberg, 1994; Paquette, Fuller, Adkin, & Vallis, 2008). Determining if steering requires attention in healthy young adults is a critical first step as this evidence can be used to support the claim that attention deficits in older adults may be one of the underlying reasons for increased risk of “Falls” during turning maneuvers. Impaired executive function in older adults (Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2010) may be responsible for poor planning and execution of steering. Age-related impairment in executive function is explained by structural changes in the frontal lobes of the brain that are linked to the control of executive function (Daigneault, Braun, & Whitaker, 1992; Mittenberg, Seidenberg, O’leary, & DiGiulio, 1989; West, 1996). The effects of aging on various domains (attention control, cognitive flexibility, working memory, information processing) of executive function may be different (Anderson et al., 2008). There is evidence reported in a functional magnetic resonance imaging study showing age-related decrease in attention control measures (Milham et al., 2002). Therefore, it is likely that the age related differences in steering performance (Paquette et al., 2008) are due to the impairment in attention skills that happen with increasing age in humans. Hence one would expect that steering performance will be much worse in older adults than younger adults; however steering performance would be even more difficult when it is performed with a secondary task that requires attention.

Examining the role of attention in steering can be done using a dual task paradigm. A dual task paradigm is a popular experimental method used by researchers to test the level of attention needed for gait control (Ebersbach, Dimitrijevic, & Poewe, 1995; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Verghese, Kuslansky, & Holtzer, 2007). It is executed by challenging attention capacities by performing a secondary cognitive task while simultaneously performing the primary motor task, in this case gait. When two stimuli require the processing unit at the same time, a “bottleneck” arises, resulting in a delay of one of the responses (Pashler, 1994). The hypothesis regarding dual task in gait is if gait is an automatic activity that does not require deliberate attention, then dual tasking will not affect gait parameters. Alternatively, when gait parameters are observed to be affected under dual task conditions, then it can be concluded that some level of cognitive attention is required by the gait task itself. Therefore, we may examine the role of attention in steering using this same dual task paradigm. It would be expected that if steering requires some level of attention, then introducing a secondary cognitive task should result in some disruption to the steering task.

The level of complexity of the secondary task has tremendous influence on dual task performance. The cognitive tasks used in gait studies can be categorized into five types based on the cognitive level involved (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2010). Mental tracking tasks show stronger effects on gait speed with increasing age and decreasing cognitive scores in healthy participants (Al- Yahya et al., 2010). These tasks also increased stride time variability in healthy participants more than other secondary cognitive tasks (Al- Yahya et al., 2010). The serial 7 subtractions task is classified as a mental tracking task that requires sustaining the information in the mind and manipulating this information (Lezak, 1995). It involves counting backwards by 7. Mental tracking tasks like serial 7 subtractions share the

higher order neural networks with gait, resulting in greater interference disturbing gait when compared to other tasks (Fuster, 2008; Gazzaley & D'Esposito, 2006). Although verbal fluency tasks are similar to mental tracking tasks in their level of complexity (Fuster, 2008; Gazzaley & D'Esposito, 2006), serial 7 subtraction tasks were used more often than other secondary tasks in the articles reviewed. In the articles reviewed, serial 7 subtractions increased dual task costs in several gait studies (Al-Yahya, Dawes, Collet, Howells, Izadi, Wade, & Cockburn, 2009; Chong, Chastan, Welter, & Do, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007; Yogev, Giladi, Peretz, Springer, Simon, & Hausdroff, 2005; Yogev, Plotnik, Peretz, Giladi, & Hausdroff, 2007; Springer, Giladi, Peretz, Yogev, Simon, & Hausdroff, 2006; Hausdroff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008). Therefore, the serial 7 subtractions task has been shown to be an effective secondary cognitive task when studying the role of attention in gait. As such, the serial 7 subtractions task was an appropriate secondary task to examine the use of attention resources while walking and turning in this study.

1.2 Statement of purpose

The purpose of this dissertation was to determine whether steering requires attention or whether it is an automatic motor synergy requiring minimal cognitive influence. This project also sought to determine the effect of age on the attentional demands required by steering. The role of attention in steering was tested by having the participants perform serial 7 subtractions while walking and making a 90° turn. The participants were tested in the baseline condition and dual task conditions to show the differences in steering performance due to the introduction of the secondary cognitive task (serial 7 subtractions) to steering.

1.3 Specific aims and hypotheses

The specific aims of the study were:

Aim 1: Determine if aging influences steering.

Hypothesis 1: We hypothesized that turning time and turn onsets of the eyes, head, trunk and pelvis would differ significantly due to age in both the baseline and dual task conditions.

Aim 2: To investigate whether the introduction of a secondary cognitive task changes steering control in healthy young adults and healthy older adults.

Hypothesis 2A: We hypothesized that if steering requires significant attentional resources, that healthy young adults would show a significant delay in the turn onsets of the eyes, head, trunk and pelvis but without any change in the sequence of body segment reorientation in the dual task condition. In addition, it was expected that an increase in turning time would occur in the dual task condition.

Hypothesis 2B: We expected healthy older adults to not only show a delay in the turn onsets of the eyes, head, trunk and pelvis, but that they might also display interruption to the sequence of body segment reorientation. Interruption to the sequence of body segment reorientation through the use of en bloc turning might occur in older adults because of potential switches to turning strategies due to a need to simplify motor control under a dual task condition. In addition, it was expected that older adults would have an increase in turning time due to the dual task condition.

CHAPTER 2: LITERATURE REVIEW

The following is a review and discussion of the control of steering and movements of body segments. In addition, the potential role of attention in steering is explored using different theoretical models, and the current literature in gait studies that used dual task paradigm is explored.

A growing body of literature has sought to investigate the control of and impairments in turning which may underlie falls incidences in various populations. Human research over the last 20 years has presented evidence that the control of steering by the central nervous system (CNS) operates via a robust pre-programmed motor synergy triggered by eye and head re-orientation (Patla et al. 1999; Hollands, Patla, & Vickers, 2002; Hollands, Ziafra, & Bronstein, 2004; Reed-Jones & Vallis 2007; Reed-Jones, Hollands, Reed-Jones, & Vallis, 2009a; Reed-Jones, Reed-Jones, Hollands & Vallis, 2009b). Steering involves reorientation of the whole body to a new direction of travel. This is typically seen when turning a corner or circumventing an obstacle and as such is an important movement for adaptive locomotion (Patla et al., 1991). Findings of a governing role of eye movements suggest that oculomotor responses during steering not only provide visual input but also play an important role in coordinating body segment movement during steering (Reed-Jones, Hollands, Reed-Jones, & Vallis, 2009a; Reed-Jones, Reed-Jones, Hollands & Vallis, 2009b).

2.1 How are turns achieved?

How the CNS coordinates steering has been mapped both spatially and temporally in young healthy adults. When steering, the center of mass (COM) of the body must be controlled in the medial-lateral direction to maintain dynamic postural stability and to accelerate the body towards the new direction of travel (Patla, Adkin & Ballard, 1999). One strategy to achieve a

redirection would be to stop, reorient the body in the desired direction in place and then proceed walking in that new direction. However, healthy adults rarely adopt this strategy and opt for redirecting the walking trajectory in an online manner that does not involve halting. This latter strategy requires a greater level of body segment coordination and timing in addition to step width regulation and movement of the COM in the direction of travel (Patla et al., 1999). Yet, the benefits of online control, a quicker and more fluid execution with less abrupt stops and starts, possibly outweigh these control issues. Patla et al. (1999) studied the biomechanics of how the subtasks of steering are coordinated: step width regulation, COM redirection and body segment reorientation. These authors used early cueing (when steering was planned early) and late cueing (when steering was planned two steps before) to examine differences in control strategies under different timing constraints. The results of this study indicated that foot placement controls deceleration of the COM in preparation for accelerating the COM in the new direction of travel. However, the hip controls COM movement in late cue conditions. Once the COM is under control, in preparation for the redirection, the head initiates the turn to the new direction of travel followed by the trunk and lower body (Patla et al., 1999). It is this initiation of head movement prior to body movement that has provided the support for hypotheses that redirecting the visual system to the new direction, to gather both information regarding the environment and travel path as well as to shift reference frames for movement to the new direction is critical for steering control (Hollands, Patla & Vickers, 2002; Grasso, Prevost, Ivanenko & Berthoz, 1998).

2.2 Head leads steering synergy

Grasso et al. (1998a) were among the first to propose steering as a feed-forward navigation control system, involving eye and head coordination in anticipation of future motor

events. These researchers observed that a coherent eye and head (or gaze) reorientation was performed in anticipation to the direction one was about to turn, even without visual stimuli (e.g. blindfolded). These striking results were the first to suggest that visual redirection was not solely for the purpose of obtaining visual information regarding the environment but that perhaps the eyes serve a further role, a role irrelevant of whether there is retinal visual information or not.

One further purpose of the study by Grasso et al. (1998a) was to examine whether anticipatory eye and head movement was based on an embedded motor pattern for turning or whether anticipatory control was based on the intended direction of travel. Grasso et al. (1998a) proposed that gaze redirection during backward locomotion should be a time-reversed copy of those observed during forward locomotion, if steering is a “hard-wired” turning motor program. Results of the study showed that in backward locomotion gaze directed opposite to the direction that was observed during forward steering. Forward and backward steering were not time-reversed copies. The authors used this evidence to support the hypothesis that eye and head movements are anticipatory behaviors relative to the intended direction of motion. Patla et al. (1999) who observed differences in control of steering dependent on the amount of time available to pre-plan the movement also demonstrated the anticipatory nature of steering. Grasso et al. (1998a) concluded that these observations ruled out an underlying hard-wired motor control synergy, that once initiated, controlled the body’s reorientation movement in a pattern of head, trunk, and lower body. However, when one considers walking backwards, the reorientation of the segments in order to turn the same corner from end to start are actually in the opposite direction from start to end in forward steering. For example, when turning around a right corner forward, one would direct the head then the trunk and feet to the right. However, when walking the right corner backwards one would need to direct the head, trunk and feet left in order to

direct the COM around the corner. Therefore, the reorientation of the segments is consistent in both the forward and backward direction such as to suggest that the head does initiate a movement pattern for the trunk and lower body to turn.

In a follow up study to understand the development and execution of steering control in children, Grasso, Assaiante, Prevost and Berthoz (1998b) observed steering behavior in children over and under the age of 5.5 years. The hypothesis addressed in this research concerned the anticipatory nature of head and eye movement prior to steering. In adults, anticipatory movements of the eyes and head build more than one second before the corner point. Feed-forward control of movement emerges early in children (6-16 months), therefore a similar anticipatory head first strategy should appear in young children while turning. In fact, these authors observed that a time lead of the head was present in all the children over the age of 5.5 years of age and two children under the age of 5.5 years. Though there was a significant difference in time lead observed between the children and those observed in adults, the results indicated that feed-forward control of steering was present at a very early stage of gait development (Grasso et al., 1998b). Grasso et al. (1998b) also noted, a developmental sequence for locomotor control from an en bloc operation of the body in the youngest children, which involves moving all the body segments together to an articulated coordination of the body with maturation. These results demonstrate a potential innate mechanism for steering control, one that perhaps becomes apparent during neuromaturation of locomotor control.

Following this work, Hollands, Sorensen and Patla (2001) investigated the effects of immobilizing the head (by fixing it to the trunk via a spinal board) on the Central Nervous System's (CNS) control of steering. These authors used both a head immobilized (HI) and head free (HF) condition to compare the kinematics of steering when the head cannot lead. These

authors observed that in the head free (HF) condition participants displayed a systematic head leading the body reorientation pattern consistent of previous findings (Patla et al., 1999, Grasso et al., 1998a). However, in the HI condition, onset of trunk yaw was early. These results indicated that when the head was unable to redirect independently from the trunk, that the head-trunk unit was used to redirect prior to the lower body. This study presented critical information regarding the need for the head to precede the body's commitment to a turn, and that under different circumstances the CNS adapts in order to achieve that goal. These authors concluded that the CNS uses anticipatory head reorientation to provide a new frame of reference used to control body reorientation coordination (Hollands, Sorensen, & Patla 2001).

Vallis, Patla and Adkin (2001) also conducted an interesting study supporting the conclusions of Hollands et al. (2001). These authors observed the effects of a sudden head perturbation on the control of online steering. Perturbations were applied to participants' heads either to assist or to oppose the direction of the turn before the transition stride. The results showed that a head perturbation in the opposite direction delayed head reorientation in the new travel direction. Head and trunk yaw occurred almost simultaneously in this condition. While a head perturbation, assisting the new direction of travel resulted in earlier head reorientation in the direction of travel. The authors proposed that the head perturbation in the opposite direction limited the ability of the CNS to acquire information about the new travel direction. This directly resulted in unsatisfactory vestibular/visual input of the intended direction change and as a result, the CNS delayed body segment reorientation to the new path until adequate sensory information regarding the new direction could be obtained.

In order to evaluate the importance of head segment orientation to generate a stable frame of reference, Vallis and Patla (2004) investigated body responses to self-generated (voluntary)

and unexpected head turns. The hypothesis was that if a voluntary head turn generated a ‘hard-wired’ steering synergy response, then an externally triggered head movement would generate a release of that same ‘hard-wired’ synergy. If the responses were limited to head movement, it would mean that the steering synergy is unique to voluntary steering tasks or that the CNS is capable of suppressing it. The results showed that during voluntary head turns, maintaining a straight walking trajectory but turning the head to the side, a subset of the steering synergy was observed where direction specific lateral changes in angular trunk yaw and COM trajectories were observed but the travel path was not altered. The authors proposed an efferent copy of the head yaw movement preserved the original direction of the travel path, suppressing the follow through on a complete steering movement. The lateral changes in trunk roll and COM trajectories reflected a “subset” of the steering synergy that could not be suppressed completely. The authors further proposed that suppression of the steering synergy could pose as a safety mechanism. When there is a conflict between the set orientation for the travel path and the updated frame of reference, the CNS can suppress release of the steering synergy to ensure whole body safety during locomotor tasks.

In the second experiment Vallis and Patla (2004) manipulated visual information during unexpected head turn trials to observe whole body effects. The results indicated that in response to unexpected head perturbations with occluded vision, significant modifications in trunk yaw modulation and lateral foot placement occurred, resulting in global modification in COM trajectories. The authors interpreted these results as the CNS perceiving the unexpected head turn as an initiation of the steering synergy. This in turn resulted in automatic trunk and body reorientation to the new travel direction. These modifications observed in COM trajectories and body segment movements in response to voluntary head turns and unexpected head perturbations

indicate a possible ‘hard-wired’ component of steering control, that the movement pattern can be triggered by a particular input or stimulus (turning of the head).

In many of the first investigations of steering control, discrete redirections of the walking path were used as the locomotor context. However, a number of researchers also began to implement planned circular paths for the study of steering motor control, as circular paths are a demanding process involving continuous cognitive-to motor transformation. Courtine and Schieppati (2003) conducted a study to compare human locomotion along a straight path and a continuously curved path. The results showed that changes in amplitudes of head, trunk and feet movement were observed between straight path walking and walking along a circular path. Later when the vision of the subjects was compromised while they walked along the curved path, only minimal changes in segment orientation was observed when compared to segment orientation when walking along the curved path with eyes open. Only a clear dichotomy in head pitch movement was observed when the turn was implemented with eyes open and blindfolded. The result of this study demonstrated again, similar to Grasso et al. (1998a), that unavailability of vision does not affect the overall coordination of body segment reorientation when changing the walking trajectory.

Together the above studies present a network of evidence for the presence of a steering synergy that is a ‘hard-wired’ motor pattern initiated by head reorientation. Head reorientation is a critical component to steering control as it is the basis for internally and/or cognitively generated reference frames for which whole body movement coordination is based. However, this ‘hard-wired’ mechanism is hierarchically modifiable and can be manipulated dependent on the movement situation. For example, when the head is unable to initiate movement, the trunk can move earlier to facilitate head reorientation prior to execution of the turn. Moreover, steering

control is observed in young children suggesting an innate component of this neurological mechanism that matures with development.

2.3 Do the eyes lead the head in steering?

Based on the research evidence presented thus far, it was accepted that the head leads the body for steering control, and that a possible underlying reason for anticipatory head reorientation was to direct the visual, and perhaps vestibular, system to the new direction of travel to obtain an allocentric reference for which to base a coordinated body response. The articulated top down control of the body to maintain dynamic stability follows the en bloc operation in the developmental sequence of locomotor control (Grasso et al., 1998b). The body segments move together as a block in en bloc turning which is also observed in clinical populations at increased risk of falling while steering (Lamontagne, Paquette, Fung, 2007; Crenna, Carpinella, Rabuffetti, Calabrese, Mazzoleni, Nemni, Ferrarin, 2007). Two functional principles and different combinations of sensory inputs (visual, vestibular and proprioceptive) are involved with the en bloc (ascending) and the articulated top down (descending) temporal organization of body segment reorientation in steering. The two functional principles are the frame of reference on which the balance control is based and the other principle concerns the choice of the degrees of freedom of various joints of the body which have to be controlled simultaneously to maintain dynamic equilibrium (Assaiante & Amblard, 1995). The balance control is organized from the feet to the head (ascending organization) when the frame of reference is the supporting surface on which the person is standing. In the case of en bloc turning, the body mainly relies on proprioceptive and cutaneous information and temporally organizes balance working upwards from the feet to the head. When the frame of reference is the gravitational vector, balance control is organized from the head to the feet (descending

organization). In this case the body relies on the gravitational vector (vestibular input) in order to stabilize the head and organize the balance working from the head to the feet (descending organization). Stabilizing gaze provides the body with stable reference frames around which body segment reorientation can be built up. The en bloc turning or the ascending temporal organization of body segment reorientation is associated with minimizing the degrees of freedom of various body joints. This is an easier way to maintain dynamic balance since there is a minimum number of degrees of freedom of the body segments involved. However it increases the rigidity of the body reducing stability and putting the body at greater risk of destabilization (Bernstein, 1967). On the other hand the top down approach involves controlling more degrees of freedom of various body joints especially the neck. Controlling more degrees of freedom by the neck joints to reorient the head first is used to obtain the visual and vestibular information for balance control (Assaiante & Amblard, 1995). Though the role of the head in steering control was well investigated in early research, the role of the eyes in the steering sequence was not clear. If the head was a trigger for the release of the pattern of body movement known as the steering synergy, then perhaps the eyes themselves also had a critical role in this purpose.

Imai, Moore and Raphan (2001) studied the interaction of body, head and eyes during walking and turning using a gravito inertial vector. Gravito inertial vector is the sum of linear accelerations acting on the head (Imai et al., 2001). They observed a close coordination between head and eye motions to orient gaze with respect to the gravito inertial acceleration vector (GIA) and compensatory control for oscillatory perturbations created by the movements of the lower body during bipedal locomotion. Compensatory pitch movements of the eyes countered the vertical translation of the head during straight walking. During turns, counter rotation of the head in yaw within 1^0 from the straight-ahead position achieved gaze stabilization. From these results,

the authors concluded that spatial maps directed the motion of legs in a top-down organization based on head and eye movements. The CNS generates appropriate head and eye movements to maintain stable gaze, which in turn generates a stable internal reference to produce body reorientation.

Hollands, Patla and Vickers (2002) were really the first to begin to measure movement of the eyes using eye-tracking technology to investigate the role of the eyes in straight path and steering navigation. This was the first study that provided information about where humans look while steering towards a new direction. They found that when redirecting the walking trajectory, participants' gaze aligned to the current plane of progression prior to, and following the transition stride. This behavior occurred in both early and late cue conditions and all participants displayed similar gaze behavior. The above research evidence supported previous hypotheses based on head only data, that the eyes and head align with the desired travel direction to provide the CNS with an allocentric frame of reference to navigate the rest of the body. The results also supported Gibson's (1966) theory of optic flow, that the centre of expansion of the optic flow field on the retina specifies the observer's heading direction.

Following the work by Hollands et al., (2002), Reed-Jones, Hollands, Reed-Jones, and Vallis (2009a) tested the hypothesis that rotation of the external visual world could induce eye redirection and as a result initiate a body steering response. This was the first study to use a virtual environment to induce coordinated steering responses while stepping in place. The participants in this study demonstrated a significant horizontal eye movement then head and body reorientation in response to the turn presented to them via a virtual environment. The onset of the eye movement triggered synergistic turning responses and revealed timing of segment rotation that was characteristic of steering behavior in real world turning. The results of this

study supported the body of work that proposed that visual redirection leads steering movements. The authors concluded that during steering the eyes serve a more complex purpose than just providing retinal visual information. The eyes may in fact provide important proprioception through which the CNS can base the degree of angular body movement required to reach the new target.

In a follow up study, Reed-Jones, Reed-Jones, Vallis & Hollands (2009b) examined if gaze fixation in a virtual environment would result in absence or decrease in the magnitude of the steering response observed previously. In the study the authors observed that when the eyes could move naturally (free gaze), the steering synergy initiated in anticipation of the corner. However, during gaze fixation, the body segments turned together in an en bloc postural response. These findings supported an intrinsic link between the eyes and the steering synergy that remains unclear. These authors further postulated that inefficiency in steering in certain clinical populations (such as frail older adults) could be attributable to deficits in visual redirection. An area of research that as of yet has been largely untouched. Ambati, Murray, Powell, Saucedo and Reed-Jones (2013) sought to expand on this concept by quantifying the natural gaze and body turning coordination in healthy young adults while changing the walking trajectory in the absence of a visual cue. The results of the experiment were consistent with previous findings where light cues were used that may have driven the anticipatory eye movement. The authors demonstrated the active control of CNS to move the eyes first in the new travel direction. It was also demonstrated that when participants fixated on a point straight ahead, restricting anticipatory eye movement, participants demonstrated an en bloc movement strategy, in which all the body segments moved together.

The hypotheses proposed through the human bipedal steering literature also have support from other research areas involving humans. For example, Land and Lee (1994) analyzed driver's gaze direction while steering a car along a tortuous road. They discovered that drivers' were looking at the tangent point on the inside of each curve, at least one to two seconds before each turn and returning to it throughout the turn. The authors proposed that the CNS considers the tangent point direction as a good predictor of the curvature of the road. This strategy is useful because the tangent point is a very reliable cue to the curvature of the road guiding the amount of angular rotation of the vehicle needed to complete the curve. These driving data support hypotheses by Reed-Jones et al. (2009a) that repositioning of the eyes to the new direction of travel serves as a spatial map for the degree of segment angular rotation required to reach the new goal.

The above studies begin to highlight the integral role of the oculomotor system in the CNS control of steering and turning movements and provide the foundation for hypotheses that the oculomotor system has a governing role in coordinating human body segment movement during bipedal steering. In particular, these studies suggest that anticipatory eye movement is critical for top-down visuomotor control of steering. The absence of top-down visuomotor control has been observed in older adults and clinical populations who experience falls while turning (Paquette et al., 2008; Crenna, Carpinella, Rabuffetti, Calabrese, Mazzoleni, Nemni, & Ferrarin, 2007; Lamontage, Paquette, & Fung, 2007). In addition, those at risk of falling use an en bloc turning strategy which increases the rigidity in the body (Assaiante, 1998), reducing the ability to stabilize oneself in case of a perturbation. Therefore, strong evidence supports the critical role of visuomotor control in steering for effective turning control.

2.4 Types of turns

Apart from body segment coordination, dynamic stability during steering also depends on the type of turn executed. A proper stepping strategy plays an important role in executing a turn while walking with stability and with lower biomechanical costs (Patla et al., 1991; Taylor et al., 2005). The types of turns embedded in locomotion are categorized into step turns and spin turns (Hase & Stein, 1999). A step turn involves moving away from the contralateral limb (Figure 1A). The sequence of actions taking place during step turn is as follows. (1) The contralateral limb is placed in front of the ipsilateral limb slightly medially with a toe in position. (2) The ipsilateral limb is then swung inside the contralateral limb in the direction of turn. (3) The contralateral limb remains in the toe in position and during push off swings in the new travel direction to reorient itself during swing rather than during stance. In contrast, a spin turn involves turning towards the ipsilateral limb (Figures 1B, 1C). There are two types of spin turns and the first three steps are the same in both types. (1) Initially the contralateral foot approaches the turning spot. (2) The ipsilateral foot is placed in front of the contralateral limb slightly laterally in a toe out position. (3) The contralateral limb is then swung outside the ipsilateral limb in the direction of the turn, while the ipsilateral limb is in a toe out position. In the case of the spin turns categorized as ‘ipsilateral pivot’ (Figure 1B) after the contralateral limb is swung, (4) the ipsilateral limb rotates on the ground before the (5) contralateral limb strikes the ground in the new travel direction. (6) The ipsilateral limb then goes into swing and steps in the new travel direction. In the case of spin turns categorized as ‘ipsilateral crossover’ (Figure 1C) the ipsilateral limb remains in the toe out position until the (4) contralateral limb strikes the ground in the new travel direction. (5) The ipsilateral limb then goes into swing and steps in the new travel direction (Hase & Stein, 1999). In the case of the step turn the center of mass (COM) remains between the two feet, whereas in the case of the spin turn the COM goes outside the

stance foot to facilitate the movement in the new travel direction. Therefore there is a reduction in stability of the body during spin turns placing greater demand on balance and increasing the risk of tripping and falling during the maneuver. The increased demand on the balance control system in spin turns is due to the movement of the COM outside the base of support requiring greater muscle forces to maintain dynamic stability. Step turns offer more stability with less muscular demand because the COM remains within the base of support throughout the movement (Taylor et al., 2005). Patla et al., (1991) showed that younger adults preferred step turns over spin turns due to the inherent benefits of the step turn strategy (Taylor et al., 2005). A recent study on turning behavior in healthy older adults showed that they preferred spin turns when asked to walk slower or faster than their natural walking speed (Akram, Frank & Chenouri, 2010). However the older adults were asked to cross their arms on the chest which could have influenced their choice of turn type. There is no clear evidence showing the preference of a turn type in older adults.

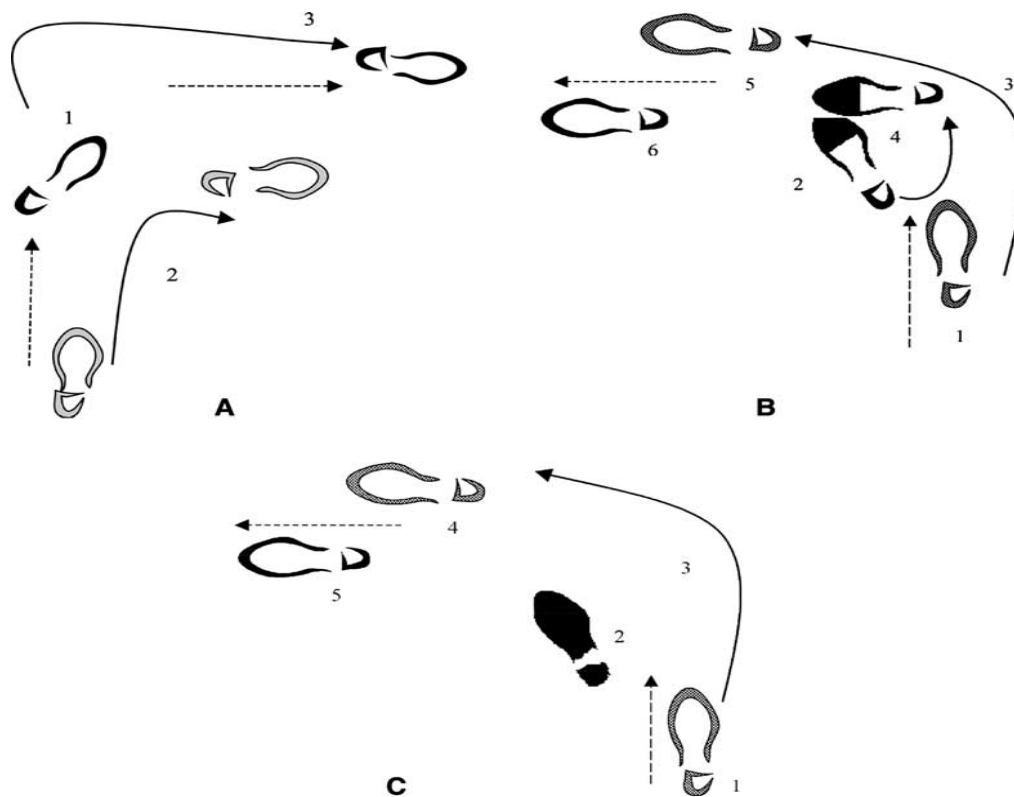


Figure 1. Types of turns

Notes: (A) Demonstrates step turn: going to the right with the right foot (ipsilateral) while the left foot (contralateral) remains in stance. (B) Demonstrates spin turn (ipsilateral pivot): going to the left with the right foot (contralateral) while the left foot remains in stance and pivots in the direction of travel before the right foot strikes the ground. (C) Demonstrates spin turn (ipsilateral crossover): going to the left with the right foot (contralateral) while the left foot remains in stance. (Taylor et al., 2005)

Turns embedded in locomotion in healthy young adults not only involve an articulated eye and body segment reorientation, but also a stable and energy efficient stepping pattern (step turn) (Patla et al., 1999; Reed-Jones et al., 2009a; Ambati et al., 2013; Patla et al., 1991; Taylor et al., 2005). Changing the direction of locomotion must be planned in the previous step to reduce the acceleration of the center of mass of the body to zero in the sagittal plane (Patla et al., 1991) control it in the medial-lateral direction to maintain dynamic postural stability and accelerate in the new direction of travel (Patla et al., 1999). Executing proper foot placement to use a step turn instead of a spin turn improves the dynamic stability and reduces muscular

demands for steering (Taylor et al., 2005). In addition to planning the steps needed to execute steering, it is also necessary to monitor these actions as they are performed and alter the steps if required. Online monitoring and modifications to ongoing movements are made based on sensory feedback. For example, when the ability to rotate the head independently from the trunk is removed (by fixating the head to the trunk with a collar), the CNS initiates trunk movement earlier to facilitate head reorientation prior to execution of the turn (Hollands, Sorensen & Patla, 2001). This shows the mental flexibility and feedback utilization are involved in steering control. Therefore steering involves several different functions like goal setting, planning, monitoring the actions planned, mental flexibility and feedback utilization. These key functions thought to be involved in steering control are components of Executive Function.

2.5 Executive function

Executive function (EF) may be defined as a construct that is composed of several inter-related cognitive skills like thought, self-control, intellect and social interaction (Anderson, Jacobs & Anderson, 2008). Some of the functions of EF include processing of external stimuli, planning the steps and actions needed to complete a task, execution of a task and verification that the task has taken the proper course (Lezak, 1995). The key elements of EF are: anticipation and deployment of attention, impulse control and self-regulation, initiation of activity, working memory, mental flexibility and utilization of feedback, planning ability and organization, and selection of efficient problem solving strategies (Lezak, 1995; Anderson, Jacobs & Anderson, 2008; Hunter & Sparrow, 2012).

The control of executive function has been associated with the pre-frontal cortex in previous studies. Damage to the pre-frontal cortex followed by executive dysfunction (Grattan & Eslinger, 1991) and significant activity in the pre-frontal cortex observed in neuro-imaging

studies while performing executive function measures helped researcher to establish this link (Lezak, 1995; Baker, Rogers, Owen, Frith, Dolan, Frackowiak, & Robbins, 1996). The pre-frontal cortex has efferent and afferent connections with other regions of the brain like the brain stem, occipital, temporal, parietal lobes, as well as limbic system and subcortical regions. This associates the EF with several other regions in the brain. Therefore executive dysfunction could be presented by, not only damage or loss to the pre frontal cortex but also impairment in other brain structures and network disconnections like white matter damage. Having an intact pre frontal cortex is important but not sufficient for the integrity of EF (Anderson, Jacobs, & Anderson, 2008; Hunter & Sparrow, 2012). Therefore in summary, EF is a psychological construct that is controlled by several neural systems (pre frontal cortex and other brain structures and their connections) that provide critical information about specific processes and the integrations of these functions.

2.6 Models of executive function

A number of neuropsychological models have been developed to provide a theoretical framework for the assessment of executive functioning. Executive control system and Supervisory attentional system are two contemporary executive function models that are composed of distinct but interrelated components. Unlike previous models that were modular, the components in these models are independent but work bi-directionally to accomplish a task.

2.6.1 Executive control system

The executive control system (ECS) is a conceptual frame work that conceptualizes EF as an overall control system with four domains: attentional control, cognitive flexibility, goal setting, and information processing (Anderson, 2002). These various factors were identified as domains of EF using different test batteries (Kelly, 2000; Levin, Culhane, Hartmann,

Evankovich, Mattson, Harward, Ringholz, & Ewing-Cobbs, 1991). According to ECS (figure 2) each of these domains performs specific tasks and can function independently but all these domains interact with each other to function as an overall system. The level of involvement of each of these domains is task dependent, which means that the level of input may vary by the nature of the task being accomplished. Each of these domains involves highly integrated cognitive processes and receives and synthesizes external stimuli from various brain structures like subcortical, motor and posterior brain regions (Anderson, Jacobs, & Anderson, 2008).

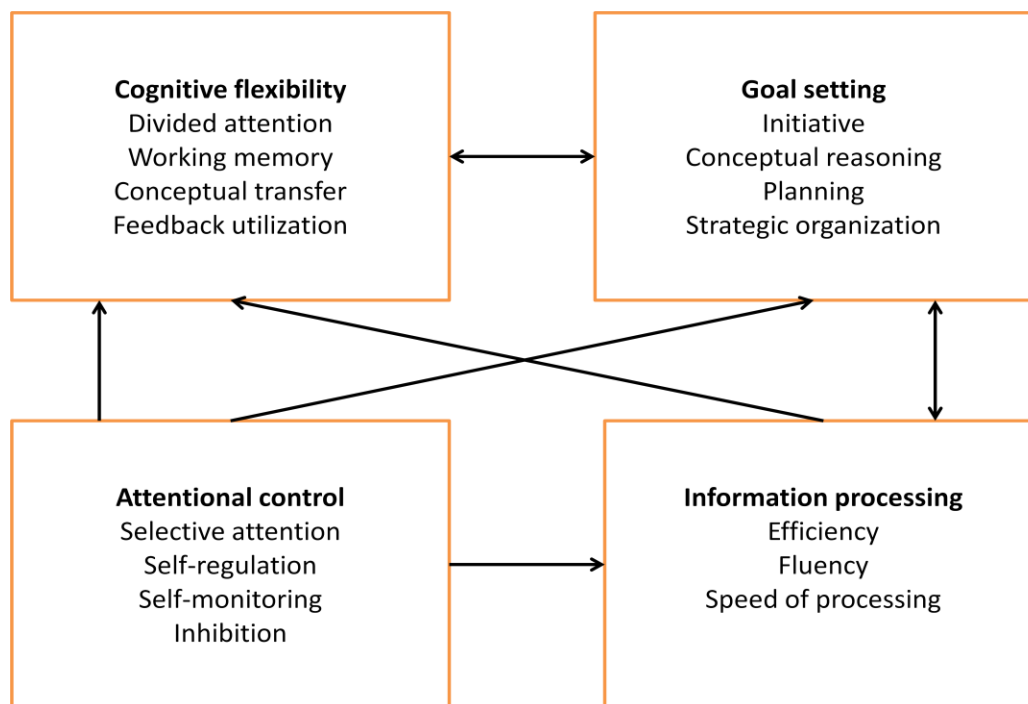


Figure 2. Executive control system (Anderson, 2002)

The attentional control domain includes the ability to attend to specific task and sustain attention for a prolonged period of time. This domain also includes the ability to regulate and monitor actions, so that they are executed as per the plan to achieve goals and avoid errors. People who have impaired attentional control; lack self-control, are highly impulsive, have difficulty sustaining attention, fail to complete tasks and respond inappropriately. Cognitive

flexibility is the principle domain of EF and it comprises of the ability to learn from mistakes, divide attention between tasks and process multiple external stimuli concurrently. Divided attention is important when an individual is performing more than one attentionally demanding task at the same time. This requires the attentional resources to be shared for processing these stimuli concurrently. Working memory is the ability to store the information temporarily and modify it later. Impairment in cognitive flexibility may result in individuals losing their ability to multitask, failing to adapt to new demands and failing to manipulate information or recollect previously stored information. Goal setting is another important domain of EF which includes the ability to initiate an activity and the ability to plan the steps necessary to complete an action. Any goal or task can be accomplished in numerous ways. Conceptual reasoning and planning is required to devise a plan that is strategic and efficient. Strategic organization refers to the ability to sequence the complex steps needed to logically complete a task. Impairment in this domain results in a deteriorated problem solving ability due to inadequate planning, lack of organization and poor conceptual reasoning. The last domain of EF in ECS is information processing. This domain refers mainly to the speed of processing because the performance on executive tasks can be compromised significantly by the information processing speed (Anderson, 2002).

Each of these domains discussed here can be shown to play an important role in steering control. Steering is a goal oriented activity that requires planning the steps required, for example decelerating the center of mass (COM) in an anterior-posterior direction whilst controlling COM movement in the medial-lateral direction and accelerating it in the new travel direction. The strategic organization allows an articulated body segment reorientation making the whole body less rigid and hence increasing the stability in case of a perturbation. Feedback utilization helps manipulate any of these steps to accommodate an obstacle or a novel situation that might prevent

fluid motion of the body segments. Attention control is required to ensure that all of these steps are monitored, manipulated and sometimes inhibited to safely execute a turn while walking. Though the functions of each of these domains are task specific, in case of steering they work bi-directionally to function as an overall system. All of these domains require attention control to monitor their activities so that the plans are executed in the correct order, errors are identified and corrected, and goals are achieved in an efficient way (figure 1).

2.6.2 Supervisory attentional system

Supervisory attentional system (SAS) is another conceptualized model developed to explain the EF. This model explains the control of two levels of action: automatic and deliberate. The automatic actions are those that do not require deliberate attention and their performance does not interfere with other actions. The other level of actions that require deliberate attention are those that require an intention to carry out or formulate a goal, devise a plan to achieve this goal, sequence the complex steps needed to accomplish this task and troubleshooting (Anderson, Jacobs, & Anderson, 2008).

The initial model developed by Norman and Shallice (1986) included two complimentary processes: contention scheduling and SAS. Contention scheduling is responsible for automatic actions. This process ensures that an appropriate well-formed schema is scheduled for completing an automatic task while inhibiting conflicting schemata. A schema is a behavioral program to complete routine tasks or actions. However in case of a novel task situation which may involve executive functions the existing schemata cannot be scheduled to perform the task. Additional attentional resources or SAS is required in these scenarios (Norman and Shallice, 1986). Shallice and Burghese (1996) extended on the SAS aspect of this model that comprised of three stages. Stage 1 is called strategy generation which includes building a new temporary

schema to accomplish the novel task. Stage 2 is the implementation of the new schema for the novel situation. Stage 3 involves monitoring the implementation of the new schema followed by rejecting the schema if found to be ineffective or manipulating it to match the necessary requirements.

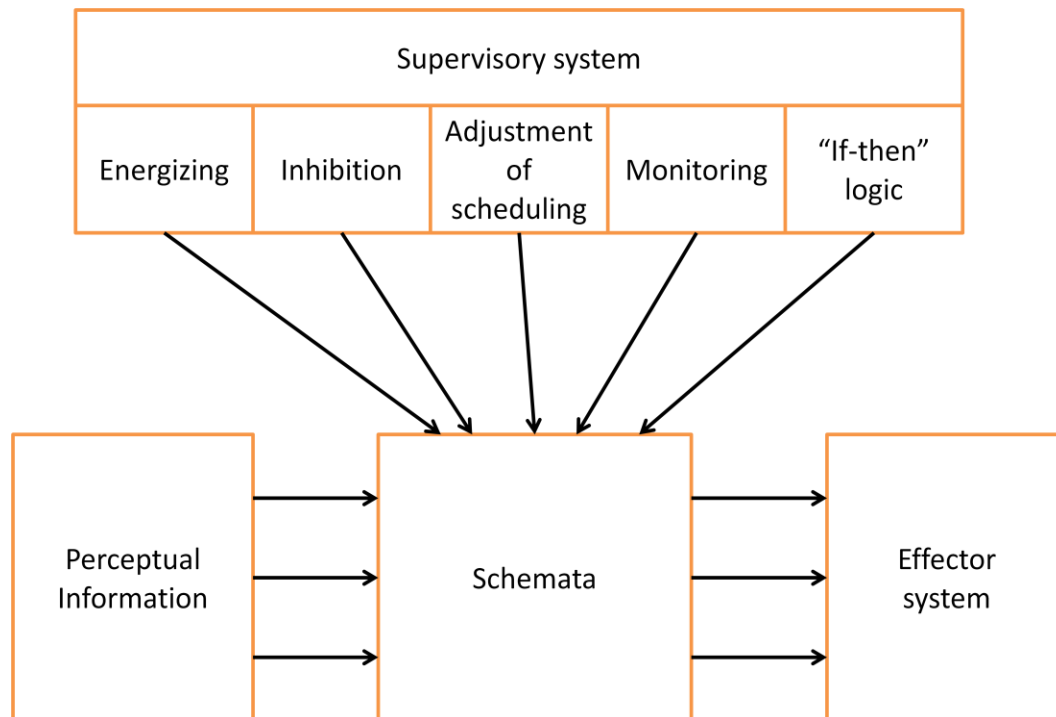


Figure 3. Supervisory systems in human attention (Stuss, Shallice, Alexander & Picton, 1995)

Stuss, Shallice, Alexander and Picton (1995) adopted the supervisory system to develop a new model (figure 3) with five independent supervisory processes for characterizing the processes involved in the control of attention across a range of tasks. These five independent supervisory processes are: energization of schemata, inhibition of schemata, adjustment of contention scheduling, monitoring of schemata and “if-then” logic. Energizing schemata refers to activating appropriate well-formed schemata to achieve a goal and also reactivating the same schemata if sustained attention is required. Inhibition of schemata refers to inhibiting inappropriate schemata from being activated. Some situations require the activation of similar

target schemata, and adjusting of contention scheduling is necessary to ensure that both the schemata are equally energized. Monitoring of schemata refers to ensuring that the energized schemata is still active, the behavior is appropriate and is not influenced by other competing schemata and that there are only a few errors made. The feedback obtained from monitoring the schemata is used by “if-then” logic to alter the process by inhibiting schemata, reenergizing schemata or by adjusting contention scheduling (Stuss et al., 1995).

The supervisory attentional system was characterized by taking into account the executive functioning, in particular attention control. This model mainly accounts for attention control and the various sub processes involved in attention control. These sub processes of attention are associated with different processes of the supervisory system (Stuss et al., 1995). The different steps involved in steering, like controlling the center of mass with a fluid motion of different body segments, may be stored as a motor program or schema that is energized while steering. The monitoring system ensures that there are no errors in the behavior and that the schema remains energized till the task, in this case steering, is executed successfully. The capacity to keep the schema energized involves maintenance of attention or the ability to sustain attention (Stuss et al., 1995). In case of errors identified by the monitoring system, where the fluid motion of the body segments cannot be implemented, “if-then” logic is utilized to select a different motor program or inhibit the erroneous movement. For example in the study where the participants’ head was attached to the trunk using a spinal board, they moved their trunk earlier to reorient the head in the new travel direction (Hollands et al., 2001). In this case where a novel situation occurs, a new temporary schema is built which involves goal setting and subsequent steps for problem solving. Implementation of a new schema will involve holding it online initially which requires working memory (Shallice & Burgess, 1996). The implementation of this

new schema (steering strategy) to accommodate the novel situation is monitored by the monitoring system. The feedback obtained is used by the 'if-then' logic system to either reject the new schema if it is ineffective or modify it to match the situation. Stuss et al. (1995) emphasized the control of attention across the different systems described in the supervisory system. Each of these supervisory processes described require a variety of independent sub-processes of attention.

2.7 Attention

The two theoretical models of EF (executive control system and supervisory attentional system) characterized executive function as an overall control system integrating different aspects of the construct. Both the models discuss the prominent role of attention in regulating and monitoring the other domains. Attention is a multi-dimensional construct which may be considered as a subordinate skill of EF or can in themselves be considered as executive processes (Park & Schwartz, 2000; Anderson et al., 2008). There are many varieties of attention and it is easier to discuss their specific functions while referring to those particular aspects of this construct. Attention can be classified into different functions which include sustained, selective, focused, divided, and alternate attention (James, 1950). Sustained attention refers to an individual's ability to attend to an incoming stimulus over a period of time (James, 1950). A real world example for sustained attention includes a soldier in a combat field looking for enemies. In steering, planning the different steps required, and monitoring those steps to obtain feedback requires maintenance of attention which is sustained attention. A person performing a selective attention task must select information for processing while blocking unnecessary stimulus information (James, 1950). For example a person looking for his seat in a crowded movie theater doesn't know where his target is located and must look through a complex visual field to find the

target. Focused attention refers to one's ability to attend to a specific stimulus coming from a known target while blocking out other distracting stimuli (James, 1950). Unlike selective attention, focused attention does not require looking for the source of information. A real world example for focused attention includes a person trying to pay attention to a conversation in a crowded cocktail party. Divided attention refers to the ability to divide attention between two tasks that are performed simultaneously (James, 1950). An example for divided attention would be the ability to perform an arithmetic operation while walking. It is difficult to differentiate between divided and alternate attention because alternate attention refers to rapid switching of attention between two tasks. Hence divided attention refers to the possibility of using both the terms (Park & Schwartz, 2000). Monitoring the behavior of two motor programs energized to perform two tasks simultaneously requires divided attention (Stuss et al., 1995). Attention control and the various sub processes of attention described above regulate and monitor the different components of executive function explained using executive control model and supervisory system of human attention (Anderson, 2002; Stuss et al., 1995).

We may characterize the involvement of attention control across a range of tasks associated with steering like goal setting, planning, mental flexibility and feedback utilization using theoretical models (ECS and supervisory system of human attention). But there is no known research providing clinical evidence to support the role of attention in steering. Hence through this dissertation we are attempting to investigate the role of attention in steering in healthy young adults. Understanding the role of attention control in steering is of foremost importance. Age-related decline in executive function and attentional control has been reported to occur in older adults in several studies (Crawford et al., 2010; Milham et al., 2002). Older adults also experience falls frequently (Tinetti, Speechley, & Ginter, 1988) and falling while

turning is 7.9 times more likely to cause a hip fracture than falling while walking in a straight path (Cumming & Klineberg, 1994). Therefore determining the role of attention in steering in healthy young adults would be a critical first step that can be used as evidence to say that one of the underlying factors responsible for the increased risk of falling in older adults while steering is attention deficits.

2.8 Aging and executive functioning

Cognitive control or executive functions are considered to be important explanatory variables in cognitive aging research. These conclusions were made based on recent neuroimaging studies which indicated age-related deterioration in the frontal lobes of the brain (Coffey, Wilkinson, Parahos, Soady, Sullivan, & Patterson, 1992; Pfefferbaum, Sullivan, Rosenbloom, Mathalon, & Lim, 1998). In cognitive terms, the changes in attentional control and a variety of memory and reasoning tasks can be explained by deterioration of executive functioning. In neuropsychological terms, age related impairment in cognition is explained by the structural changes in the frontal lobes of the brain (Anderson et al., 2008). Since executive functioning is associated with frontal lobes, a theory called “frontal-executive theory of aging” was proposed to explain the link between the structural changes in the frontal lobes of the brain and the corresponding impairment of executive functioning (Daigneault, Braun, & Whitaker, 1992; Mittenberg, Seidenberg, O'leary, & DiGiulio, 1989; West, 1996).

The frontal-executive theory proposes that executive dysfunction with aging can be attributed to the early, localized changes in the structure of the frontal lobes of the brain. Several neuro imaging studies have been conducted to observe the functional activation of the frontal lobes of the brain during cognitive performance in healthy old and healthy young adults (Coffey et al., 1992; Pfefferbaum et al., 1998). A mixed pattern of results were reported in these studies.

Older adults showed lower frontal activation while performing tasks related to memory encoding and attentional control (Petit-Taboue, Landeau, Desson, Desgranges, & Baron, 1998; Grady, 2002). This may be interpreted as older adults exercising poorer efforts while performing complex cognitive tasks (Maden, Turkington, Provenzale, Denny, Langley, & Hawk, 2002).

However, a different pattern has been observed in other studies. Higher frontal lobe activation was observed in older adults while performing complex cognitive tasks when compared to younger adults. Increased prefrontal activation with aging while performing complex cognitive tasks can be explained using compensatory mechanisms (Reuter-Lorenz, 2002; Grady, 2002). A variety of hypotheses using compensatory mechanisms have been proposed to explain this behavior. According to the prefrontal effort hypothesis older adults recruit more neural networks than younger adults because the complex cognitive tasks are more difficult for older adults than younger adults who find them relatively easy (Tisserand & Jolles, 2003). The strategic recruitment hypothesis suggests that due to the structural changes in the brain that develop with aging, older adults recruit additional neural structures as a cognitive strategy to carry out a task. The reorganization hypothesis suggests that the intact neural networks reorganize themselves to compensate for the lost neural networks with aging (Park & Schwartz, 2000; Anderson et al., 2008). Therefore, there is a great deal of evidence that the neural networks of EF lie in the prefrontal lobes of the brain and damage to these regions will impact executive control processes.

Executive functions include multiple skills and it is highly unlikely that aging affects all these skills in the exact same way. Increasing age compromises the brain's ability to implement attentional control which influences other domains of executive function like working memory (Milham et al., 2002). Since attention control regulates and monitors the other domains of

executive function, the impact of decreased attention control will be seen on the overall system (Anderson, 2002). Based on the theoretical models discussed earlier, impairments in attention control might influence steering as well. Hence impairment in attention with age is likely to affect steering performance. A mixed pattern of results were observed in studies related to body segment coordination while walking and turning in older adults. Though Paquette et al. (2008) reported age related changes in the timing and sequence of body segment reorientation while turning, a few other studies reported otherwise. Fuller, Adkin and Vallis (2007) reported that older adults used the same top-down segmental sequence while walking and turning like healthy young adults. Akram, Frank and Fraser (2010) observed that healthy older adults did not show any differences in the top-down temporal sequence of body segment reorientation while walking and turning at different velocities or turn magnitudes (45° and 90°). These relatively new articles that investigated the temporal organization in steering in older adults are not very useful to make definite conclusions about steering behavior in older adults. This is because in contrast to the previous articles on steering discussed earlier, not only did these studies exclude eye data but also there were many other methodological variations. For example the magnitude of the turn investigated was only 40° (Fuller et al., 2007; Paquette et al., 2008) when most of the turning in activities of daily living happen between 76° and 120° (Sedgman, Goldie, & Iansek, 1994). In the study conducted by Fuller et al. (2007), a 2 dimensional video camera was used for data collection and the data analysis to determine turn onsets of body segments were determined by examining the videos by two research assistants. Using a two dimensional camera for data collection and biomechanical analysis that was done visually would not validate the comparisons made in this study to the previous literature which mainly comprised of studies that used 3 dimensional motion capture systems. Akram et al. (2010) investigated the turn onsets of shoulder

and pelvis to show the temporal organization of body segments while steering in older adults. Though these studies challenge drawing definite conclusions about temporal organization of body segment reorientation in older adults while steering, these findings may be used to hypothesize the steering behavior in older adults in this dissertation. We may not observe any differences in the top-down temporal sequence of body segment reorientation in older adults while steering (Akram et al., 2010). Hence using a secondary cognitive task with steering might reveal the deficits not seen while performing the steering task alone. This dissertation is the first study to investigate the influence of age on steering by determining the temporal organization of eyes, head, trunk and pelvis in steering while performing a secondary cognitive task in healthy older adults.

2.9 Dual task methodology in gait

Examining the role of attention in steering can be implemented using dual task methodology. Dual task methodology is an experimental method used to assess cognitive motor interference in gait. A growing body of research shows that gait and postural control are linked to cognitive function and these processes are not automatic, but consume some amount of attentional resources (Woollacott & Shumway-Cook, 2002). Dual tasking has become a common method used to test whether gait requires attention (Ebersbach, Dimitrijevic, & Poewe, 1995; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Verghese, Kuslansky, & Holtzer, 2007). Dual tasking in gait is achieved by challenging attentional capacities with a secondary cognitive task while participants perform a gait task. The working hypothesis of dual task paradigms in gait is that if gait is an automated activity that does not require attention, then performing a secondary cognitive task should not affect gait, however if gait control does require attention then interference from the secondary cognitive task should be

observed. The interference caused by dual task paradigm in gait can be explained using Pashler's (1994) neuropsychological theory. When a person receives two stimuli successively, the response to either the second stimulus or both the stimuli is delayed when the time interval between the two stimuli is reduced. This phenomenon is called psychological refractory period effect. Pashler (1994) describes PRP effect using two factors that work together; they are a "central bottleneck" and a preparatory limitation. According to bottle neck theory certain responses require a single mechanism dedicated to them for a while. During this time if there is a second stimulus that requires the same subset of units, the neural network cannot select two different responses at the same time. This results in the delay of one or both the tasks. In simple words, when two stimuli require the processing unit at the same time, a bottle neck results, and the response to the stimuli of only one of the two tasks is processed first. Therefore the inability to select two responses at the same time is one of the causes for dual task interference. Another reason for PRP effect is the preparatory limitation. Bottleneck is also caused by the fact that preparation for the tasks is less effective when other tasks must be prepared at the same time.

2.10 Effects of dual task methodology

Over the past two decades the effects of dual tasking have been studied in different populations like healthy young adults, healthy older adults, and clinical populations. However, methodological variations make it difficult to draw definite conclusions. Discrepancies in the results of various experiments on dual task paradigm in gait have raised many issues. These issues involve differences in methods, subject groups, and lack of agreement concerning the dual task paradigm. One of the issues with current research is the lack of standardization in the dual task paradigm and a consensus needs to be reached on the research protocol. These are some of the gaps in the current articles reviewed.

Most of the studies on healthy young adults have reported that the performance of a secondary task influences gait (table1) (Ebersbach, Dimitrijevic, & Poewe, 1995; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003; Bootsma-van der Weil, Gussekloo, de Craen, van Exel, Bloem, & Westendorp, 2003; Shkuratova, Morris, & Huxham, 2004; Beauchet, Dubost, Herrmann, & Kressig, 2005; Grabiner & Troy, 2005). They showed that healthy young adults reduced their gait speed and there was also a decline in the performance of the secondary task due to dual tasking. However, a few studies reported increase in stride time, step width, stride time and stride time variability (Al-Yahya, Dawes, Collet, Howells, Izadi, Wade, & Cockburn, 2009; Beauchet, Dubost, Hermann, Kressig, 2005; Parker, Osternig, Lee, Donkelaar, & Chou, 2005). Therefore, the evidence provided by these studies supports the hypothesis that even in healthy young adults gait consumes some amount of attentional resources. This claim is supported by recent brain imaging studies which reported the involvement of pre frontal cortex in preparation of gait and controlling gait speed (Harada, Miyai, Suzuki, & Kubota, 2009; Suzuki, Miyai, Ono, Konishi, Kochiyama, & Kubota, 2004). Gait speed is also associated with the measures of executive function which has connections in the pre frontal cortex of the brain (Suzuki, Miyai, Ono, & Kubota, 2008). Therefore gait control shares the same set of neural networks as the executive function, and hence healthy young adults reduce their gait speed when asked to perform a cognitive task simultaneously with gait. Some studies that reported no dual tasking costs in healthy young adults may have used secondary tasks that were less challenging, or the participants in these studies prioritized gait over the secondary task as per the instructions given (Lajoie, Teasdale, Bard, & Fleury, 1993; Lajoie, Teasdale, Bard, & Fleury, 1996; Abernethy,

Hanna, & Plooy, 2002; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002; Gage, Sleik, Polych, McKenzie, & Brown, 2003). Most of these studies included other groups apart from healthy young adults and the difference in gait velocity caused by dual tasking was used to distinguish healthy individuals from clinical groups.

Gait speed was the most commonly reported gait parameter showing the effects of dual task methodology in healthy older adults. This is because gait speed is used as a measure of functional performance that is used to predict falls (Hardy, Perera, Roumani, Chandler, & Studenski, 2007; Palombaro, Craik, Mangione, & Tomlinson, 2006). Older adults reduced their gait velocity and also showed a decline in secondary task performance in response to dual task condition (table 1) (Coppin, Shumway-Cook, & Saczynski, 2006; Bloem et al., 2001; Bootsma-van der Weil et al., 2003; Shkuratova et al., 2004; Faulkner, Redfern & Rosano, 2006; Verghese, Kuslansky, & Holtzer, 2007; Hausdroff, Schweiger, Talia, Yogev-Seligmann, & Giladi, 2008). Most of these studies also observed an increase in stride time variability, stride length variability, cadence variability and decrease in step length apart from reduced gait velocity and decline in secondary task performance in healthy older adults due to the dual tasking paradigm (Beauchet, Kressig, Najafi, Aminian, Dubost, & Mourey, 2003; Brown, de Bruin, Doan, & Suchowersky, 2009; Chong, Chastan, Welter, Do, 2009; Delval, Krystkowiak, Delliaux, Dujardin, Blatt, Destee, 2008; Hackney & Earhart, 2009; Lindenberger et al., 2000; Dubost, Kressig, & Gonthier, 2006; Hollman, Kovash, Kubik, & Linbo, 2007; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). Dual tasking costs increase with aging. Older adults demonstrated decline in cognitive task performance, reduced gait speed, and a greater number of missteps when walking over a narrow route through a complex course (Lindenberger et al., 2000). It is not surprising to see that the effects of dual tasking in gait are more deteriorating in older adults because with increasing

age neuroanatomical and neurophysiological changes occur in the brain especially in areas associated with executive function and attentional resources (Crawford et al., 2010). Because the gait control and executive function share the same subset of neural networks, the strong deleterious effect on executive function is observed in the form of higher dual tasking costs in older adults (Harada, Miyai, Suzuki & Kubota, 2009; Suzuki, Miyai, Ono, Konishi, Kochiyama, & Kubota, 2004).

Table1: Dual tasking in gait studies

<u>Article</u>	<u>Subjects</u>	<u>Dual task used</u>	<u>Effects on gait in healthy young and healthy older adults only unless stated otherwise</u>
Abernethy et al., 2002	Healthy young(HY)	Response to a visual stimuli	No effect on gait
Al-Yahya et al., 2009	HY	Serial 7 subtractions	Increase in step width, stride length and stride length variation remained the same
Beauchet et al., 2003	HY, Healthy Old(HO)	Counting backward by 1	Only the older participants showed increase in stride length variability and speed variability
Beauchet et al., 2005	HY	Counting backward by 1	Reduced speed, increase in stride time and stride time variability, no difference in stride length and stride length variability
Bloem et al., 2001	HY, HO	Walking through obstacles, holding a tray	Motor errors increased with the complexity of the task. Younger subjects gave higher priority to motor task over cognitive task

Bootsma Van der Weil et al., 2003	HY, HO	Verbal fluency	Affected gait in both the groups
Brown et al., 2009	HO & people with Parkinson's disease	Serial subtractions by 3	Older adults showed decrease in speed and stride length
Catena et al., 2007	HY, people with concussion	Counting backward by 1, Spelling backward, reciting in reverse	Reduction in speed, step with and step length remained the same
Catena et al., 2009	HY, people with concussion	Serial 7 subtractions, Spelling backward, reciting in reverse	Decrease in COM velocity in A-P direction only in clinical group
Chong et al., 2009	HY, HO	Serial 7 subtractions	Speed and step length decreased only in older participants
Coppin et al., 2006	Community dwelling elderly	Walking while talking, walking while picking up an object, carrying a large package, walking over obstacles, walking while wearing a weighted vest	Subjects with low EF measures walked slower while walking over obstacles and while walking and picking up an object
Delval et al., 2008	HO & people with Huntington's disease	Serial subtractions by 2 or 3	Increase in speed variation, stride length variation, cadence variation
Ebersbach et al., 1995	HY	Memory task, Fine motor (opening & closing buttons), combination of both the tasks, Finger tapping	Reduction in gait speed only due to finger tapping task
Faulkner et al., 2006	Community dwelling elderly	Reponse to an auditory stimuli, visuospatial decision task	Reduced gait velocities
Gage et al., 2003	HY, HO	Verbal response to an auditory stimulus	No effect on gait
Galletly and Brauer,	HO & people with	Serial subtractions by	Reduction in speed,

2005	Parkinson's disease	3	stride length and cadence
Hackney and Earhart, 2009	HO & people with Parkinson's disease	Serial subtractions by 3, 4 or 6	Reduction in speed, stride length, swing time and cadence. Increase in stance time, step width and gait asymmetry
Hartmann et al., 2009	HO	Serial subtractions by 3	Reduction in speed, cadence and step length. Increase in step time and step length variation
Hausdorff et al., 2003	People with Parkinson's disease	Serial 7 subtractions	Increase in gait variability
Hausdorff et al., 2008	HO	Serial 7 subtractions, phoneme monitoring	Gait speed and swing time decreased, swing time variability increased
Hollman et al., 2007	HY, HO	Spelling backward	Speed reduced in both the groups, but stride velocity variability increased in older participants
Laessoe et al., 2008	HO & community dwelling older adults	Serial 7 subtractions	Reduction in speed
Lajoie et al., 1993	HY	Response to auditory stimuli	No effect on gait
Lajoie et al., 1996	HY,HO	Response to auditory stimuli	No effect on gait in HY. HO walked slower
Li et al., 2001	HY, HO	Memorization task	Reduction in gait speed. Dual task costs were more in older adults
Lindenberger et al., 2000	HY, Healthy Middle Aged, HO	Memorization task	Reduction in gait speed increased with age
Morris et al., 1996	HO & people with Parkinson's disease	Reciting in reverse	Reduction in speed, stride length and cadence
O'Shea et al., 2002	HO & people with Parkinson's disease	Serial subtractions by 3	Reduction in stride length and speed
Paquette et al., 2008	HY	Serial subtractions by 3	Reduction in speed
Parker et al., 2005	HY & people with	Counting backward	Reduction in speed,

	concussions	by 1, reciting in reverse, spelling backward	stride length and increase in stride time
Priest et al., 2008	HY,HO	Serial subtractions by 3, 4 or 6	Reduction in speed and increase in stride velocity variability
Shkuratova et al., 2004	HY, HO	Transferring coins from right pocket to left pocket	Decrease in stride length and increase in cadence
Sparrow et al., 2002	HY, HO	Response to auditory stimuli, response to visual stimuli	No effect on gait
Springer et al., 2006	HY, HO and Elderly fallers	Serial 7 subtractions, Listening to text, Listening + Phoneme monitoring	Reduced gait velocity in all three groups. In addition increased gait variability was observed in elderly fallers
Van Iersel et al., 2007	HO	Serial 7 subtractions, serial 13 subtractions, verbal fluency	Reduced gait velocity, increased stride variability
Verghese et al., 2007	HO	Recitation of alternate letters of the alphabets	Reduced gait velocities were observed in subjects who preferred the cognitive task over gait
Weerdesteyn et al., 2003	HY	Auditory stroop test	Increase in number of errors while avoiding obstacles
Yogev et al., 2005	People with Parkinson's disease, HO	Serial 7 subtractions, Listening to text, Listening + Phoneme monitoring	Reduced gait velocity in both groups. In addition increased gait variability was observed in people with PD
Yogev et al., 2006	People with Parkinson's disease, idiopathic fallers, HO	Serial 7 subtractions	Gait asymmetry increased significantly for people with PD and idiopathic fallers but not healthy older subjects

2.11 Secondary cognitive tasks

The complexity of the secondary task involved with walking has tremendous influence on the dual task performance. For example, responding to an auditory stimulus during gait did not reduce the gait velocity (Lajoie et al., 1993) but counting back from 50 reduced the gait speed and increased the stride time variability (Beauchet et al., 2005). A variety of secondary tasks have been used in these studies to show the effects of dual task paradigm on gait (Table 1). However there is no agreement concerning the secondary task that can be considered as gold standard in dual task paradigm. This is one of the issues with the current research. There is a lack of standardization in dual task paradigm and a consensus needs to be reached on the research protocol.

The cognitive tasks employed in these studies can be categorized into five general domains based on cognitive level (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2010). Reaction time tasks involve measuring the time taken for behavioral response to a sensory stimulus (Strauss, Sherman, & Spreem, 2006). These task results are used as processing speed measures, where a low processing speed implies an attentional deficit (Lezak, 1995). Discrimination and decision making tasks are used to measure the ability to select information for processing while blocking unnecessary stimulus information (Al-Yahya et al., 2010). They are used as a measure for selective attention. Mental tracking tasks measure the ability to hold information in the mind and also manipulate that information. The results of this task are used as a measure of sustained attention and information processing speed (Lezak, 1995). Short-term memory tasks involve the ability to hold information in the mind without performing any mental process. Verbal fluency tasks involve recitation of words of a particular category spontaneously. The results of this task are used as measures for executive functions (Lezak, 1995).

Al-Yahya et al. (2010) reported that among the five different cognitive tasks used in gait studies with a dual task paradigm, the tasks involving internal interfering factors disturbed the gait parameters more than external interfering factors. The tasks involving internal interfering factors are mental tracking, verbal fluency where no external stimulus is involved to generate a response. It is likely that these cognitive tasks require the same subset of higher complex neural networks as gait, resulting in greater interference that disturbs gait (Fuster, 2008; Gazzaley & D'Esposito, 2006). The tasks involving external interfering factors are reaction time tasks and discrimination and decision-making tasks which need external stimulus. Processing of these tasks is stimulus driven that involves lower order neural networks that are shared with gait control (Fuster, 2008). Therefore there is less interference in gait due to these tasks.

It was reported that in healthy participants (healthy young and healthy older adults) age and mini mental exam score (MMSE) were associated with dual task interference of mental tracking tasks effect on gait speed (Al-Yahya et al., 2010). So in other words the effects of mental tracking task on gait speed increased with increasing age or decreasing MMSE score in healthy participants. Mental tracking tasks were also observed to increase stride time variability more than other secondary cognitive tasks in healthy participants (Al-Yahya et al., 2010). In the review of articles on dual tasking with gait, serial 7 subtractions was the most commonly used secondary cognitive task. It is a mental tracking task that involves internal interfering factors (Al-Yahya et al., 2010). Serial 7 subtractions involves counting backwards by 7. This task has been suggested for challenging the attentional capacities, especially the ability to sustain attention (Lezak, 1995). The serial 7 subtraction task was observed to reduce gait velocity in healthy young and healthy older adults (Van Iersel et al., 2007), and have additional effects like increased gait variability in elderly fallers (Springer et al., 2006). Hence serial 7 subtractions may be considered as an effective secondary cognitive task to challenge the attentional capacities and influence gait. Therefore this task may be used to examine the role of attention in steering. It

would be expected that if steering requires deliberate attention, then performing serial 7 subtractions task simultaneously should cause interference in steering and disrupt steering performance.

CHAPTER 3: METHODOLOGY AND RESEARCH APPROACH

3.1 Participants

The proposed study involved a one-time visit to the Stanley E Fulton Biomechanics and Motor Behavior Laboratory in the University of Texas at El Paso for no more than two hours. Twenty five healthy young volunteers (13 male and 12 female) between the ages of 18-30 years were recruited from the University of Texas at El Paso campus. Nineteen healthy older adults (9 male and 10 female) over the age of 65 were recruited by displaying flyers in public places around the El Paso county area. The experiment had two groups: participants between the ages of 18-30 were assigned to healthy young adults group and participants over the age of 65 were in the healthy older adults.

All the participants were screened for their turn preference (step turn versus spin turn). Participants with preference for spin turning were not included in the study because the most prevalent turn type is step turning (Patla et al., 1991). A general health questionnaire (Goldberg & Williams, 1988) was administered prior to inclusion in the study to ensure healthy volunteers were free of any neurological disorders (e.g. vertigo and hearing disorders) and did not have any medical conditions that could put them at increased risk by participating in the study (e.g. heart conditions). The study was entirely and exclusively conducted on the University of Texas at El Paso campus and no outside sites or agencies were involved.

The sample size was determined using G power 3.1 with a set α level of 0.05, with a medium effect size (0.25) determined from prior research findings (Ambati et al., 2013; Reed-Jones et al., 2009a; Reed-Jones et al., 2009b; Springer et al., 2006; Shkuratova et al., 2004; Dubost et al., 2006), with a desired β of 0.20 and a correlation value among the dependent variables of 0.50 (Reed-Jones et al., 2009a). The sample size determined can also be supported

using the sample size table for repeated measures (Stevens, 1992). The effect size due to dual tasking in gait variables varied from low to high values in different gait variables and populations (Springer et al., 2006; Shkuratova et al., 2004; Dubost et al., 2006). All the gait variables were considered for the assessment of gait stability. The effect sizes observed in previous steering studies that used the same dependent variables as this project were very large (Ambati et al., 2013; Reed-Jones et al., 2009a; Reed-Jones et al., 2009b). Although these studies had different interventions, the dependent measures recorded were intended to assess postural stability, akin to the current study. Since the effect size varied from high to low values in gait studies for different gait variables and it was relatively high for all the variables in steering studies, a conservative effect size (medium) was used to determine the sample size (Cohen, 1992).

3.2 Study design

The design of the study was an ABCA-ACBA control group design where the independent variables were task condition and age group. We used a control group (younger adults) and an experimental group (older adults) to determine the effects of age group on the dependent variables. A common weakness of a control group study design is a possible pre-test intervention interaction, which was not applicable in this experiment. Pre-test intervention interaction is the awareness created in the participants due to the pre-test that somehow enhances the dependent variables later (Cottrell & McKenzie, 2011). However in this experiment the pre-test condition was the baseline condition which did not create any awareness about the next condition that was administered. To determine the effects of task condition on the dependent variables the participants in each group performed the following. There were three types of activities involved: the baseline condition (A) represents walking and turning 90°, dual task

condition (B) represents walking and turning 90° while reciting serial 7 subtractions out loud. Task condition C involved performing serial 7 subtractions out loud while sitting (C). This was administered to obtain the serial 7s score that was used as a covariate in the statistical analysis. The possible threats to internal validity that might affect the dependent variables were fatigue and testing effect (Cottrell & McKenzie, 2011). The possible variance in the dependent variables could arise from the fatigue caused by the numerous walking trials. The participants in the experiment were instrumented with reflective markers and an eye tracker that was attached to the head that might cause anxiety. This anxiety might have affected the dependent variables in the first few trials before the participants got used to walking with the instruments attached to their bodies. To control for the effects of these extraneous variables (fatigue and testing effect) we used an ABCA-ACBA design. However the task condition B involved performing serial 7 subtractions while walking and turning and the task condition C involved performing serial 7 subtractions in single task condition. Therefore performing B before C or performing C before B might cause a practice effect on the later condition. In order to control for practice affects, the order of the tasks: baseline condition (A), dual task condition (B), and single task of serial 7 subtractions (C) were counterbalanced between the research participants. We controlled for extraneous factors fatigue, testing effect and practice effect using an ABCA study design that was counter balanced between the participants. Half of the participants in each group performed the trials in the ABCA order, and the other half performed the trials in ACBA order.

3.3 Variables

3.3.1 Dependent variables

- Eye reorientation onset measured with respect to turn onset
- Head reorientation onset measured with respect to turn onset

- Trunk reorientation onset measured with respect to turn onset
- Pelvis reorientation onset measured with respect to turn onset
- Time taken to turn

3.3.2 Independent variables

- Task condition (Baseline, Dual task)
- Age group (Healthy young, healthy old)

3.3.3 Covariate

- Serial 7s score

3.4 Measures and instrumentation

Three dimensional kinematic data was collected at 120 Hz using a Vicon motion capture system (Vicon, San Francisco, California). Participants had reflective markers attached to the head (via a headband), trunk, pelvis and feet segments (taped to the front of the participant's shirt and shoes). Movements of the head, trunk and pelvis were captured by eight high resolution cameras. Each camera has a ring of LED strobe lights fixed around the lens. As the subject moves through capture volume light from the strobe is reflected back into the camera lens and strikes a light sensitive plate creating a video signal. These cameras capture a 3 dimensional image of the subject's position in space. This data was used to calculate the kinematics of the body during walking and turning trials in normal ambient lighting. The movement trajectories of all the body segments obtained from VICON motion capture system were processed to determine their respective turn onsets (milliseconds). The marker data were used to determine the heel strikes of the ipsilateral foot before and after the turn stride to determine the time taken to turn (milliseconds).

Eye movement was recorded using the ASL Eye Tracker system (Applied Science Laboratories, Bedford, MA, USA). This system requires the participants to wear a headband that has a small camera attached to the top. A reflective acrylic surface is mounted to the headband which sits just below the participant's left eye (not occluding vision). The small camera uses this reflective surface to capture the image of the left eye and does not capture other structures on the face. The head band also has a head mounted scene camera that provides a head-oriented view of the environment. Raw analog data regarding vertical and horizontal eye position were recorded via analog to digital conversion directly into the Vicon data capture. This setup allowed time synchronization of the kinematic and eye tracking data.

Calibration of eye-in-scene involved a 9-point eye calibration matrix while eye-in-head calibration involved a vestibular ocular reflex (VOR) trial. In the VOR calibration the participants were asked to fixate their gaze to a central point displayed on the screen in front and rotate their head at their own pace: up, down, left and right. A linear regression of raw eye position versus head position was used to convert eye data to eye-in-head coordinates. The movement trajectories for the eyes were further processed to determine the turn onset (milliseconds).

3.5 Procedures

The following procedure was used to collect data on healthy young adults and healthy older adults. After receiving the informed consent, the participants were administered with the general health questionnaire (Goldberg & Williams, 1988). Reflective markers were attached to various land marks on the body and the eye tracking system was fitted on the participant. After the participants were equipped with the markers and eye tracker before starting the experimental trails the participants walked on a straight path with a maximum length of 5 meters (5 trials). The

information from the straight path walking trials was used during data reduction to process the experimental trials and determine the turn onsets (dependent variables). The straight path walking trials were only meant for data reduction and were not a part of the experimental trials.

The experimental trials mainly involved walking along a straight path and redirecting the walking trajectory to the right or left (90°) around a marker placed in the center of the walk way in different task conditions. The turn direction does not affect the turn onsets of different body segments in healthy adults (Ambati et al., 2013), which is why turn direction was not considered for analysis. But to control for any unknown effects due to turn direction we used both right (5 trials) and left turns (5 trials) randomized within each task condition. The participants performed three types of activities: in the baseline condition (A) the participants walked and made a 90° turn; in the dual task condition (B) the participants walked and made a 90° turn while performing serial 7 subtractions out loud; in the single task serial 7 subtractions condition (C) the participants performed the serial 7 subtractions out loud for 45 seconds while sitting, which was approximately the same amount of time taken to finish the walking and turning task. The numbers assigned for serial 7 subtractions were produced using the random function (RAND()) in Microsoft Office (2013) excel spreadsheet before the participant arrived. The score on the single task serial 7 subtractions (C) was be used to control for the differences in the participants' individual ability to perform the serial 7 subtractions. Evaluation of performance on serial 7 subtractions (C) was obtained by subtracting the number of mistakes from the number of subtractions made in the given time. In the dual task condition (B) the participants were asked to perform serial 7 subtractions out loud while walking and tuning to ensure that they were complying with the conditions of the task.

We administered the experimental trials as per the research design, which was ABCA-ACBA in each group. Therefore half of the participants in each group performed the trials in the following order: (1) baseline (10 trials); (2) dual task (10 trials); (3) Serial 7 subtractions; (4) baseline (10 trials). The other half of the participants in each group performed the trials in the following order (1) baseline (10 trials); (2) Serial 7 subtractions; (3) dual task (10 trials) (4) baseline (10 trials). The participants were instructed to walk at their normal pace on the level ground under each condition. The instructions for the dual task condition (B) were to walk and make a 90^0 turn at a comfortable pace while performing the serial 7 subtractions out loud. No instruction for priority of one of the tasks was given.

3.6 Data reduction

Analysis of segment displacement was focused on rotations about the yaw axis (vertical axis). The five straight trials (STRAIGHT) were windowed and ensemble averaged together to create control trajectory movement profiles for the eye, head, trunk, and pelvis during normal straight walking. Rotation responses of the eyes and other body segments during turning were then analyzed with respect to the control profiles. A conservative two standard deviation (2SD) boundary of the control trajectory was used to calculate the segment rotational responses. Thus, rotation responses of body segments were recorded provided that the movement trajectory deviated beyond two standard deviations of the control walking profile and continued towards the turning direction of instruction (right or left). A Matlab code was used to determine the exact frame where the movement trajectory for each segment started deviating in the new travel direction.

3.7 Statistical design

Mixed model ANOVA was used to determine the interaction effect of both the independent variables task condition and age group on the turning time. A significant interaction effect of the task condition and age were further analyzed by testing the effects of age on turning time in the baseline and dual task conditions. Since the two groups were significantly different the effects of the task condition on the turning time were analyzed for the two age groups independently using repeated measures ANOVAs.

Mixed model MANOVA was used to determine the interaction effect of both the independent variables task condition and age group on the turn onsets of the eyes, head, trunk and pelvis. A significant main effect of age on the turn onsets were further analyzed by testing the effects of age on the turn onsets of the eyes, head, trunk and pelvis in the baseline and dual task conditions. Since the two groups were significantly different the effects of the task condition on the turn onsets of the eyes, head, trunk and pelvis were analyzed for the two age groups independently using repeated measures MANOVAs. Pair wise comparison for significant effects of the task condition on each variable was determined when significant overall effect was observed.

Since the covariate did not have linear relationships with any of the dependent variables it was not included in the analysis.

CHAPTER 4: RESULTS

This dissertation explored the effects of performing serial seven subtractions on steering in healthy young adults and healthy older adults. Data collection occurred from February 1, 2014 to April 10, 2014 at the Stanley E Fulton Biomechanics and Motor Behavior Laboratory in the University of Texas at El Paso. The motion capture data was processed using work station software (Vicon, San Francisco, California) and analyzed using SPSS software Package 2.0. The purpose of this dissertation was to determine whether steering requires attention or whether it is an automatic motor synergy requiring minimal cognitive influence. This project also sought to determine the effect of age on the attentional demands required by steering. The aims were rearranged to organize the results as per the statistical analysis.

The aims of the research were:

Aim 1: Determine if aging influences steering.

Aim 2: Determine if dual tasking influences steering in healthy young and healthy older adults.

The study involved a one-time visit to our laboratory for no more than two hours. Twenty six healthy young volunteers (13 males and 13 females) were recruited from the University of Texas at El Paso campus. Twenty six healthy older adults (13 males and 13 females) were recruited from the Golden age program at the Ross Moore Building in UTEP and also by displaying flyers in public places around the El Paso county area. A general health questionnaire (Goldberg & Williams, 1988) was administered to all the participants to ensure that they did not have any neurological disorders or medical condition that could put them at increased risk by participating in the study (e.g. heart conditions). Data collected from one young female participant and two older adults (one male and one female) were dropped due to technical issues in the lab the resulted in data corruption. Two older adults (male) refused to participate due to the

numerous walking trials involved in the experiment. Three older adults (two female and one male) could not complete the experiment as they were fatigued from standing while being prepared for the experiment (marker attachment and eye tracker calibration). All the data analysis used a total sample size of 44. Twenty five younger adults with a mean age of 22.9 ± 2.9 years (12 female and 13 male) and nineteen older adults with a mean age of 72.1 ± 5.3 (10 female and 9 male) completed the experimental protocol successfully. Table 2 describes the demographics for the healthy young and healthy older adults included in the study.

Table 2: Average age, weight and height for the two age groups

Age Group(N)	Age	Weight(kg)	Height(cm)
<i>Young</i>			
Female(12)	22.0 \pm 2.7	60.7 \pm 10.1	162.3 \pm 5.8
Male(13)	23.8 \pm 2.8	89.4 \pm 15.2	178.8 \pm 6.1
Total(25)	22.9 \pm 2.9	76.2 \pm 19.6	170.4 \pm 10.9
<i>Old</i>			
Female(10)	70.7 \pm 3.7	65.9 \pm 9.9	162.3 \pm 8.3
Male(9)	73.4 \pm 6.3	80.9 \pm 9.5	175.3 \pm 6.6
Total(19)	72.1 \pm 5.3	70.4 \pm 10.5	167.1 \pm 9.1

4.1 Experimental design

An ABA design was used to assess the effects of the dual task on steering in healthy young and healthy older adults. Baseline conditions were administered before and after the dual task condition for all the participants to control for the threats to internal validity such as fatigue, testing and practice effects. Results of the analysis on turning time during the baselines and dual task conditions are depicted in figure 4. Upon visual inspection of the group performance the groups showed they were quicker in turning during the two baseline conditions and much slower

during the dual task condition. This performance for both groups indicates that variables such as learning and fatigue did not influence performance and thus these variables did not threaten internal validity.

The effect size of the dual task condition compared to the baseline conditions before and after was computed. Each data point represents mean turning time per group per trial. We considered three random trials from each condition (baseline before, dual task and baseline after) for analysis to identify any possible effects of extraneous variables. Standard mean difference was used as a source to determine the effect size (Dunst, Hamby & Trivette, 2004). In healthy young adults a 39.8 standard deviation advantage was found in the turning time in the dual task condition when compared to baseline before, and a 34.77 standard deviation advantage was found in turning time in the dual task condition when compared to baseline following the dual task condition. This indicates large effect in turning time in the dual task condition in healthy young adults. In older adults, a 16.5 standard deviation advantage was found in the turning time in the dual task condition when compared to baseline before, and a 23.04 standard deviation advantage was found in turning time in the dual task condition when compared to baseline following the dual task condition. This large effect size indicates that the dual task also increased the turning time in older adults as well.

This analysis was conducted to indentify threats to internal validity due to fatigue and learning effects. Since there were no measurable effects of fatigue and leaning, the following analysis across groups was accomplished. This analysis shows that the healthy young and older groups turning times were increased as a function of the dual task condition. The return to baseline following the introduction of the dual task showed the negative influence of the dual task on the turning time across both groups of the participants.

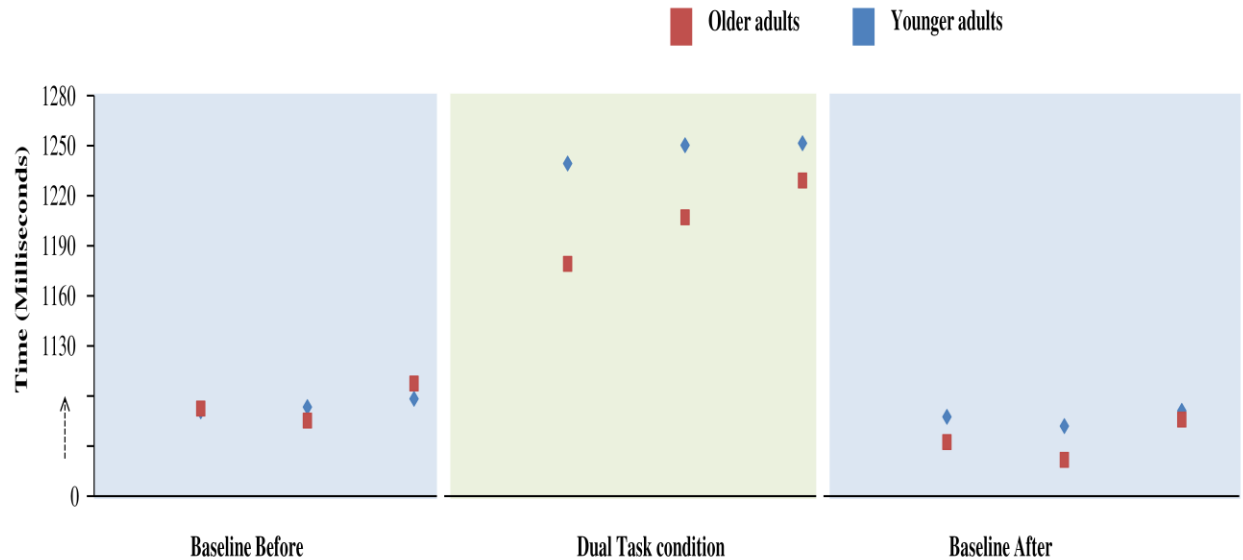


Figure 4: ABA design

Notes: Total time taken to complete the turn in healthy young (Blue) and healthy older adults (Red) in baseline before (BB), dual task (DT) and baseline after conditions (BA). The data points represent the average turning time per trial per group. ABA design was used to control for extraneous factors like fatigue, testing and practice effects.

Since the two baseline conditions were not statistically different, they were collapsed for further analysis. Therefore for remaining analyses the independent variable ‘task condition’ had two levels: Baseline condition and dual task condition.

4.2 Turning time

4.2.1 Effects of age and task condition on turning time

A MIXED model ANOVA (2 groups x 2 conditions) tested the effects of the within-subjects factor task condition and the between subjects factor age together on the turning time. There was a significant interaction effect of task condition and age on the turning time based on the multivariate test of significance (Pillai’s test) ($F(1,42)=6.419$, $p=0.015$, $\eta^2=0.127$). This indicates that the dual task condition affected the turning time differently in the young and older adult groups.

Based on this result, analysis of age difference in each of the task conditions was examined independently. First, the test for the effects of age on turning time in the baseline condition was performed. The effects of age on the turning time in the baseline were determined using a one way ANOVA with age as the independent variable containing two levels (healthy young and healthy old). The analysis revealed no significant difference in the turning time due to age between healthy young and healthy older adults in the baseline condition ($F(1,42)=0.116$, $p=0.734$) (see Figure 5). Levene's test of homogeneity of variances indicated no significant difference in the variances across the groups ($p=0.508$).

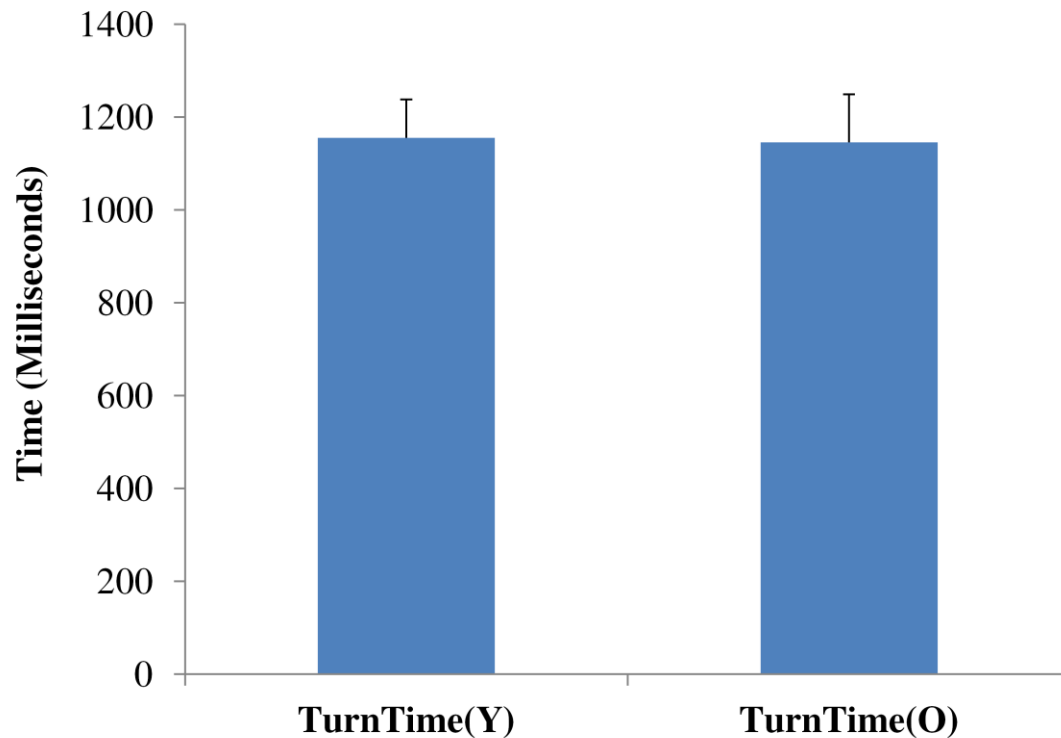


Figure 5: Turning time for younger adults and older adults in the baseline condition

Second, the effect of age on turning time in the dual task condition was examined. The effects of age on the turning time in the dual task condition were determined using one way ANOVA with age as the independent variable containing two levels (healthy young and healthy

old). The analysis revealed a statistically significant difference due to age in the turning time between healthy young and healthy older adults in the dual task condition ($F(1,42)=4.816$, $p=0.034$) (see Figure 6). Levene's test of homogeneity of variances indicated no significant difference in the variances across the groups ($p=0.074$). This result indicates that the younger adults took a greater amount of time to turn when compared to the older adults in the dual task condition.

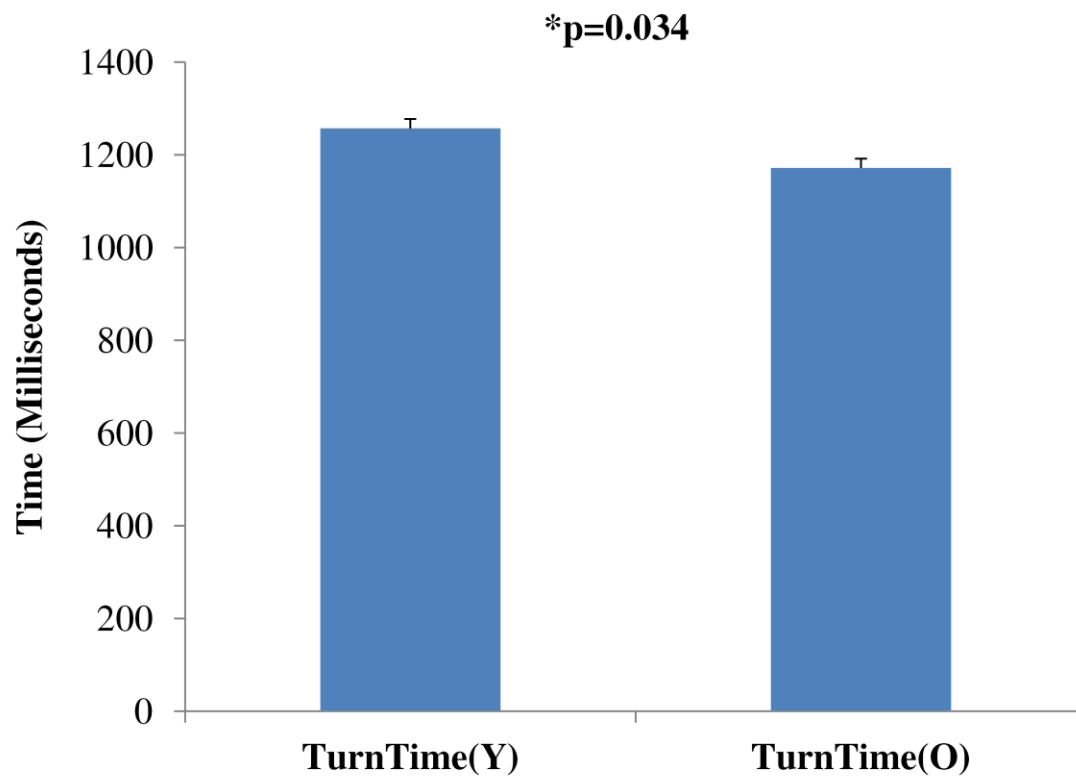


Figure 6: Turning time for younger adults and older adults in the dual-task condition

Since the dual task condition affected turning time differently in healthy young and healthy older adult groups the effects of task condition were analyzed separately for the two groups.

4.2.2 Effects of task condition on turning time in healthy young adults

Repeated measures ANOVA with one within-subjects factor ‘task condition’ was used to determine the effects of the dual task condition on the turning time in healthy young adults. There was a significant main effect of the within-subjects variable task condition on the turning time based on the multivariate test of significance (Pillai’s test) ($F(1,24)=16.633, p<0.001, \eta^2=0.409$). This shows that the dual task condition increased the turning time in younger adults.

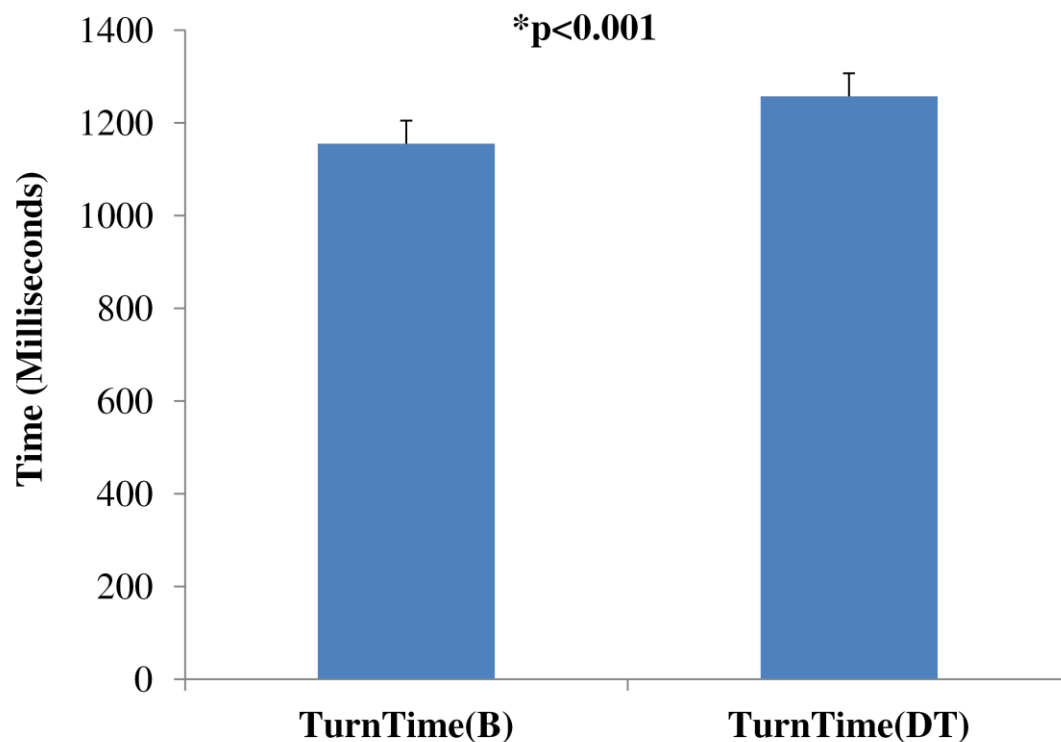


Figure 7: Turning time for younger adults in baseline condition and dual task conditions.
Notes: Turning time was calculated as the difference in time between the heel contacts of the ipsilateral foot in the turn stride.

4.2.3 Effects of task condition on turning time in healthy older adults

Repeated measures ANOVA with a within subjects factor ‘task condition’ was used to determine the effects of the dual task condition on the turning time in healthy older adults. There was a significant main effect of the within-subjects variable task condition on the turning time

based on the multivariate test of significance (Pillai's test) ($F(1,18)=4.678, p=0.049, \eta^2=0.180$).

This shows that the dual task condition increased the turning time in the older adults.

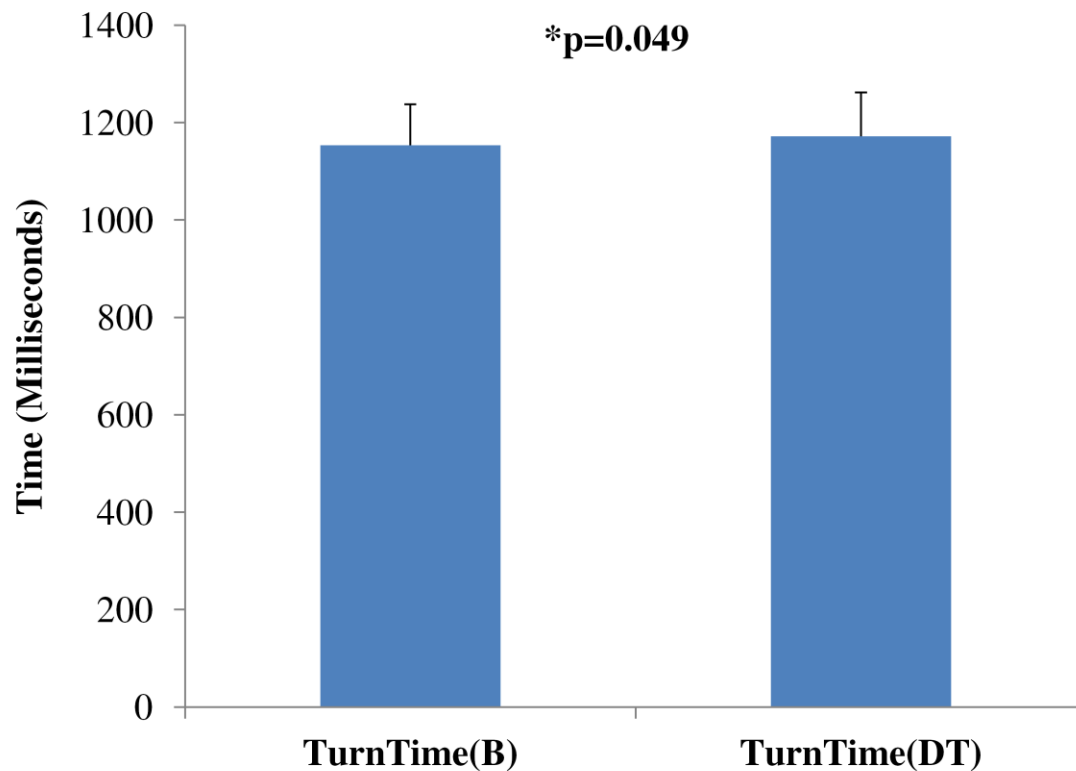


Figure 8: Total time taken to complete the turn for older adults in the baseline condition and dual task conditions.

Notes: Time to turn was calculated as the difference in time between the heel contacts of the ipsilateral foot in the turn stride.

4.3 Turn onsets of the eyes, head, trunk and pelvis

4.3.1 Effects of age and task condition on turn onsets of the eyes, head, trunk, pelvis

A MIXED model MANOVA (2 groups x 2 conditions) was used to test the within-subjects effects of the independent variables Task condition and age interaction on the turn onsets of the eyes, head, trunk and pelvis. There was no significant interaction effect of task condition and age on the turn onsets of eyes, head, trunk and pelvis based on the multivariate test of significance (Pillai's test)($F(4,39)=2.397, p=0.067$). However we observed a significant main

effect of age on the turn onsets of the segments based on the multivariate test of significance (Pillai's test) ($F(4,39)=3.293$, $p=0.020$, $\eta^2=0.252$).

Based on the main effect, we examined the effects of age on the turn onsets of the eyes, head, trunk and pelvis for the baseline condition and dual task conditions independently. Multivariate analysis of variance was used to determine effects of the between subjects variable Age on the turn onsets of eyes, head, trunk and pelvis in the baseline condition. A statistically significant main effect of age on the dependent variables (turn onsets of eyes, head, trunk, and pelvis) in the baseline condition was determined based on the Multivariate test of significance (Pillai's test) ($F(4,39)=5.489$, $p=0.001$, $\eta^2=0.354$). Tests of between-subjects effects revealed significant differences in the turn onsets of eyes ($F(1, 42)=4.625$, $p=0.037$, $\eta^2=0.10$) and turn onsets of trunk ($F(1,42)=4.090$, $p=0.050$, $\eta^2=0.097$). This result indicates that there were significant differences in the turn onsets of the eyes, head, trunk and pelvis due to age in the baseline condition (see Figure 9).

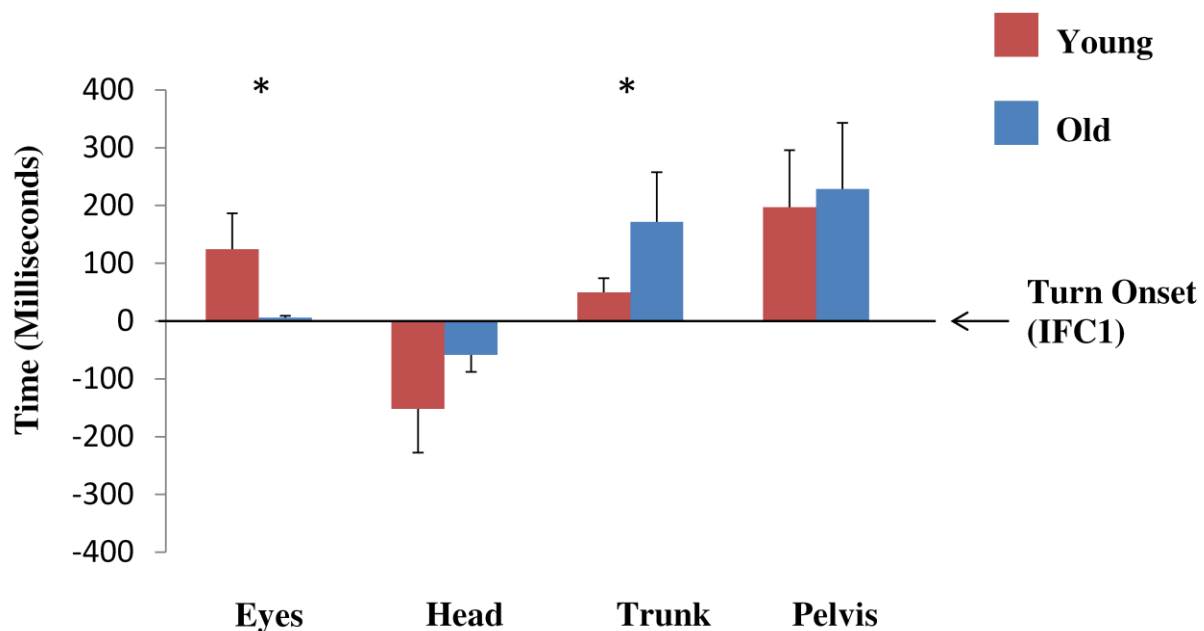


Figure 9: Turn onsets of the eyes, head, trunk and pelvis segments for younger adult and older adult groups in the baseline condition

The effects of the between subjects variable Age on the turn onsets of the eyes, head, trunk and pelvis in the dual task condition was also determined using the Multivariate analysis of variance. Multivariate analysis revealed that there was no effect of age on the turn onsets of the eyes, head, trunk and pelvis in the dual task condition ($F(4,39)=1.383$, $p = 0.258$) (see Figures 8). This indicates that there were no differences in the turn onsets of the eyes, head, trunk and pelvis due to age in the dual condition.

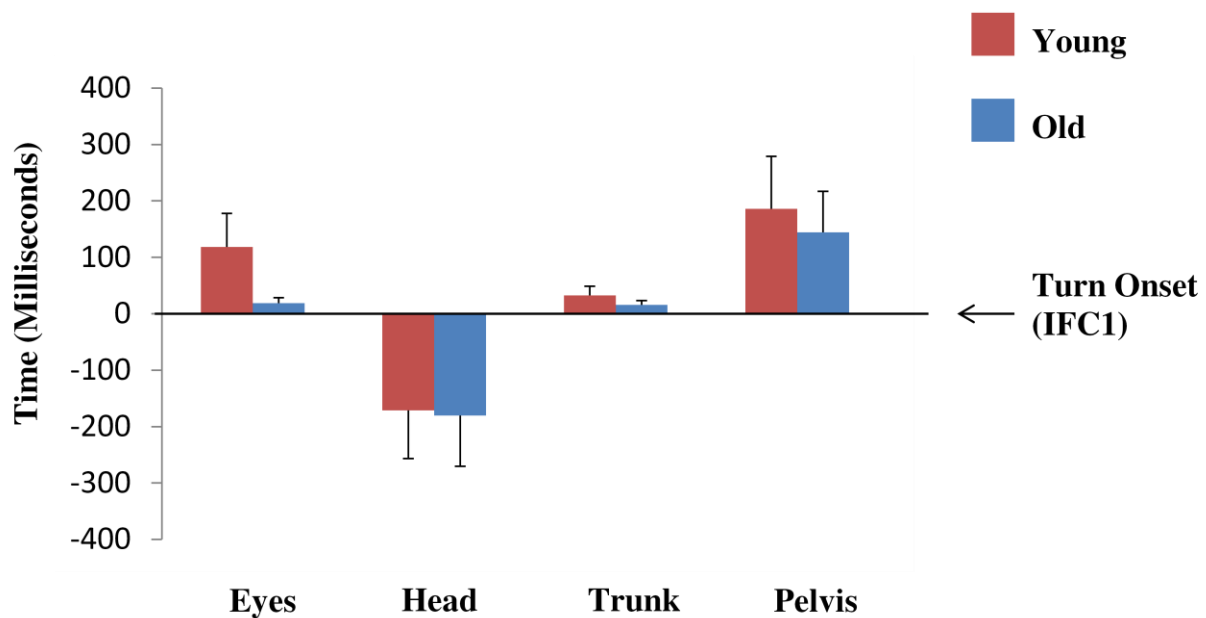


Figure 10: Turn onsets of the eyes, head, trunk and pelvis segments for younger adult and older adult groups in the dual task condition

Since we found a significant main effect of age on the turn onsets of the eyes, head, trunk and pelvis, we performed separate analysis on each group to determine the effects of task condition.

4.3.2 Effects of task condition on the turn onsets in healthy young adults

Repeated measures MANOVA with one within-subjects variable ‘task condition’ was used to determine the effects of the dual task condition on the turn onsets of eyes, head, trunk

and pelvis in healthy young adults. There was no significant main effect of the within-subjects variable task condition on the dependent variables based on the multivariate test of significance (Pillai's test) ($F(4,21)=0.774$, $p=0.555$). Thus the dual task condition did not affect the turn onsets of the eyes, head, trunk and pelvis in younger adults.

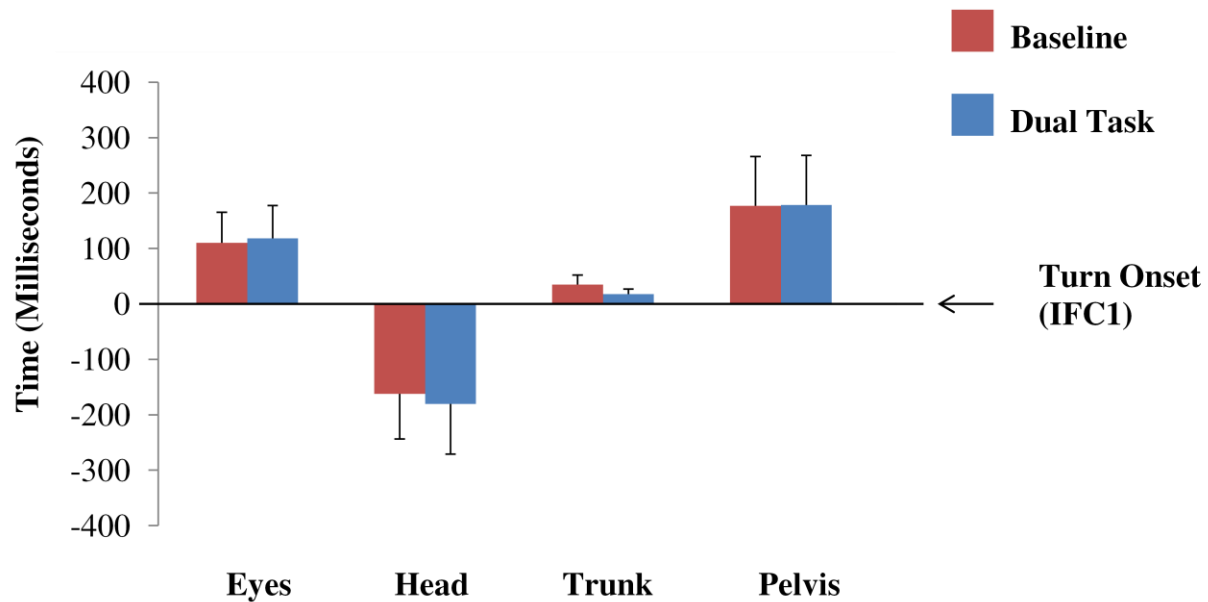


Figure 11: Turn onsets for healthy young adults in baseline and dual task conditions

Notes: A comparison of the sequence and timing of segment reorientation between baseline and dual task conditions in healthy young adults. In the figure, Zero (on Y axis) represents turn onset.

4.3.3 Effects of task condition on the turn onsets in healthy older adults

Repeated measures MANOVA with a within-subject variable Task condition was used to determine the effects of the dual task condition on the turn onsets of eyes, head, trunk and pelvis in healthy older adults. There was a significant main effect of the within-subjects variable task condition on the dependent variables (turn onsets of eyes, head, trunk and pelvis) based on the multivariate test of significance (Pillai's test) ($F(4,15)=5.077$, $p=0.008$, $\eta^2=0.559$). Pair-wise comparisons adjusted for multiple comparisons (Bonferroni) revealed significant differences in the turn onsets of head ($p=0.013$), turn onsets of trunk ($p=0.002$) and turn onsets of pelvis

($p=0.022$). Thus the dual task condition affected the turn onsets of various body segments in the older adult group.

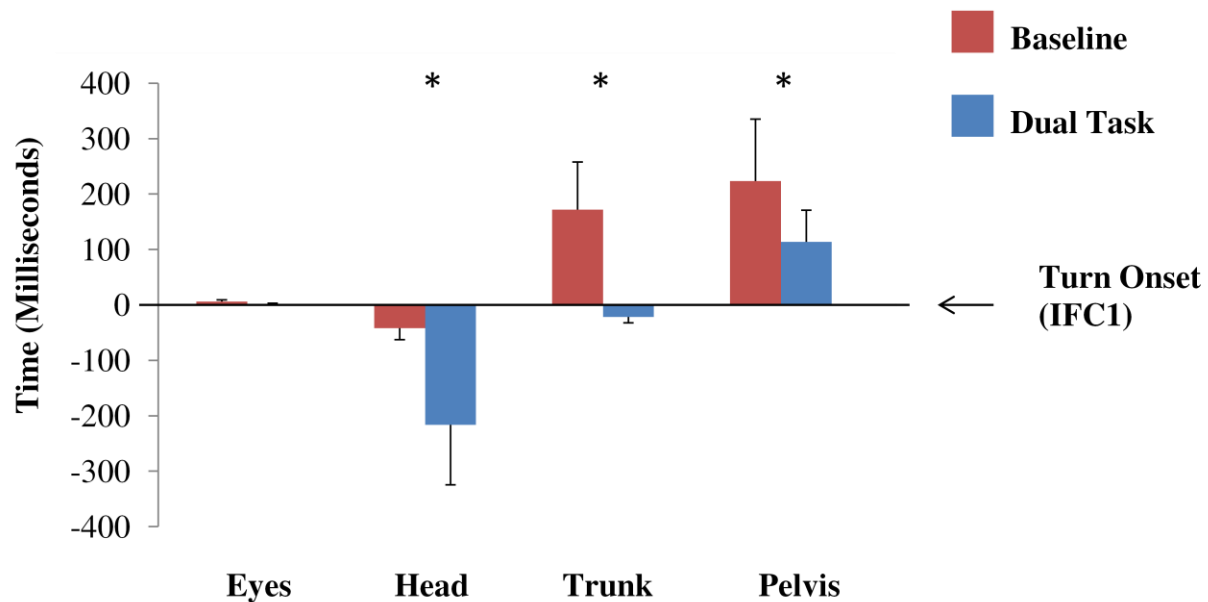


Figure 12: A comparison of the sequence and timing of segment reorientation between baseline and dual task conditions in healthy older adults. The differences between the timing of segment reorientation between the two conditions was statistically significant for head, trunk and pelvis segments (indicated by asterisk)

4.4 Covariate analysis

The serial 7s score obtained from the single task serial 7 subtractions task was supposed to be used as a covariate in the statistical analysis to control for the differences in the participants' ability to perform the serial 7 subtractions while sitting. Before conducting covariate analysis, the covariate (serial 7s score) was checked for the existence of linear relationships with the dependent variables, that is turn onsets of the eyes, head, trunk, pelvis and turning time. One of the assumptions of covariate analysis is that the covariate must have a linear relationship with the dependent variables (Stevens, 1992). Since the serial 7s score was not related to the dependent variables, it was not included in the statistical analysis.

CHAPTER 5: DISCUSSION

5.1 Overview

The purpose of this dissertation was to determine whether steering requires attention or whether it is an automatic motor synergy requiring minimal cognitive influence. This project also sought to determine the effect of age on the attentional demands required by steering. Therefore, the specific aims of the research were (1) to determine if aging influences steering; (2) to investigate the role of attention in steering, using dual task paradigm in healthy young adults and healthy older adults.

The dependent variable ‘Turning time’ was not correlated to the other four dependent variables: Turn onset of the eyes, Turn onset of the head, Turn onset of the trunk and the Turn onset of the pelvis. Hence, the statistical analysis was performed separately for ‘Turning time’ to determine the effects of age, task condition and the interaction effects, followed by similar analysis for the remaining dependent variables: Turn onsets for the eyes, head trunk and pelvis. However, in this chapter, we will discuss steering performance based on all these variables.

It was hypothesized that (1) Turning time and turn onsets of the eyes, head, trunk and pelvis would differ significantly due to age in both the baseline and dual task conditions (2) that healthy young adults would show a significant delay in the turn onsets of the eyes, head, trunk and pelvis without any change in the sequence of body segment reorientation in the dual task condition, as well as an increase in the turning time in the dual task condition (3) that healthy older adults might not only show a delay in the turn onsets of the eyes, head, trunk and pelvis, but that they might also display interruption to the sequence of body segment reorientation, observed through the use of an en bloc turning behavior, when dual tasking. As well it was

expected that older adults would also have an increase in turning time due to the dual task condition.

The hypotheses of this study were partially met. The results indicated that the turning time was affected differently by the dual task condition in healthy young and healthy older adults. It was also observed that the turn onsets of the eyes, head, trunk and pelvis were significantly different in the two groups (healthy young and healthy old) in the baseline condition. Since the two groups were significantly different, the effects of dual tasking on turning time and the turn onsets of eyes, head, trunk and pelvis were studied separately in the two groups.

The results indicate that healthy young adults took significantly longer turning time in the dual task condition when compared to their turning time in the baseline condition. There was no significant difference in the turn onsets of eyes, head, trunk and pelvis due to the dual task condition in healthy young adults. There was also no change in the sequence of body segment reorientation due to the dual task condition. In older adults because attention capacities can be diminished (Milham et al., 2002), we expected to see not only an increase in turning time but also disruption the body segment sequence during the dual task condition, indicating difficulties in dividing attention between two tasks. As expected we observed that older adults did take significantly longer turning time in the dual task condition when compared to that in the baseline condition. The results also showed that most of the body segments (head, trunk and pelvis) reoriented significantly earlier in the dual task condition when compared to their corresponding turn onsets in the baseline condition. However, the older adults also did not show any difference in the sequence of body segment reorientation in the dual task condition.

5.2 Effects of age on steering

In the baseline condition, no significant differences were observed in the turning time for the young and older adult groups (see figure 5). Analysis of turn onsets of the eyes, head, trunk and pelvis revealed significant differences in the turn onsets for the eyes and pelvis segments in the baseline condition (see figure 9). We may notice in figure 9 that the turn onsets of all the body segments occurred relatively early in younger adults. Since these four dependent variables (turn onsets of eyes and other body segments) were correlated, the difference between the two groups became significant when all the variables were taken into account.

In the baseline condition, the turn onsets of the head, trunk and pelvis in older adults occurred later when compared to the corresponding turn onsets in younger adults (see figure 9). However, only the trunk onset timing was statistically different. Trunk muscles play an important role in regulating the acceleration of Center of Mass (COM) in the medial lateral (ML) direction while steering (MacKinnon & Winter, 1993; Winter 1995). Horak and Nashner (1986) described the body as a double pendulum that rotates about the ankle and hip joints. Moving the trunk about the hip joint provides the acceleration needed to translate the COM in ML direction. Using the trunk and hip musculature is the most effective way to control COM behavior (Patla et al., 1999; Hollands et al., 2001). Therefore regulating lateral COM acceleration through the control of trunk movement requires appropriate action of trunk musculature. However, if these muscles are relatively weak then this strategy is not effective. Muscle weakness, reduced sensory functions and slowdown of psychomotor processing are common explanations for locomotor impairment in older adults (Tinetti & Speechley, 1989; van Dieen, Pijnappels, & Bobbert, 2005; Lajoie & Gallagher, 2004). The delayed trunk onset we are observing in older adults may be because of a combination of different reasons mentioned above.

One of the previous studies on executing a 180^0 turn showed that there was no difference in the time taken to complete the turn between healthy young and healthy older adults (Thigpen, Light, Creel & Flynn, 2000). But Thigpen et al., (2000) observed differences in the number of steps taken to complete the turn and the initial stepping strategy used. The authors say that older adults who experience loss of coordination simplify their movements by making them simpler, smaller and slower (Thigpen et al., 2000). This supports the late turn onsets of body segments we are observing in older adults in the baseline condition.

In the dual task condition it was observed that there was no difference in the turn onsets of the eyes, head, trunk and pelvis between younger and older adults (see figure 10). However, the older adults took significantly less turning time when compared to younger adults (see figure 6). There are two potential reasons why there were no significant differences in the turn onset timings but a significant difference in the turning time. The first theory uses the compensatory mechanism used to explain higher frontal lobe activation observed in older adults while performing complex cognitive tasks when compared to younger adults (Reuter-Lorenz, 2002; Grady, 2002). It suggests that due to the structural changes in the brain that develop with aging leading to attentional deficits (Daigneault, Braun & Whitaker, 1992; Mittenberg, Seidenberg, O'leary & DiGiulio, 1989; West, 1996), the older adults recruit additional neural structures as a cognitive strategy to carry out a task. The older adults in this study may have recruited more neural networks than younger adults in the dual task condition that led to similar turn onset timings of different body segments and lesser turning time. Another potential reason is that the older adults who experience decline in the ability to divide attention may have prioritized the motor task over performing the cognitive task. This unconscious strategy to pay more attention to steering might be one of the keys to avoiding hazards and preventing falls in healthy older

adults. This strategy in healthy older adults, may have led to turn onsets similar to younger adults, but a reduced turning time in dual task condition.

One finding of this study that is not consistent with the findings from the gait studies is the time taken to complete the turn or the turning time in the dual task condition. Both the young and older adult groups increased their turning times in response to the dual task condition with respect to their corresponding turning times in the baseline condition. However, the younger adults took significantly longer time to complete the turn in the dual task condition when compared to the older adults. We discussed earlier that the possible reasons for this inconsistency may be due to prioritization of the locomotor task or employing additional neural structures by older adults in response to increased attentional load in the dual task condition. This finding warrants the need for more studies investigating steering. Future studies might want to modify the experimental protocol by including the participant scores on serial 7 subtractions in the dual task condition. These scores might reveal if the older adults were prioritizing the motor task over the cognitive task or if they were recruiting additional neural networks as a cognitive strategy to cope with the dual task condition. Modifying the experimental protocol may be useful in recognizing the exact reason for this inconsistency we observed in the turning time. Future research investigators should also exercise caution while recruiting older adults for this experiment. The older adult group in this study consisted of individuals who were trained in the exercise program at the University of Texas at El Paso campus. Older adults in this group were probably able to deal with increased attentional load because of their training at the University. Therefore we future research should recruit older adults who are not trained to handle dual tasking. They will represent the typical steering behavior observed in older adults who are at risk of falling while steering.

After examining the effects of age on the turning time and the turn onsets of the eyes, head, trunk and pelvis, we determined the interaction effect of age and task condition. There was an interaction effect observed only on the turning time. This means that the dual task condition affected the turning time differently in young and older adults. The turning times increased in both the groups due to the dual task condition, but the younger adults had a longer turning time than the older adults. This does not necessarily mean their performance worsened due to dual task condition. The younger adults in this group may have taken more time to attend to both the tasks and also navigate safely. In the event of an unexpected perturbation, the person who is moving faster will not be able to maintain dynamic balance resulting in a fall. There was no interaction effect of age and task condition on the turn onsets of the eyes, head, trunk and pelvis. However, we observed significant differences in the turn onsets of these segments due to age in the baseline condition which was discussed earlier. Since the two groups were different in the baseline condition, the interaction effect of age and task condition cannot be used to analyze the effects of dual tasking across the two groups. Hence, the effects of dual task condition on the turn onsets of the eyes, head, trunk and pelvis were studied separately in both the groups.

This is the first clinical study to examine the effects of dual tasking on steering in healthy young and healthy older adults. Turning time did not change across young and older adult groups in the baseline condition, but the turning time was affected differently in young and older adult groups by the dual task condition. We observed that aging influenced the turn onsets of eyes, head, trunk and pelvis in the baseline condition. There were no differences in the turn onsets across the young and older adult groups in the dual task condition. Based on the effects of age observed on the turning time and the turn onsets of the eyes, head, trunk and pelvis, we may say that aging influenced steering in this study. Future studies should examine the effects of task

prioritization in healthy groups to understand how they strategize to navigate safely. Future studies might also want to extend this protocol in frail older adults or clinical populations to observe the strategies used in these groups.

5.3 Effects of dual tasking on steering in healthy young adults

The results of the study support our hypothesis that a coordinated redirection of eyes and axial body segments in steering require attention. This is the first study to provide clinical evidence that supports the role of attention in steering in healthy young adults. Using a cognitive task that involved serial 7 subtractions while walking and turning made it possible to examine the role of attention in steering. The healthy young adults took significantly longer to complete the turn in the dual task condition. However, there were no differences in the turn onsets of eyes and other body segments due to dual task condition (see figures 7 and 11). This means that the eyes and other body segments moved significantly slower in the dual task condition relative to the baseline condition.

The potential reason why there was a significant increase in the time taken to turn, but there were no differences in the turn onsets of eyes and other axial body segments in dual task condition, can be explained by discussing the role of attention in steering. The fact that the steering task suffered (increase in turning time) in the dual task condition shows that steering is an attention-demanding task. The interference of these two tasks indicates that they are both complex tasks requiring attention. It would not be meaningful to just say that these tasks interfere with each other. The interference would make more sense when we discuss what the cause of interference was or where in the information processing activities the interference occurred. The cognitive task used in dual task condition involved counting backwards by 7. It is a mental tracking task that is used to measure sustained attention and information processing speed (Al-

Yahya et al., 2010). This task does not involve an external stimulus to generate a response. The primary locomotor task involved is steering (walking and turning 90^0). The participants used an articulated top down control strategy to maintain dynamic stability while steering in the dual task condition (see figure 11). This is one of the two strategies used for balance control in steering (Assaiante & Amblard, 1995). In the case of an articulated top down balance control strategy, the body relies on the gravitational vector in order to stabilize the head and organize the balance working from the head to the feet. Stabilizing gaze provides the body with a stable reference frame for body segment reorientation coordination (Assaiante & Amblard, 1995; Imai, Moore & Raphan, 2001). The other balance control strategy in steering that was ruled out is the en bloc strategy or the bottom up strategy. It was ruled out; because both younger and older adult groups reoriented the head first in both baseline and dual task conditions (see figures 11 & 12). There were also significant intersegment timing differences between head and trunk turn onsets which indicate articulated movement of these segments. In this study, we only observed the top-down balance control strategy during steering in young and older adult groups across both the task conditions.

It may be presumed that early stages of steering, that is body segments reorientation were done without attention, but attention was required at the later stages. Figure 13 shows various stages of information processing in steering, and it is possible that attention may be required from one particular stage in this flowchart. Early stages of information processing do not require attention (Broadbent, 1958; Deutsch & Deutsch, 1963; Keele, 1973; Norman, 1969). Sensory storage is considered the most peripheral, involving translation of sensory information into neurological codes (Schmidt & Lee, 1999). Perceptual analysis involves the process that abstracts some preliminary simple meaning from the sensory stimuli. The next stage is selecting

an appropriate response and then readying a movement for production (Keele, 1973). In the case of steering with serial 7 subtractions, it is possible that the interference was occurring at the perceptual analysis stage. This is because after head reorientation the sensory information (visual and vestibular) obtained was probably being processed in the perceptual analysis stage to obtain an allocentric reference frame that was used to build a coordinated body response. It has been proposed by several scientists that perceptual analysis and later stages require attention (Broadbent, 1958). Since the nature of the cognitive task chosen for the dual tasking condition is such that it requires sustained attention (Lezak, 1995), there was bound to be interference. This resulted in slower movement of the body segments that increased the time taken to turn in the dual task condition.

Until this point, the discussion focused on the interference occurring at the perceptual analysis stage. However, we must also consider the possibility of interference occurring at other stages of the information processing in steering. Some scientists see the perceptual stage as being automatic, with the later stages requiring attention (Deutsch & Deutsch, 1963; Treisman, 1969; Norman, 1969). In such a case, there might be a difference with respect to where the proposed interference occurred in the chain of processes. According to this concept, information processing is attention free till perceptual analysis stage. Therefore, after perceptual analysis of the sensory information obtained from the head reorientation was done, memory contact would have been made for items in related categories or items closely associated with these stimuli. Selective attention further decides which of these memory contacts will receive further processing for subsequent operations like readying a movement for production. It is likely that the interference between the two tasks occurred at this stage and resulted in delayed turning time.

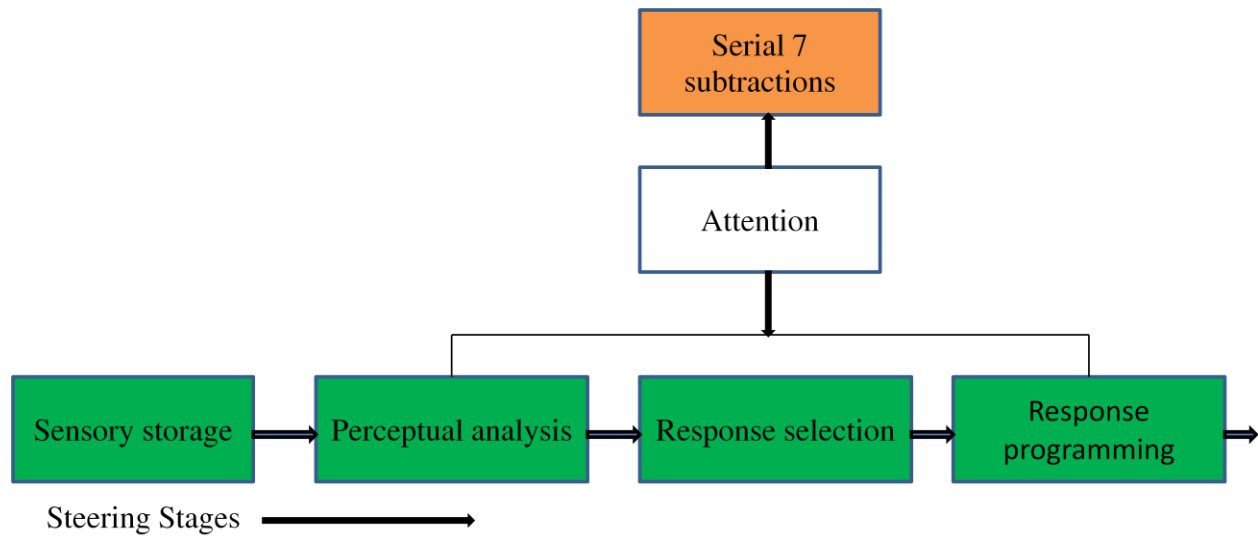


Figure 13: Information processing in steering

Notes: Flowchart indicating different stages in the steering task and showing how interference is occurring at the perceptual analysis stage

Thus, the younger adults in this study could cope with the increased attentional load by taking greater time to complete the turn without changing the articulated top down control of the body to maintain dynamic stability. This does not mean that there was a decline in steering performance. Taking more time to complete the turn was probably a safety strategy since they executed the turn using the more stable top-control of the body segments. In case of an unexpected perturbation a person moving slower will be able to regain balance without any trouble. Findings of increased time to complete a task are also consistent with previous literature on the effects of dual tasking on gait in young adults where decreased gait velocity is observed when dual tasking (Ebersbach, Dimitrijevic, & Poewe, 1995; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003; Bootsma-van der Weil, Gussekloo, de Craen, van Exel, Bloem, & Westendorp, 2003; Shkuratova, Morris, & Huxham, 2004; Beauchet, Dubost, Herrmann, & Kressig, 2005; Grabiner & Troy, 2005).

Although this is the first study to investigate the role of attention in steering using a dual task paradigm, the results of this study can be supported by the findings of other gait studies that examined gait variables, like gait speed and stride length using dual task paradigm. Those studies showed consistent evidence that supports the hypothesis that even in healthy young adults gait consumes some amount of attentional resources (Ebersbach, Dimitrijevic, & Poewe, 1995; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001; Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003; Bootsma-van der Weil, Gussekloo, de Craen, van Exel, Bloem, & Westendorp, 2003; Shkuratova, Morris, & Huxham, 2004; Beauchet, Dubost, Herrmann, & Kressig, 2005; Grabiner & Troy, 2005). Most of these studies on healthy young adults reported that all participants mostly reduced their gait speed and stride length due to dual tasking. Although walking along one direction involves descending pathways from higher centers and sensory feedback from the periphery, the spinal pattern generators produce a stereotyped rhythmic pattern that makes walking automatic to a great extent (Grillner, 1973). Steering does not involve a rhythmic pattern, making it a relatively more complicated locomotor activity that requires inhibition of movement in one direction while accelerating movement in another without stopping (Patla et al., 1991). This lends support to the fact that performing a complex locomotor activity, like steering with a secondary cognitive task in the current study, resulted in increased turning time.

Overall, the steering task suffered during dual-task condition, which may suggest that the steering requires attention resources even in healthy young adults. Having an intact attentional system may have helped the younger adults to maintain similar turn onsets timings of eyes, head, trunk and pelvis in the dual task condition, which indicate increased stability. However, overall

increasing cognitive load did in fact have an effect on the overall execution of a turning movement.

One finding of this study that was not consistent with the top down strategy of the steering control is the timing of eye reorientation. This is in contrast to the results of previous studies that highlighted the integral role of the oculomotor system in the Central Nervous System (CNS) control of steering and turning movements (Reed-Jones et al., 2009a; Reed-Jones et al., 2009b; Ambati et al., 2013). These studies suggest that anticipatory eye movement is critical for top down temporal organization of body segment reorientation in steering. However, head reorientation appears to be a reference base to organize the top-down balance control in both the groups across all conditions in the current study.

Many previous studies emphasized that an articulated operation of head-trunk control corresponds to descending temporal organization of unperturbed postural control (Hollands et al., 2002; Reed-Jones et al., 2009a). Anticipatory head reorientation occurs to obtain visual and vestibular information and build the balance control from the head to feet. Gaze stabilization before body segment reorientation is very critical for maintaining dynamic stability during steering (Assaiante & Amblard, 1995; Assaiante, 1998). The turn onset of the eyes observed in the results does not represent the exact time of their turn onset. The eyes and head moved together in this experiment in all conditions for both the groups. The eye movement in the experiment was recorded using an eye tracker (Applied Science Laboratories, Bedford, MA, USA) which was attached to the head. It measured the movement of the eyes in the yaw plane relative to the head. If the eyes had stayed still when the head moved, we would have received a negative movement signal associated with the eyes. Since they moved with the head, there was no movement recorded during head turn onset. However, when the eyes adjusted later for the

movement of the head, the eye saccade was recorded in the software. Thus, the eyes appear to be moving much later on in the plot (see figures 11 & 12).

The precedence of eye reorientation to head reorientation is still under debate. Recent articles provide evidence of eye reorientation occurring prior to head reorientation (Reed-Jones et al., 2009a; Reed-Jones et al., 2009b), and some studies (Land, 2004) show that the eyes and head move together during gaze stabilization. Reed-Jones et al. (2009a) highlighted the integral role of vision in the CNS control of steering. The studies stated that the eye reorientation not only provides visual information, but also provides important proprioception, through which the CNS can base an articulated body segment reorientation. However, Land (2004) ruled out the central role of vision in gaze stabilization and stated that vision may augment vestibular mechanism during the early part of the turn. Hence, according to Land (2004), the eyes and head move together during head reorientation while executing a turn. Eye reorientation may not occur prior to head reorientation when the task is repeated in the same environment, because the CNS has the visual information regarding the new travel direction. In the current study, the participants moved their eyes and head together during all the turning trials. It appears that the vision control was augmenting the vestibular control during head reorientation which was observed as the eyes and head moving together.

Head reorientation appears to be inherent to all the steering trials recorded in the current study. It still means that the two groups were using the gravitational vector as the frame of reference instead of the supporting surface to build their balance control. This functional principle is associated with the articulated top down control to maintain dynamic stability while steering, which is safer than the bottom up or ascending organization of body segment reorientation (Assaiante & Amblard, 1995; Assaiante, 1998).

5.4 Effects of dual tasking on steering in healthy older adults

The findings for older adults support our hypothesis partially. This is the first study to evaluate the top down temporal organization of body segment reorientation during steering in older adults using motion capture technology. This is also the first study to evaluate the role of attention in steering in older adults. Statistical analysis of older adult group data revealed significant differences in most dependent variables between baseline and dual task conditions (see figures 8 & 12). The turn onsets for head, trunk and pelvis segments occurred earlier in the dual task condition. This means, older adults reoriented most of their body segments earlier when they had to recite serial 7s while steering (figure 12). However, the results also indicate that there was a significant increase in the time taken to turn between the two conditions (figure 8). Large variability in the turn onsets due to the task condition, and also, having a significant difference in turning time implies that the older adults moved their body segments slower in the dual task condition. This provides evidence that steering requires deliberate attention in older adults. The older adults were able to cope with the increased load on attentional capacities by increasing their turning time and also reorienting the body segments early.

It was hypothesized that due to diminished attention resources (Milham et al., 2002), older adults might do worse in the dual task condition. Although older adults showed greater within subject variability in the turn onsets of head, trunk and pelvis (see figure 12), it appears that the segment reorientation occurred earlier in the dual task condition. Since the turning time increased, and the turn onsets of head, trunk and pelvis varied due to dual task condition; we may say that dual tasking influenced the steering performance in older adults. The interference between the steering task and serial 7 subtractions may be explained using figure 13. Similar to younger adults, the older adults used the articulated top down control strategy to execute the turn

(see figure 12). The various stages involved in the steering process are sensory storage, perceptual analysis, response selection and response programming (see figure 13). Head reorientation occurring prior to body reorientation provides sensory information (visual and vestibular) for dynamic balance control in the top-down steering strategy. The neural codes of sensory information obtained from the sensory storage stage must be analyzed in the perceptual analysis stage (Schmidt & Lee, 1999). Perceptual analysis involves the process that abstracts some preliminary simple meaning from the sensory stimuli. The next stage is selecting an appropriate response and then readying a movement for production (Keele, 1973). Several researchers say that the perceptual analysis and the later stages require attention (Broadbent, 1958). The older adults also performed serial 7 subtractions while steering in the dual task condition. Serial 7 subtractions is a mental tracking task that requires sustained attention (Lezak, 1999). Hence, in spite of earlier head reorientation, the serial 7 subtractions task may have delayed the analysis of the sensory (visual and vestibular) information in the perceptual analysis stage that requires attention. Therefore, we observed interference due to dual task condition in the form of increased turning time and a variance in the turn onsets of various body segments in the older adult group.

We can discuss some of the potential reasons why earlier onsets of the segments were observed due to the dual task condition. The earlier turn onsets of the head, trunk and pelvis were not expected in the older adult group in response to the dual task condition. Older adults may have coped with the increased attentional load due to the dual task condition by reorienting the head earlier. By reorienting the head early they were able to afford the time needed to process the sensory information for appropriate response selection. This appears like a defense mechanism or adaptation technique in order to obtain the required sensory information for steering. They had

to perform two attentionally demanding tasks with diminished attention resources in the dual task condition. The first one was ‘steering’ that involved processing sensory information obtained from head reorientation that requires attention; and the other one was the serial 7 subtractions task that required sustained attention (Al- Yahya et al., 2010). Knowing their processing would be slow due to dual tasking, they may have adopted a strategy to reorient the head early to obtain the sensory information needed to execute the turn safely. Therefore, the interference of the serial 7 subtractions task with the steering task at the perceptual processing stage (figure 13) may have resulted in the slower movement of the body segments after reorientation that resulted in longer turning time. The results of older adults associated with the dual tasking condition show the ability of the CNS to adapt under different circumstances. This adaptive nature of the CNS in steering control was demonstrated in several studies. Hollands et al., (2001) showed that immobilizing the head (by fixing it to the trunk via a spinal board) resulted in earlier trunk onset while steering when compared to the head free condition. The study showed how CNS adapted to the new condition by reorienting the head-trunk unit early only to achieve the early head reorientation while steering. Vallis, Patla and Adkin (2001) observed that when unexpected head turns occur in the wrong direction, the CNS delays the movement of the center of mass in the intended travel direction, because it does not have the necessary sensory information. Thus the results in this study not only demonstrate the role of attention in steering, but also provide critical information regarding the adaptive nature of CNS to reorient the head prior to other body segments.

Another potential reason for the earlier onsets could be prioritization of the motor task over the secondary task. Most of the previous gait studies reported a decline in motor task performance in healthy older adults due to dual tasking (Coppin, Shumway-Cook, & Saczynski,

2006; Bloem et al., 2001; Bootsma-van der Weil et al., 2003; Shkuratova et al., 2004; Faulkner, Redfern & Rosano, 2006; Verghese, Kuslansky, & Holtzer, 2007; Hausdroff, Schweiger, Talia, Yogev-Seligmann, & Giladi, 2008). It was observed that when the participants were given instructions to focus on walking and not on the secondary cognitive task, they walked at a speed similar to the single-task condition (Canning, 2005). Bloem et al. (2001) reported that healthy elderly gave priority to the stability of gait when walking and performing a cognitive task. The healthy elderly might be using the “posture first” strategy to avoid hazards and prevent falls while walking (Lindenberger, Marsiske, & Baltes, 2000; Schrodt, Mercer, Giuliani, & Hartman, 2004; Gernin-Lajoie, Richards, & McFadyen, 2005). Since attention deficits are inherent in the elderly (Milham et al., 2002), there is bound to be interference with the secondary task, unless they prevented the secondary task altogether. It might be that the older adults in the current study, although they were not asked to, prioritized the steering task over the serial 7 subtractions task. This may have caused the earlier turn onsets. The secondary task was not prevented in the dual task condition. Hence, working with diminished attention resources might have caused a delay in the turning time in spite of prioritizing steering over the secondary cognitive task.

Prioritization of the motor task, especially in novel situations, is considered to be an appropriate strategy (Grabiner & Troy, 2005). Hence, the articulated top-down (significant intersegment timing difference) control of eyes, head, trunk and pelvis was probably maintained even during the dual task condition. By scoring the serial 7 subtractions task in the dual task condition we can have stronger evidence to support this claim.

This is the first study to report the temporal organization of the eyes and axial body segments during steering in older adults using motion capture technology. A mixed pattern of findings have been reported in previous studies about the timing and sequence of body segment

coordination in older adults (Paquette et al., 2008; Fuller, Adkin & Vallis, 2007; Akram, Frank & Fraser, 2010). Fuller et al. (2007) only investigated the body segment coordination in a 40° turn when most turning in activities of daily living happen between 76° and 120° (Sedgman, Goldie & Iansek, 1994). They used a video camera for data collection, and the turn onsets of body segments were based on the visual examination of the videos. The comparisons to this study would not be valid due to the differences in the technology used for data collection, the experimental protocol and also data processing. Akram et al. (2010) only used shoulder and pelvis reorientation to evaluate the top down control of the body while steering. These studies either had methodological variations or poor evidence to support their claims. Although these studies reported top down control of body segment reorientation in older adults, the results of our study provide definitive conclusions. The results of this study provide strong evidence to support the existence of top-down control of body segment reorientation in older adults based on the timings of the turn onsets of eyes, head, trunk and pelvis.

As scientists we should remain open minded about making comparisons to similar previous studies even with different variables. Therefore we might want to look at gait studies which use increased gait variability as a marker for the loss of stability. According to prominent motor control theories, such as Motor Control Theory and Dynamical System Theory, increased variability in a movement pattern indicates loss of stability, while decreased variability indicates a behavior with high stability (Kamm, Thelen & Jensen, 1990; Thelen, 1995; Summers & Anson, 2009). Therefore, an increase in variability in turn onsets of eyes, head, trunk and pelvis due to the dual task condition may indicate loss of stability in older adults. However, Dynamical Systems Theory states that variability is an important component of human movement, showing the ability to adapt to our ever changing environment. It is important that this variability remains

within the optimal levels. A high level of variability infers the motor control process as too erratic and a very low level of variability indicates that the motor control process is unyielding (Stergiou, Yu & Kyvelidou, 2013). Hence in future projects quantifying the level of variance in the movement variables to assess stability would be beneficial.

5.5 Study strengths

The study has several strengths. First, it is distinctive in that no other study has ever examined the role of attention in the top down control of body segment coordination in steering. Second, it provides robust clinical evidence about dynamic balance control while steering in healthy older adults. The older adults showed significant variability in the turn onsets of body segments due to dual task condition that indicates loss of stability. Third, the results of this study provide some interesting avenues for further research in balance control in steering. Finally, the study attained sufficient power in the results providing strong evidence that support the study findings.

5.6 Study limitations

This study had several limitations. First, the study did not include the cognitive task score as a covariate or one of the dependent variables. The results indicated that the performance in the steering task suffered due to the dual task situation. However, the interference could have affected the cognitive task as well. There are four ways in which the interference could be occurring: (1) Both the steering task and cognitive task could suffer; (2) Only the steering task could suffer in performance while the cognitive task was relatively unaffected; (3) Only the cognitive task could suffer while the steering task was unaffected; (4) The cognitive task could be prevented from occurring altogether while the steering task was in progress. The results in our study show that either case (1) or case (2) occurred in the dual task condition. In order to make

stronger conclusions regarding attention, having the scores from the cognitive tests during dual tasking would have helped.

Second, the score on the serial 7 subtractions alone while sitting did not have a linear relationship with any of the dependent variables. This was included in the experimental protocol to control for the differences in the individuals' ability to perform this operation. However, since the covariate did not have a linear relationship with any of the dependent variables, it was not used in the statistical analysis.

Lastly, the study sample included a convenience sample that was drawn from University of Texas at El Paso (UTEP) campus and El Paso County area. The younger adults were mostly students who were physically active (approximately 5 to 10 hours every week). The older adults who participated in this study were from the Golden age program and a private gym for the elderly near UTEP campus. The present sample of this research presents a threat to the external validity of the study.

5.7 Directions for future research

The current study provides a spring board for future studies exploring the role of attention in steering. It is recommended that future studies assess the contribution of attention to the primary steering task and the secondary cognitive task. The fact that two complex tasks interfere with each other (or do not) might not be very meaningful by itself, because it would not be clear what the cause of interference was or where in the information processing activities the interference occurred. The future studies should aim to target various processing stages using different types of secondary tasks and attempt to explain the patterns of interference found.

Though we noticed a delay in the time taken to turn due to the dual task condition in both younger and older adult groups, there is a possibility for further research with respect to segment

velocities. One of the variables that future studies might want to include is the angular velocity of the segments in the yaw plane. The results of this study suggest that segments moved slower in response to the dual task condition. Measuring the angular velocity of the segments would be a crucial analysis to determine if the segments did in fact turn more slowly throughout the turn. Slower angular velocities during the turn provide evidence as to whether interference from the cognitive task was occurring after the response selection stage in the response programming stage that is responsible for the execution of the movement (figure 13).

We may also study the level of variance in the segment angular velocities using sample entropy or approximate entropy. The new model developed by Stergiou and Decker (2011) states that optimal variability of biological system displays stability; where, as a system with high regularity or a very random movement, would indicate that the motor control process is either unyielding or too erratic, respectively. Therefore, future studies may use the approximate entropy or sample entropy algorithm to determine the levels of variance in segment angular velocities for young and older adult groups.

The risk of falling and sustaining a fracture during turning maneuvers is ten times higher in people with Parkinson's disease and stroke survivors when compared to their healthy counterparts (Stack and Ashburn, 1999; Hyndman and Ashburn, 2003). Most of the previous studies only examined gait parameters, such as step length, stride length and number of steps taken to turning on the spot to assess turning behavior. Assessing eyes and axial body segment coordination during steering may provide the clinicians with important information about dynamic balance dysfunction that might not be seen during routine exam. The knowledge obtained from these studies can be used to design experimental methods to assess the deficits in

different cognitive domains that might be contributing to the risk of falling during steering in these groups.

Prioritization of gait, especially in novel situations, is considered to be an appropriate strategy. It is suggested that in future research studies on steering, this question be explored using different task conditions. The participants may be given instructions to focus on the motor task in the first condition and then focus on the secondary task in the next condition. By assessing the performance on both the tasks during the two conditions, the patterns of interference could demonstrate where and when the two tasks are interfering with each other.

5.8 Summary and conclusion

This dissertation sought to determine if aging influenced the attentional demands required by steering. The current study also investigated whether steering requires attention or whether it is an automatic motor synergy requiring minimal cognitive influence using dual task paradigm in healthy young adults and healthy older adults. Steering is a fundamental but complex component of locomotion. Our study revealed that the older adults turned their body segments significantly later than the younger adults in the baseline condition. There was no difference in the time taken to complete the turn across the young and older adult groups in the baseline condition. The role of attention in steering was tested by having participants perform serial 7 subtractions while walking and making a 90⁰ turn. Our results revealed that dual tasking affected steering performance in both younger adults and older adults. Younger adults did not show any difference in the timings of the turn onsets of the segments, but took significantly longer time to complete the turn. The older adults moved their body segments significantly earlier in response to dual tasking, and they still took longer time to complete the turn in the dual task condition. The results support the fact that aging influences steering and also that steering is an attention-demanding

task. The temporal organization of body segment reorientation in a top down fashion during steering involves perceptual analysis and response selection that need attention. The interference of the cognitive task with steering may have occurred at the perceptual analysis stage of steering that resulted in greater turning time.

In conclusion, the results of the current study showed the potential of using dual tasking to investigate the role of attention in steering. In addition, the coping strategies to increased attentional load in healthy young and healthy older adults should be investigated further using additional variables such as angular velocity.

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APPENDIX A: INFORMED CONSENT

University of Texas at El Paso (UTEP) Institutional Review Board

Informed Consent Form for Research Involving Human Subjects (Ages 18-Adult)

Protocol Title: Examining the role of attention in steering using dual task paradigm.

Principal Investigator: Anthony Salvatore PhD

Co-Investigator: Venkata Naga Pradeep Ambati MS (Student Investigator)

UTEP: Interdisciplinary Health Science PhD Program

1. INTRODUCTION

You are being asked to take part voluntarily in the research project described below. Please take your time making a decision and feel free to discuss it with your friends and family. Before agreeing to take part in this research study, it is important that you read the consent form that describes the study. Please ask the study researcher or the study staff to explain any words or information that you do not clearly understand.

2. WHY IS THIS STUDY BEING DONE?

Our research study aims to determine whether there are objective differences in turning while performing a secondary task between healthy older adults and healthy young. You are being asked to be in the study because you are either a healthy older adult or a healthy young adult.

This study will assist us in evaluating and understanding how performing a secondary task influences the body segment coordination while turning. This is important as older adults are known to have structural changes in the brain that comes with aging which changes their capability to divide attention between two tasks. This increases their risk of falling during turning manoeuvres. If you decide to enroll in this study, your involvement will last about two hours.

3. WHAT IS INVOLVED IN THE STUDY?

If you agree to take part in this study, the research team will collect data on the movement of your head, trunk, feet and eyes. The assessment of these factors will be done using an eye tracker and a motion capture system.

You (all participants) will be asked to complete a general health questionnaire prior to inclusion in the study to ensure you (healthy volunteers) are free of any neurological disorders (e.g. vertigo and hearing disorders) and do not have any medical conditions that could put you at increased risk by participating in the study (e.g. heart conditions). This test will take about 5-10 minutes.

You (all participants) will then take a Mini-Mental State Exam (MMSE). The MMSE is a commonly used verbal test that measures cognitive function and is widely used in research with older adults and clinical populations. This test will take about 5-10 minutes.

You (all participants) will then take a Trail Making Test (TMT). The TMT is a paper-and-pencil task given in two parts: A (TMT-A) and B (TMT-B). This test is commonly used to measure executive functioning which is an major domain of cognitive system. The test will take about 5 minutes.

Following these tests you will have reflective markers attached to the head (via a headband), trunk, pelvis and feet segments (taped to the front of your shirt and shoes). Movement of the head, trunk and feet will be captured by eight high resolution cameras. Eye movement will be recorded using an ASL Eye Tracker system (Applied Science Laboratories, Bedford, MA, USA). This system requires you to wear a headband to record the eye movement using a camera that captures the image of your left eye. Once the equipment is placed and calibrated you will begin the walking trials. You will be asked to walk along a straight path or redirect your straight walking path to the right and to the left to a maximum of 5 meters. For half of the turning trials you will be asked to perform serial 7 subtractions out loud starting from 500. The total duration of the protocol should take no longer than 2 hours. You will be given adequate breaks during trials.

4. WHAT ARE THE RISKS AND DISCOMFORTS OF THE STUDY?

The potential risks that may occur with participation in the proposed research include those generally associated with walking i.e. fatigue and changes in blood pressure may occur during testing period. There is a minimal risk of falling associated with walking and turning however we will have two trained spotters present at all times that will walk beside you to ensure your stability and safety.

5. WHAT WILL HAPPEN IF I AM INJURED IN THIS STUDY?

The University of Texas at El Paso and its affiliates do not offer to pay for or cover the cost of medical treatment for research related illness or injury. No funds have been set aside to pay or reimburse you in the event of such injury or illness. You will not give up any of your legal rights by signing this consent form. You should report any such injury to V.N. Pradeep Ambati at (915-

408-8067) and to the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

6. ARE THERE BENEFITS TO TAKING PART IN THIS STUDY?

There will be no direct benefits to you for taking part in this study. This research may help us to understand the body coordination associated with turning and performing a secondary cognitive task in healthy old and healthy young adults. This will lead to better understanding of the falls during turning maneuvers.

7. WHAT OTHER OPTIONS ARE THERE?

You have the option not to take part in this study. There will be no penalties involved if you choose not to take part in this study.

8. WHAT ARE MY COSTS?

There are no direct costs. You will be responsible for travel to and from the research site and any other incidental expenses.

9. WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

You will be paid \$30 in the form of a gift card for taking part in this research study.

10. WHAT IF I WANT TO WITHDRAW OR AM ASKED TO WITHDRAW FROM THIS STUDY?

Taking part in this study is voluntary. You have the right to choose not to take part in this study.

If you do not take part in the study, there will be no penalty.

If you choose to take part, you have the right to stop at any time. However, we encourage you to talk to a member of the research group so that they know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them.

The researcher may decide to stop your participation without your permission, if he or she thinks that being in the study may cause you harm.

11. Who do I call if I have questions or problems?

You may ask any questions you have now. If you have questions later, you may call

V.N. Pradeep Ambati.

Graduate Research Assistant

Interdisciplinary Health Science PhD Program

College of Health Sciences

University of Texas at El Paso

(915) 408-8067

If you have questions or concerns about your participation as a research subject, please contact the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

12. WHAT ABOUT CONFIDENTIALITY?

Your part in this study is confidential. None of the information will identify you by name. All records will be kept in a locked cabinet in a locked office.

13. AUTHORIZATION STATEMENT

I have read each page of this paper about the study (or it was read to me). I know that being in this study is voluntary and I choose to be in this study. I know I can stop being in this study without penalty. I will get a copy of this consent form now and can get information on results of the study later if I wish.

Participant Name: _____ Date: _____

Participant Signature: _____ Time: _____

Consent form explained/witnessed by: _____

Printed name: _____

Date: _____ Time: _____

VITA

Venkata Naga Pradeep Ambati was born and raised in Hyderabad, India. He graduated with a Bachelor's degree in Biomedical Engineering from Osmania University, Hyderabad, India in the year 2007. In fall 2007 he started his Master's program in Biomedical Engineering at the University of South Florida. He was awarded the graduate research assistantship in his first semester to work as a research Assistant at the James A Haley Veterans' Medical Center, Center of Excellence, Tampa in December 2007. As a research assistant he provided bioengineering support to several biomedical projects that studied gait and balance deficits in persons with these disabilities. The majority of the projects at VA Tampa were multi disciplinary in nature that inspired him to join the Interdisciplinary Health Sciences PhD program at UTEP that mainly trains the next generation of interdisciplinary researchers and academicians. His research at UTEP focused on understanding the mechanics of gait in healthy and clinical populations. In particular he studied the neurological link between the oculomotor and somatomotor systems for the purpose of locomotor activities. He published several articles in reputed journals as first and second author while pursuing his doctoral degree at UTEP.

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This dissertation was typed by Venkata Naga Pradeep Ambati.