OBSTACLE NEGOTIATION KINEMATICS:
AGE-DEPENDENT EFFECTS OF POSTURAL THREAT

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DEDICATION

I dedicate this thesis to my Poppa, John Joseph Lacey. You have taught me the meaning of dignity.

ABSTRACT

The effects of postural threat and the potential consequences of obstacle contact on the obstacle negotiation kinematics among younger and older adults were examined. Seventeen older (OA; 7 males, 10 females; mean age, 68.94 ± 4.85) and fifteen younger adults (YA; 5 males, 10 females; mean age, 22.53 ± 2.77) negotiated virtual and real obstacles while walking at a self-determined velocity along a 7.2m walkway under 4 different conditions of postural threat. Postural threat was manipulated by varying the width (0.60m versus 0.15m) and height (floor versus elevated (0.00m versus 0.60m)) of the walkway. Postural threat altered crossing kinematics for all subjects. Specifically, age-related differences emerged with increasing postural threat, however the changes observed among older adults were considerably different from those of younger adults. Additionally, there was an effect for the potential consequences of obstacle contact, however, no age-related differences emerged. These results revealed an effect for postural threat and obstacle characteristics on the negotiation strategies of younger and older adults. Both postural threat and obstacle characteristics elicit conservative crossing kinematics in younger and older adults. Specifically, these findings illustrate age-dependent differences in obstacle negotiation strategies and that postural threat affects older adults differently than younger adults whereas the potential consequences of obstacle contact affects younger and older adults equally.

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GENERAL INTRODUCTION

The purpose of this thesis was to examine the effects of postural threat on obstacle negotiation kinematics among younger and older adults. Two separate and complete studies are presented. The behavioral kinematics used by older and younger adults to negotiate an obstacle under conditions of postural threat are examined in the first study. The second study investigates the effects of the potential consequences of obstacle contact on the negotiation kinematics of older and younger adults. The general discussion addresses the relevance and contributions of the findings of this thesis to the current literature. Furthermore, the application of our research findings to reduce the risk and occurrence of falls in both younger and older adults are presented.

1. Background

One out of every three adults over the age of 65 falls each year (Tinetti & Speechley, 1989). These falls occur during activities of daily living (ADL) such as getting dressed, walking across the street, or negotiating an icy sidewalk. Of the 33% of individuals experiencing falls each year, 40% of these fallers are admitted to hospital. Associated with falling during ADL are high medical costs, and loss of independence and function (Begg & Sparrow, 2000). Furthermore, falling is the leading cause of accident-related death in older adults (OA) (Pavol, Owings, Foley, & Grabiner, 2001). Fall-related deaths claim 185 of every 100,000 elderly lives each year, almost ten times the number of deaths occurring among 15 to 29 year olds due to motor vehicle accidents (Winter, 1995). With current demographic trends predicting an increase in the number of elderly individuals to rise to 21% of the Canadian population by 2006, it is likely that the high incidence of falls will increase in future decades (Statistics Canada - Recensement 1988) unless researchers can develop methods to maintain and improve the postural control of OA.

Why is the prevalence of falling among OA so high? Previous researchers (Gabell, Simons, & Wayak, 1985; Prudham & Evans, 1981; Ashley, Gryfe, & Annies, 1977) reported that 50% of all falls experienced by the elderly occur during gait. Although 50% of falls occur during gait, the most common cause of reported falls among OA was due to tripping over an obstacle (Overstall, Exton-Smith, Imms, & Johnson, 1977). This finding suggests that obstacle detection and/or negotiation abilities decline with age. Furthermore, a variety of physiological and biomechanical changes associated with aging may also alter the ability of OA to control gait and avoid obstacles. Shumway-Cook and Woollacott (2001) reported that advanced age contributes to a decrease in function in many of the sensory and motor systems that are required for effective and safe locomotion. These age-related declines in sensorimotor function have been associated with the high occurrence of falls among the elderly (Woollacott & Tang, 1997; Alexander, 1994; Tinetti & Speechley, 1989) and have been suggested to contribute to OA being less able to anticipate, compensate, and recover from a disturbance while walking.

The purpose of this general introduction is to provide an overview of the current state of knowledge regarding obstacle negotiation ability among young and older adults. To achieve this goal, I will review the terminology and fundamental principles of biomechanics as they relate to postural control and gait. The first section of this thesis details the age-related changes in the kinematics of locomotion. The second section of this literature review provides an overview of the sensorimotor and cognitive contributions to postural control and gait and targets age-related changes in these areas. The effects of fear of falling on gait will also be examined. The final section addresses the issue of obstacle avoidance and summarizes the current literature regarding obstacle avoidance in the elderly for the purpose of justifying the work presented in this thesis.

2. Postural Control

2.1 Biomechanics and Terminology of Postural Control During Standing

Postural control is the ability to control the position of the body in space for the dual purposes of stability and orientation (Shumway-Cook & Woollacott, 2001). In biomechanical terms, the position of the body may be described as the net location of the body's mass, or the center of mass (COM). To maintain balance and prevent falls, the COM must remain within the limits of the base of support (BOS) (Shumway-Cook & Woollacott, 2001). The BOS can be defined as the points of contact between the body and the support surface in a given situation (i.e. feet on a sidewalk define the area known as the BOS). If the COM exceeds the limits of the BOS, such as may occur following a nudge or a push, the body will become unstable and a loss of equilibrium will occur unless compensatory actions counteract the applied force. For example, a forward step would be taken following a bump to the back that is of sufficient magnitude to displace the position of the COM beyond the limits of the BOS. This step serves to adjust the dimensions of the BOS and ensure the COM is in an appropriate position for the body to remain upright.

2.2 Postural Control During Locomotion

It is known that most falls occur when the body is in motion and not during static tasks (Maki & McIlroy, 1996; Campbell, Borrie, & Spears, 1989). For example, Maki and McIlroy, (1996) indicated that 54% of falls are due to a slip, trip, overstepping, or a BOS problem during weight transfer. These numbers reinforce the fact that falling is caused during quiet standing but more often during locomotion. As is the case with upright stance, gait demands coordinating the movements of the COM with those of the BOS. Unlike quiet standing however, gait involves a series of continuous and controlled disequilibriums in which the COM is constantly exceeding and re-entering the limits of the BOS. To initiate gait, the COM must be accelerated beyond the limits of the BOS. The forward acceleration of the COM is analogous to voluntarily falling forward (Winter, 1995). The resulting relationship between the COM and the BOS produces a situation of disequilibrium that must be counteracted to prevent instability. To prevent instability, the BOS is adjusted anteriorly so that the COM is repositioned within the BOS. This continuous forward movement of the body propels the COM forward and further steps occur. However, the motion of the COM beyond the BOS places the body in a state of potential instability. Therefore, an individual is more vulnerable to a loss of balance (LOB) or a fall during gait than during quiet standing or sitting.

2.2.1 Kinematics and Terminology of Locomotion

During gait, a series of steps are taken alternately between the left and right lower limbs to produce patterned strides. A stride is defined by the distance traveled between successive stance periods of a limb (Winter, 1995). The terminology associated with locomotion is illustrated in Figure 1. Relevant terms include: gait cycle, step length, double limb support, single limb support, stance phase, swing phase, lead toe off, trail toe off, lead heel contact, and trail heel contact.

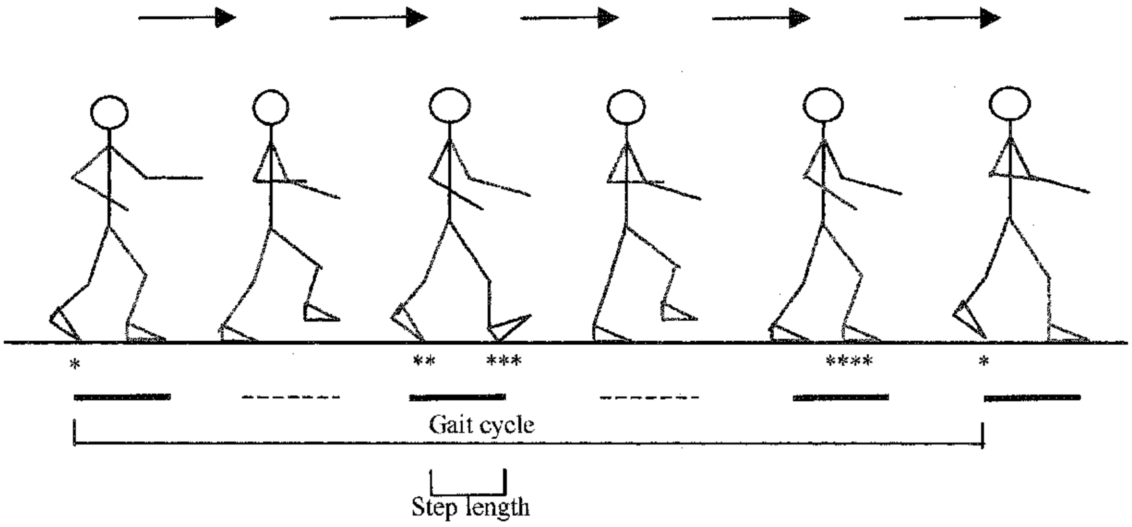


Figure 1: Schematic diagram of a full gait cycle in forward human locomotion (shown via arrows). Blue represents the lead limb (in this case the limb that initiates gait) while red represents the trail limb. The bold line indicates the double limb support phase (DLS) when both feet are in contact with the ground. The dashed line indicates the single limb support phase (SLS) when one foot is contacting the grounds. Stance phase of a limb is defined as the time that limb is in contact with the ground. Swing phase of a limb is defined as the time that limb is not in contact with the ground. Position terms: * = lead toe off, ** = trail toe off, *** = lead heel contact, **** = trail heel contact. Note: a step is defined as the distance from toe off of one limb to heel contact of the contralateral limb while a gait cycle is defined as the toe off of one limb to the next toe off of the same limb.

During mid-point of the swing phase, when the trail foot is closest to the ground, the toe is traveling at its maximum linear velocity and is at its minimum vertical displacement, less than 1cm above the ground (Winter, 1995; Winter, 1991). Thus with a toe clearance height of less than 1cm and maximum swing velocity, the mid-point of the SLS phase may be considered the most dangerous phase of the gait cycle.

2.2.2 Age Related Changes in the Kinematics of Gait

An abundance of research evidence has demonstrated that OA walk differently than younger adults (YA) (Prince et al., 1997; Judge, Ounpuu, & Davis, 1996; Buchner et al., 1996; Alexander, 1994; Nutt, Marsden, & Thompson, 1993). For example, Winter (1991) reported that OA walked with wider strides and shorter steps compared to younger adults (YA). Slower walking velocities among OA due to shortened stride lengths and decreased stride velocity have also been documented by Judge and colleagues (1996). In addition, it is also reported that OA spend more time in the DLS phase of gait than YA (Judge et al., 1996; Winter, 1991; Murray, Kory, & Clarkson, 1969; Winter, Patla, Frank, & Walt, 1990; Winter et al., 1990). The DLS phase is thought to be the more stable of the two gait phases since there are two feet in contact with the walking surface. Therefore, the adoption of a longer DLS (61% of the gait cycle) causes the walking velocity of OA to decrease (Judge et al., 1996). Speculation from these findings follows that OA are adopting a slower and potentially more conservative walking strategy than YA (Judge et al., 1996; Winter, 1991; Murray et al., 1969).

It is known that the age-related changes in sensory function have a negative impact on postural control (Woollacott, 1989). Although a decline of the sensory systems negatively affects the ability of OA to avoid falling, there are many alterations observed in the age-associated musculoskeletal system that also provide explanation for the difficulty that OA demonstrate in maintaining their balance. For example, muscular strength and joint range of motion (ROM) decrease significantly with age (Aniansson, Grimby, Hedberg, Rungren, & Sperling, 1978). As a result of these physical declines, ROM for the hip and knee during normal gait do not approach the limits of passive joint ROM among OA. This alteration implies that OA are not reaching the potential ROM available. This discrepancy may be due to articular disease or musculotendinous tightness (Judge et al., 1996). Thus, the aging process, combined with the body's inherent instability, makes postural control and locomotion an especially difficult task for the elderly.

3. Obstacle Avoidance

During locomotion, it is rare to experience prolonged situations that are void of clutter, crowds, or constraints. Indeed, external factors such as icy sidewalks, poorly lit hallways, narrow walkways, and obstacles frequently contribute to the challenge OA have in maintaining their balance. Tripping over obstacles is one of the most common causes of reported falls in the elderly (Overstall et al., 1977). In fact, uneven pavement was the leading cause of falls in one year (Crosbie & Ko, 2000). In addition to trips over expected obstacles, OA have high rates of falling due to trips over unexpected or suddenly appearing obstacles (Cao, Ashton-Miller, Schultz, & Alexander, 1998).

The movement solution used to avoid an obstacle is referred to as the avoidance strategy. These strategies have been defined by Austin and colleagues (1999) based on the observation that individuals adopt stereotypical movement patterns to avoid an obstacle in their path. Four movement patters were defined for all age groups: 1. increasing vertical clearance as obstacle height increased; 2. neither increasing or decreasing vertical clearance based on obstacle height; 3. decreasing vertical clearance with increasing obstacle height; 4. interference (obstacle contact) (Austin et al., 1999). Similarly, Chen and colleagues have classified the possible movement patterns for obstacle avoidance: step shortening (SS), step lengthening (LS) (Chen, Ashton-Miller, Alexander, & Schultz, 1994a; Chen, Ashton-Miller, Alexander, & Schultz, 1991) and normal (NS). SS involves shortening the normal gait stride to contact the walkway before the obstacle and to take an extra crossing step, while LS involves a lengthening of the normal stride to take a longer crossing step, (Chen et al., 1994a; Chen et al., 1991) and NS shows a normal gait pattern during obstacle negotiation.

3.1 Biomechanics of Safely Negotiating An Obstacle

When stepping over an obstacle the first limb to cross the obstacle is the lead limb, the second to cross is the trail limb. A successful crossing is defined as crossing both limbs over the obstacle without contacting it and creating a stable BOS within which the COM is located. Specifically, obstacle crossing requires that the lead limb clear the obstacle and create a stable foot position that contributes to a stable BOS, and that the trail limb avoid contact with the obstacle during the swing phase of trail limb crossing (Crosbie & Ko, 2000). The movement of each limb during obstacle crossing may be described by independent kinematic parameters. The lead limb reaches a higher toe clearance in the vertical direction as well as increased vertical hip position. In addition, the lead limb travels with a higher velocity compared to the swing limb (Patla, Rietdyk, Martin, & Prentice, 1996). Patla and colleagues (1996) reported that the trail limb appeared to move 'automatically' being pulled forward by the momentum of the COM. Since the lead limb is being guided visually and the trail limb is not, (Patla, Prentice, Rietdyk, Allard, & Martin, 1999) the only requirement for the trail limb is to avoid obstacle contact. Observations have been made that individuals may prefer to use one limb over the other as their dominant lead limb. This may be a positive strategy because one limb may be physically fit for lead limb requirements but it may also be a detriment to the individual. For example, limb preference may reflect dominance and consistency in the crossing limb used. If presented with an obstacle in a time-restricted situation, it may be impossible to adjust one's stride to maintain the use of a dominant crossing limb. For example, a time restricted situation may require the use of a SS (Chen, Ashton-Miller, Alexander, & Schultz, 1994b) forcing the non-dominant limb to become the lead limb creating instability to the individual during obstacle crossing.

Regardless of the strategy used during obstacle negotiation, successful avoidance requires that the hips are elevated and walking speeds are slowed (Pavol et al., 2001). These accommodations help to ensure sufficient time and joint ROM for obstacle crossing. Interestingly, Chou and colleagues (2001b) reported that individuals adopt a forward lean during obstacle avoidance. It was speculated that although a forward lean served to minimize vertical displacement of the COM, this alignment does place individuals in a position of potential risk. The reason for this increased fall risk is that the length of the moment arm for the head, arms and trunk (HAT) segment around the hip joint is increased by forward inclination. Consequently, the gravitational torque of the HAT segment increases, and threatens the possibility of a forward fall unless adequate oppositional torque is generated.

4. Factors Affecting Obstacle Negotiation Kinematics

Obstacle negotiation requires integration between the cognitive and sensorimotor systems. Potential dangers must be recognized and an appropriate response must be selected by the central nervous system (CNS) and executed by the motor system. This response is referred to as a negotiation strategy and is defined as the patterns of movement adopted to avoid obstacle contact and a subsequent fall (Chen et al., 1994a; Chen et al., 1991).

4.1 Effects of Environmental Context on Obstacle Avoidance

Research indicates that there are a number of factors that influence negotiation strategies. Environmental context can be described as the components of the external environment that have an effect on our balance. For example, stepping on an icy surface, walking in a crowded hallway or negotiating a curb are components of environmental context. The availability of negotiation strategies may be limited by the constraints imposed by the environmental context. For example, the need to step with one foot directly in front of the other in a crowded place (Daubney & Culham, 1999) may limit the number of safe, available responses. Patla and colleagues (1999) manipulated environmental context by presenting a light spot at various positions along a walkway. When the light was presented, individuals were asked to avoid stepping on the spot. The results from this study revealed that foot placement strategies are highly dependent on the relationship between the undesirable landing area and normal foot placement. This study simulates an altered environmental context by forcing subjects to place their foot in undesirable landing areas. In a true environment, individuals encounter real obstacles such as patches of ice or roots on a path that they wish to avoid. If alternative response strategies are limited, such as when walking on a narrow path, stability may have to be compromised.

4.2 Effects of Available Response Times on Obstacle Avoidance

Available response time (ART) is the amount of time that an individual has to avoid contacting an obstacle. ART is measured as the estimated time between obstacle appearance and obstacle contact, should the individual continue to walk at a constant speed. Chen and colleagues (1994b) have demonstrated that the frequency of successful negotiation is strongly correlated with ART. However, when ART is minimized, individuals alter their gait patterns to adopt movement strategies that take less time for balance recovery (Patla et al., 1999). For example, when confronted with an obstacle and given a short ART, individuals may opt to use a LS to allow for more time to implement a change in the swing limb trajectory (Patla et al., 1999). Similar avoidance strategies have been reported when individuals are asked to stop suddenly before an obstacle. Cao and colleagues, (1998) reported that OA did not perform as well as YA when given the same ART and asked to stop before an obstacle. Results revealed that OA required longer ARTs to stop safely and avoid contacting an obstacle. Finally, longer ARTs resulted in individuals selecting a toe off position that was more posterior to the obstacle compared to the toe off positions chosen when shorter ARTs were provided (Chen et al., 1994b). This increased toe off distance serves to expand the distance between the foot and the obstacle and reduces the risk for tripping during the swing phases of gait (Chen et al., 1991).

4.3 Effects of Obstacle Height and Type on the Kinematics of Obstacle Crossing

It has already been established that crossing obstacles is a challenging task for both YA and OA because it requires the coordination of complex movements, often under time restricted or physically demanding situations. Unfortunately, obstacle crossing is often performed improperly and often leads to a fall (Tinetti & Speechley, 1989). Another factor known to alter negotiation kinematics are the characteristics of the impending obstacle. Fragile obstacles, with more potential for danger if contacted, appear to influence crossing kinematics within individuals demonstrating increased vertical displacement and velocity of the lead limb during crossing (Patla et al., 1996). In addition, as obstacle height increases, individuals demonstrate slower speeds and increased vertical foot clearance as well as an increase in the velocity of the foot during crossing descent (Patla, 1991; Chen et al., 1991).

Participants crossing obstacles of varying heights were also observed by Rosengren and McAuley (1998). These authors reported that the participants' preparatory steps became shorter, crossing step lengths decreased and recovery steps (if obstacle contact occurred) were longer when crossing higher obstacles. These findings imply that as obstacle height increases, crossing is conservative and preparation for crossing occurs during a number of preliminary steps. The short crossing steps observed by Rosengren and McAuley (1998) can be attributed to heel contact following the obstacle being very close to the obstacle. Although a short obstacle-heel distance may be a conservative strategy, it may also increase the risk for obstacle contact during descent of the lead limb. Interestingly, the trend in vertical crossing seems to contrast that of horizontal movements. Simultaneous to the observation of shorter crossing strides for higher obstacles, is an increased vertical crossing height for obstacles of increasing height (Austin et al., 1999). Adrian and Cooper (1995) have reported that there may be a maximum height of approximately 23cm for successful vertical clearance. Interestingly, this maximum obstacle height corresponds to that of a normal curb height which is often observed to be the cause of many trips and falls in the elderly. Conversely, Austin and colleagues (1999) reported a maximum obstacle height of 12.6cm, nearly half that of normal curb height. Unfortunately, many obstacles in the external environment are at non-optimal heights (i.e. snow bank, step), increasing the risk for falls in both older and younger adults.

4.4 Effects of Age on Strategies For Obstacle Avoidance

Finally, a major factor contributing to the difficult task of obstacle negotiation is that of age. As we know, avoiding contact with an obstacle can be performed in a variety of ways. The choice of avoidance strategy depends on the amount of time an individual has to respond to an obstacle (Patla et al., 1999; Chen et al., 1994b). However, given the same ART, YA tend to use the LS more often than OA who tend to use a SS (Chen et al., 1994b). The work of Patla and colleagues (1999) revealed that obstacle avoidance strategies serve to minimize whole body COM movement by altering step kinematics to minimize foot displacement. This trend occurs more frequently among the elderly, possibly because OA are more conservative in their movement patterns than YA (Chen et al., 1994b). Additionally, OA attempt to implement crossing strategies that are within the plane of progression for walking. For example, a forward step over the obstacle rather than a side step around the obstacle appears to be preferable among the elderly. Patla (1999) suggests that the majority of muscles required for forward obstacle negotiation are already active during walking. Therefore, extra muscle activation is not required for a forward step negotiation strategy. Consequently, ART is maximized when a forward crossing motion is used rather than a side crossing motion (Patla et al., 1999).

Regardless of length of ART however, YA are more successful at obstacle negotiation compare to OA. The increased success of YA may be due to the 30ms more required by OA compared to YA to negotiate an obstacle (Chen et al., 1994b). Thus, OA are more likely than YA to contact an obstacle as ART decreases. From these findings, it can be speculated that OA may be limited by the processing demands required to ensure successful obstacle negotiation in time-restricted activities. This deficit supports the findings that the visual, vestibular and somatosensory systems are declining and the integration of the sensory information is slowed.

Although most avoidance strategies require one step for implementation, (Patla et al., 1999) research has revealed that OA initiate the negotiation strategy one step earlier in their gait cycle than YA (Chen et al., 1994b). Depending on the degree of perceived threat associated with contacting the obstacle, individuals will implement either the LS or SS. Patla and colleagues (1999) examined the concept of foot contact position as a measure of threat. These authors reported that if the entire foot was in danger of contacting the obstacle, LS would be used. However, if only the forefoot was to contact the obstacle a SS would most likely be used. We can therefore speculate that contacting the obstacle with the entire foot is perceived to be more threatening and a LS is used to provide more time for swing limb trajectories to be safely adjusted (Patla et al., 1999).

The gait adjustments required for successful obstacle negotiation become increasingly difficult as we age. As described earlier, the aging process contributes to a decrease in muscle mass, vision, and joint range of motion (Shumway-Cook & Woollacott, 2001). Chen and colleagues (1991) examined the effects of aging on obstacle avoidance performance. Although OA tend to use SS more often than YA, other age-related kinematic differences were also observed. In particular, pre-obstacle toe distance and post-obstacle heel distance differed between younger and older adults. Specifically, OA demonstrated longer toe distances from the back of the obstacle prior to crossing, compared to YA. As the distance between the foot and the obstacle decreases, the possibility of contact with the obstacle in either the lift off or braking phase increases. Consequently, this finding supports the notion that OA are using a conservative strategy during the ascent phase, decreasing the risk for contact with the obstacle. As well, OA demonstrated lower heel crossing heights compared to YA. Although not lifting the leg as high off of the ground may serve to reduce the probability of a LOB by minimizing COM displacement, it also causes the foot to be closer to the obstacle and, in fact, increases the chance of contacting the obstacle during crossing. We can therefore hypothesize that a low crossing height may be placing OA at a greater risk for obstacle contact, compared to YA.

5. Summary

It is now evident that OA fall more often than YA, with alarmingly high rates of injury and fall related death in those over the age of 65. It is also evident that tripping is one of the major causes of reported falls, accounting for half of the reported falls in the elderly each year (Overstall et al., 1977). Many factors play a role in determining whether or not an individual is at a risk for falling. And although OA are demonstrating a decline in the various systems contributing to postural control, it is not conclusive that these deficits increase their risk of falling.

One factor that may contribute to the high rate of trip-related injuries among the elderly is fear of falling. Fear of falling is a factor of major importance when considering falling during locomotion among OA. In addition to the high rates of falls and fall injuries experienced by OA it is also known that OA report a general fear of falling (Tinetti & Williams, 1998). Fear of falling is a low confidence in mobility tasks (Tinetti, Richman, & Powell, 1990) that may lead to a debilitating anxiety regarding balance ability (Lachman, Howland, Tennstedt, Jette, & Peterson, 1998). Fear of falling is now established to be highly prevalent among the elderly, affecting almost 60% of community dwelling seniors (Brouwer, Walker, Binda, Rydahl, & Culha, 2001). Although fear of falling primarily develops as a consequence of a fall episode (often referred to as the Post Fall Syndrome) (Tinetti, de Leon, Doucette, & Baker, 1994), it is now known that fear of falling is prevalent among many seniors who have never experienced a fall. Furthermore, although many seniors live with a persistent and debilitating fear of falling, many others experience fear of falling only in specific situations or environmental contexts, such as walking on ice or negotiating a curb or stair (Rosengren & McAuley, 1998).

Past research has explored the notion of postural threat to explore the influence of fear of falling on postural control and locomotion. In these studies, individuals were tested under environmental contexts that alter the potential consequences of instability. The underlying premise was that individuals experience heightened physiological arousal, similar to that which may occur in situations that create a fear of falling (Brown, Gage, Polych, Sleik, & Winder, in press; Adkin, Frank, Carpenter, & Peysar, 2000; Carpenter, Frank, & Silcher, 1999; Brown & Frank, 1997). Results to date indicate that the CNS imposes tighter control of posture and gait as postural threat increases (Brown et al., in press; Adkin, Frank, Carpenter, & Peysar, 2002; Carpenter, Frank, Silcher, & Peysar, 2001; Adkin et al., 2000; Carpenter et al., 1999; Brown & Frank, 1997). However, since gait is rarely unobstructed, we sought to examine the effects of postural threat on the obstacle negotiation strategies of younger and older adults. Additionally, we also sought to investigate whether the alterations in obstacle negotiation kinematics that emerge among younger and older adults under conditions of postural threat are influenced by the potential consequences of obstacle contact.

OBJECTIVES OF THE THESIS

The goal of this thesis was to examine the effects of postural threat on the ability of younger and older adults to effectively avoid obstacles. Effective obstacle avoidance was defined as either stepping over or around an obstacle without a LOB. Two different questions were examined through two separate studies: Study 1: Are the kinematics of obstacle negotiation for younger and older adults altered under environmental contexts that vary postural threat? Study 2: Is the effect of environmental context on obstacle negotiation kinematics influenced by the potential consequences of obstacle contact?

To examine the question presented in Study 1, obstacle avoidance kinematics for a virtual obstacle (light beam) were monitored across varying conditions of postural threat. The question presented in Study 2 was examined by comparing negotiation kinematics for the virtual vs. a real obstacle (block) in each condition of postural threat.

The manipulation of postural threat was achieved according to the work of Brown and colleagues (in press) in which participants were instructed to walk along a walkway, either in a wide or narrow constraint and an elevated or non-elevated constraint. The height and width manipulations were designed to increase the consequences of instability and to limit the strategy options available to avoid an obstacle. A condition of low postural threat was introduced [unconstrained floor (UCF)] by instructing participants to walk along a wide, floor level walkway. A condition of high postural threat [constrained elevated (CE)] was presented by elevating and constraining the walkway, limiting the available obstacle avoidance strategies for the participants as well as increasing the consequences of instability.

I predicted that conditions of postural threat and increased potential consequences of obstacle contact would alter the kinematics of obstacle negotiation.

Secondly, OA were expected to be affected by these manipulations more than YA, particularly under conditions of increased postural threat.

STUDY 1: OBSTACLE NEGOTIATION KINEMATICS: AGE-DEPENDENT EFFECTS OF POSTURAL THREAT

1. Introduction

Deterioration in the sensory, motor, and cognitive systems occur with aging (Shumway-Cook & Woollacott, 2001; Maki & McIlroy, 1996). For example, declines in muscle strength (Aniansson et al., 1978), joint range of motion (Maki & McIlroy, 1996; Alexander, 1994), visual acuity (Koroknay, 1995), and vestibular system sensitivity (Sloane, Baloh, & Honrubia, 1989) occur with advanced aging. Additionally, cognitive changes such as dementia, altered mental status, and decreased information processing capacity and speed are also associated with aging (Salthouse, Fristoe, Linewater, & Coon, 1995). It is now well accepted that these intrinsic changes alter the ability of older adults to maintain balance and thus contribute to an increased risk and number of fall occurrences (Alexander, 1994). Since 32% of OA fall at least once a year, and 24% of these falls result in serious injury (Tinetti & Speechley, 1989), issues of fall prevention and safety during obstructed gait deserve further research attention.

Statistics suggest that extrinsic challenges to postural control that emerge as a natural occurrence of daily life also play a significant role in the number of falls among OA. For example, it has been reported that tripping over an obstacle or slipping on a patch of ice account for 30-50% of all falls in the elderly (Tang & Woollacott, 1998). Thus, in addition to exploring the consequences of the intrinsic challenges to postural control that are inherent to the aging adult, research efforts have also examined age-related differences in the ability to tolerate extrinsic postural challenges.

The high rate of trip-induced falling among the elderly has led to a number of research efforts describing how the movement strategies of younger and older adults differ when negotiating an obstacle (Patla et al., 1999; Chen et al., 1991). The premise of work in this area has been to examine the effects of age on motor performance and to explore how age-related changes may contribute to increased fall risk in the elderly. We now know that during obstacle negotiation tasks OA demonstrate shorter crossing step lengths, slower crossing velocities, and shorter post-obstacle heel strike distances than YA (Chen et al., 1991). In addition, it has been reported that OA have a longer pre-obstacle toe approach distance than YA (Begg & Sparrow, 2000). Interestingly, Begg and Sparrow (2000) reported that when negotiating a raised surface, vertical toe clearance heights among OA were significantly lower than those demonstrated by YA. These findings suggest that OA are at a greater risk for tripping during obstacle negotiation tasks than YA because the probability for obstacle contact is enhanced by the low clearance height.

Although we are now well informed about the age-related differences in the kinematics of obstacle negotiation, our knowledge remains limited regarding the potential contributions of factors, other than age-dependent sensorimotor limitations, that may also influence the expression of motor output. One such factor is fear of falling. Fear of falling is a low confidence in mobility tasks (Tinetti et al., 1990) that may lead to a debilitating anxiety regarding balance ability (Lachman et al., 1998). Fear of falling has now been established to be highly prevalent among the elderly, affecting almost 60% of community dwelling seniors (Brouwer et al., 2001). Although fear of falling primarily develops as a consequence of a fall episode (often referred to as the Post Fall Syndrome) (Tinetti et al., 1994), it is now known that fear of falling is prevalent among many seniors who have never experienced a fall. Furthermore, although many seniors live with a persistent and debilitating fear of falling, many others experience fear of falling only in specific situations or environmental contexts such as walking on ice or negotiating a curb or stair (Rosengren & McAuley, 1998).

Recently, laboratory groups have explored the notion of postural threat to test the potential influence of fear of falling on postural control and locomotion. In these studies, individuals were tested under environmental contexts that alter the potential consequences of instability, the underlying premise being that individuals will experience heightened physiological arousal, similar to that which may occur in situations that create a fear of falling (Brown et al., in press; Adkin et al., 2000; Carpenter et al., 1999; Brown & Frank, 1997). Our knowledge to date is that the reactive (Brown & Frank, 1997) and anticipatory control of upright stance are altered (Adkin et al., 2002) when the environmental context increases postural threat (Carpenter et al., 2001; Carpenter et al., 1999). In addition, we also know that the kinematics of gait are altered by postural threat (Brown et al., in press). Interestingly, alterations in gait kinematics observed among OA are substantially different than those of YA, leading to more conservative gait adaptations among OA compared to YA. Thus, if OA become more conservative than YA under threatening environmental contexts, the possibility remains that the age-dependent differences in obstacle negotiation kinematics that are suggested to contribute to increasing the risk for falling among the elderly may diminish when the consequences of instability are more severe. The purpose of this study was to investigate whether the obstacle negotiation kinematics used by older and younger adults were affected by postural threat.

We expected that regardless of age, the kinematics of obstacle negotiation would differ under conditions of postural threat. In particular, participants were expected to show conservative movement patterns evidenced by a shortening of crossing step length, and a slowing of crossing velocities (Chen et al., 1991). We also expected a longer pre-obstacle toe approach distance and a shorter post-obstacle heel strike distance as postural threat increased (Chen et al., 1991). Additionally, increased clearance heights (Begg & Sparrow, 2000) and increased crossing velocities for both limbs, as well as the whole body COM, were expected for the negotiation of obstacles as postural threat increased. More importantly, however, we expected that the alterations in gait kinematics would differ between younger and older adults. All kinematic measures were expected to show age-dependent differences with OA showing more conservative changes than YA across conditions of increasing postural threat.

2. Methods

2.1 Participants

Seventeen older (OA; 7 males, 10 females; mean age, 68.94 ± 4.85) and fifteen younger adults (YA; 5 males, 10 females; mean age, 22.53 ± 2.77) participated in this study. All participants voluntarily provided informed consent prior to beginning this study. Clearance to conduct this study was provided by the Human Research Ethics committee of the University of Lethbridge. All participants were free from non-age-related neurological and orthopaedic conditions that might affect gait and/or cognitive function. OA were required to undergo a neurological screen, comprised of standard sensorimotor tests of function, an electronystagmogram to exclude potential vestibular pathologies and a complete Mini-Mental State Evaluation to confirm cognitive status. A neurologist performed all neurological screenings.

All participants were asked to complete a Falls History form that assessed fear of falling (1 [not afraid] to 10 [very afraid]), fear of heights (1 [not afraid] to 10 [very afraid]), time since last fall (months), and if and when a fall was a result of tripping on an object. These questions served to assess participants' perceptions of their balance and their ability to avoid falling when faced with an obstacle in their path. Participants wore a t-shirt or blouse, shorts, running shoes, and a safety harness over their clothes.

2.2 Equipment

A custom designed elevated walkway was constructed (University of Lethbridge Technical Services Dept.). The walkway was 7.20 m in length and the width varied between experimental conditions (0.15 m or 0.60 m). The surface of the elevated walkway was located 0.60 m above the floor. When walking on the elevated surface, the safety harness worn by the participants was attached to a coupling that moved along a steel track anchored to the ceiling above the walkway.

2.3 Manipulation of Postural Threat

Four conditions of postural threat were included in this study: 1) Unconstrained Floor (UCF): walking along the floor within a width of 0.60m; 2) Constrained Floor (CF): participants were required to keep their feet within two strips of black tape placed 0.15m apart; 3) Unconstrained Elevated (UCE): walking along a wide (0.60m) walkway elevated 0.60m above the floor; and 4) Constrained Elevated (CE): participants were asked to walk along an elevated (0.60m), constrained (0.15m) walkway. The width of the constrained elevated walkway restricted the placement of the foot of the participants similar to that of the CF condition (Figure 2). The UCF condition was least threatening and the CE condition provided the most postural threat.

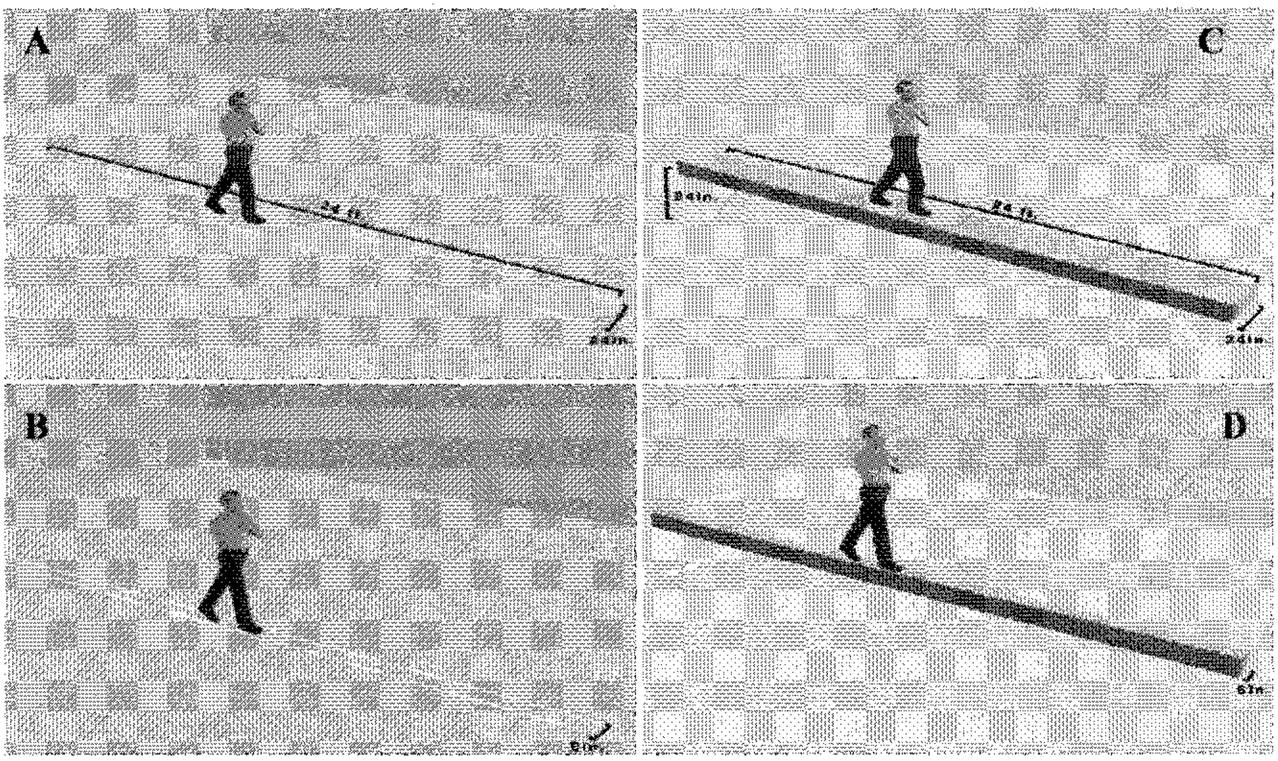


Figure 2: Schematic of the testing conditions of postural threat imposed to participants during all trials. (A) UCF: Unconstrained Floor, (B) CF: Constrained Floor, (C) UCE: Unconstrained Elevated, (D) CE: Constrained Elevated. Subjects wore a safety harness (not pictured) in all testing conditions.

2.4 Procedure

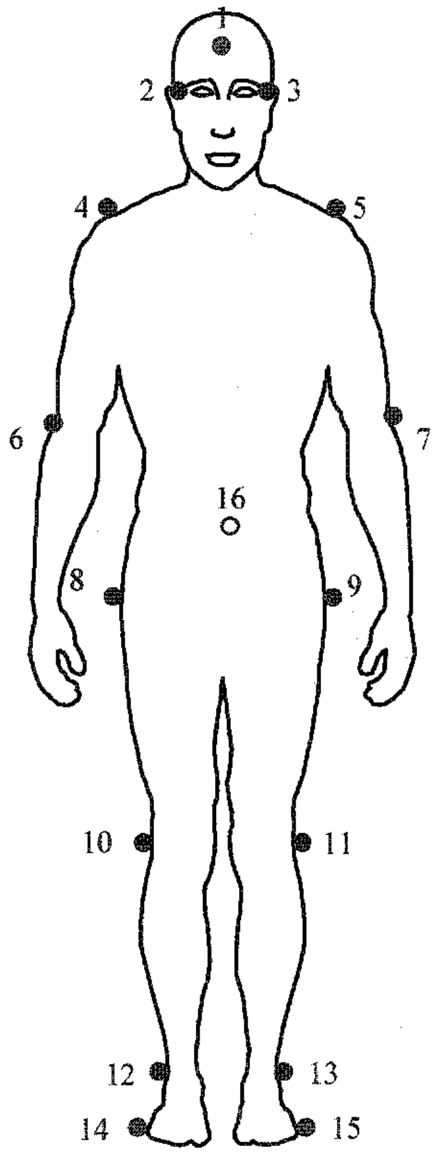
Participants were asked to walk at a comfortable speed along the length of the walkway in each of the four conditions of imposed postural threat. Participants performed a total of nine walking trials in each of the four conditions (total of 36 trials). Six of nine trials involved obstacle negotiation and three were control trials in which participants walked the length of the walkway without the challenge of obstacle avoidance. The six obstacle negotiation trials required that participants walk along the walkway and step over an obstacle placed on the walkway. The obstacle was either a flat beam of light (3 trials) or a foam block (3 trials) that was visible from trial onset. The light beam is referred to hereafter as the 'virtual' obstacle; the foam block is referred to as the 'real' obstacle. The virtual obstacle was projected by a theatre lamp (500 W, virtual obstacle height 0.00m, virtual obstacle width 0.60m or 0.15m (varied according to walkway width), virtual obstacle length 0.15m) that was located at ceiling height. The real obstacle (height 0.23m, width, 0.60m or 0.15m (varied according to walkway width), length 0.15m) was placed in the participants' walking path. Data collected during the real obstacle trials were analyzed and presented in a subsequent study (McKenzie, Study 2). Participants were instructed to keep their arms crossed in front of their chest to ensure visibility of the reflective hip markers for the duration of the walkway, including obstacle negotiation.

Trials were randomized within each condition. Condition order was presented using a Latin-square design (Tabachnick & Fidell, 1996) so that approximately the same number of participants could be randomly assigned to each of the 4 possible order combinations (i.e., 1 = UCF, CF, UCE, CE; 2 = CF, UCF, CE, UCE; 3 = UCE, CE, UCF, CF; 4 = CE, UCE, CF, UCF). This method was used to prevent practice effects as conditions increased or decreased in the severity of postural threat. Condition 1 was performed by 4 YA and 5 OA, condition 2 was performed by 4 YA and 3 OA, condition 3 was performed by 3 YA and 4 OA and condition 4 was completed by 4 YA and 4 OA. Each participant received 3 practice trials of unobstructed walking in each condition prior to data collection in that condition.

2.5 Instrumentation

Passive, infrared-reflective markers were placed on twenty anatomical landmarks. These landmarks were the forehead, sacrum, and bilaterally on the temple, acromion process, lateral epicondyle of the humerus, greater trochanter of femur, fibular head, heel, and the base of the fifth metatarsal (Figure 3). Kinematic data were collected at a frequency of 120 Hz using a 6 camera reflective marker data collection system (Peak Performance Technologies and Peak Motus 2000 software, Englewood, CO). Digital video data were also collected for all trials using frontal and sagittal views of walking.

Finger cuffs with silver/silver chloride electrodes from a BioDerm Skin conductance Level Meter (UFI, Moro Bay, CA, USA) were attached to the middle phalanges of digits 3 and 4 to monitor galvanic skin conductance (GSC) throughout testing. The duration of data collection was dictated by participant walking velocities but did not exceed 20s for each trial.



1. Forehead
2. R. Temple
3. L. Temple
4. R. Acromion process
5. L. Acromion process
6. Lateral epicondyle of R. Humerus
7. Lateral epicondyle of L. Humerus
8. Greater trochanter of R. Femur
9. Greater trochanter of L. Femur
10. R. Fibular head
11. L. Fibular head
12. R. Heel
13. L. Heel
14. Head of R. 5th metatarsal
15. Head of L. 5th metatarsal
16. Sacrum (posterior)

Figure 3: Schematic illustration of the placement of 16 reflective markers.

2.6 Measures of Interest

Results from the Falls History form were compiled to assess fear of falling levels, number of falls, cause of falls, and time since last fall. A fall was defined according to the definition forwarded by Tinetti and colleagues (1988): unintentionally coming to rest on the ground or at some other lower level, not as a result of a major intrinsic event or overwhelming hazard. Data for all measures were compiled using spreadsheets (Excel, Microsoft Co.).

Behavioral coding from video records provided data regarding the frequency of obstacle contacts and number of times an individual lost their balance. LOB was defined as a disruption or alteration in normal gait that required the harness or investigator assistance to maintain an upright stance.

Custom written algorithms were used to process kinematic and analog data and to determine event occurrences (Matlab, The Mathworks, Natick, MA, USA). For kinematic analysis, raw marker coordinate data were filtered using a dual pass 4th order digital Butterworth filter with a cut-off frequency of 3Hz. All velocity data were calculated using differentiation by the finite differences method.

Selected measures describing displacement and velocity characteristics of the lead and trail limbs during the crossing phase of obstacle negotiation were obtained. The lead limb was selected as the first limb to cross the obstacle; the trail limb was assigned to the second crossing limb (Chen et al., 1994a). Obstacle crossing was defined as the step used to cross the obstacle, framed by the trail toe approach position prior to the obstacle, to the lead heel strike position following the obstacle. Eight measures were selected to assess the effect of postural threat on the negotiation strategies of older and younger adults when negotiating the two types of obstacles. Table 1 provides full descriptions and Figure 4 illustrates the measures of interest.

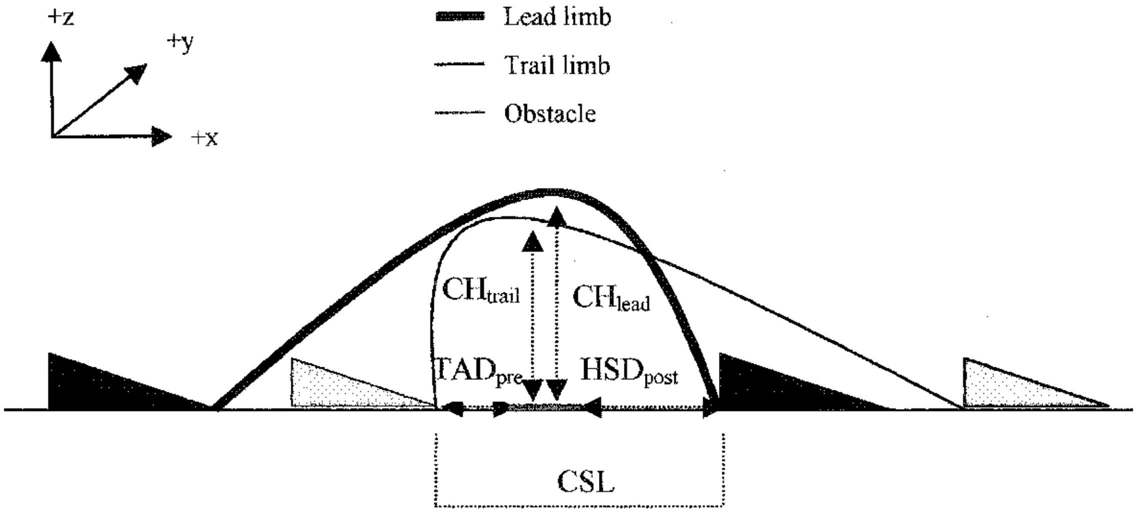


Figure 4: Measures of interest. Bold lines indicate the lead limb trajectory and normal lines indicate the trail limb trajectory during obstacle negotiation. Solid fill indicates the lead foot and grey fill indicates the trail foot. Note: TAD$_{pre}$ – distance from trail toe to edge of obstacle (x), HSD$_{post}$ – distance from lead heel to edge of obstacle (x), CSL – distance from the trail toe off to the lead heel contact (x), CH$_{lead}$, CH$_{trail}$ – height of lead and trail toe above the top of the center of the obstacle (z).

Table 1: Measures of interest and corresponding abbreviations and definitions.

Measure of Interest	Acronym	Description of Measure
Crossing step length (m)	CSL	Length of the step involved in crossing the obstacle defined from trail toe approach to lead heel strike
Lead crossing velocity (m/s)	CV$_{lead}$	Mean horizontal linear velocity of the lead limb during the crossing step
Trail crossing velocity (m/s)	CV$_{trail}$	Mean horizontal linear velocity of the trail limb during the crossing step
Whole body COM velocity (m/s)	CV$_{COM}$	Mean horizontal linear velocity of the whole body COM during the crossing step
Obstacle-heel strike distance (m)	HSD$_{post}$	Horizontal distance from the front edge of the obstacle to the lead heel contact position following crossing
Obstacle-toe approach distance (m)	TAD$_{pre}$	Horizontal distance from the rear edge of the obstacle to the trail toe off position prior to crossing
Lead cross height (m)	CH$_{lead}$	Vertical distance between the lead toe and the center of the top of the obstacle during crossing
Trail cross height (m)	CH$_{trail}$	Vertical distance between the lead toe and the center of the top of the obstacle during crossing

Mean galvanic skin conductance (GSC) was determined by calculating the average galvanic skin response value across each trial (Maki & McIlroy, 1996). A logarithmic transformation was applied to meet normal distribution requirements for statistical analysis. Due to technical limitations, GSC from 11 OA and 5 YA were included in this analysis.

2.7 Statistical Analysis

Data from the Falls History form were compiled and converted to percentages for each individual. Results regarding fear of falling and fear of heights were analyzed using separate t-tests to determine differences in the mean total scores of all categories. Number of steps taken, time since last fall and frequency of fall occurrence due to a trip were analyzed by Chi-squared tests to determine any differences in mean total scores for these categories.

The effect of postural threat on physiological arousal levels was assessed using a 2-way [Condition (UCF/CF/UCE/CE) x Group (YA/OA)] Repeated Measures Analysis of Variance (RM ANOVA). The eight kinematic measures of crossing kinematics were analyzed using mixed factor [Condition (UCF/CF/UCE/CE) x Group (YA/OA)] RM ANOVA. These measures were CSL, CV_{lead}, CV_{trail}, CV_{COM}, CH_{lead}, CH_{trail}, TAD_{pre} and HSD_{post}. Post hoc tests were performed using t-tests for the analyses of significant univariate results. To avoid type I errors from ANOVA results, alpha was adjusted to 0.006 using Bonferroni's correction. Significance was set at $p < 0.05$ for all other tests.

3. Results

Changes in obstacle negotiation kinematics as a result of aging are already well established (Austin et al., 1999; Chen et al., 1994b; Chen et al., 1991) and will not be presented in the current study . In this study, we have focused on the effects of postural threat on obstacle negotiation kinematics among younger and older adults. Our analysis in this regard targeted the effect of postural threat on the kinematics of the crossing phase of obstacle negotiation among younger and older adults.

3.1. Participant Data

Results from independent t-tests on participant history revealed that there was not a significant difference between YA and OA in their perceived fear of falling ($\underline{t}$ (30) = 1.575, $\underline{p} > 0.05$). When participants were asked to rate whether they were afraid of heights (Y/N), more OA responded with a fear of heights than YA ($\chi^2(1, N=32) = 4.96$, $\underline{p} < 0.05$). Although more OA reported having a fear of heights than YA, OA and YA did not differ in how long it had been since they last fell ($\chi^2(1, N=32) = 1.01$, $\underline{p} > 0.05$). Of the falls that both groups did experience, there were no age-related differences in the number of falls that were due to tripping ($\chi^2(1, N=32) = 1.12$, $\underline{p} > 0.05$). Furthermore, of the four OA who reported one fall within the last year, three of these falls were due to uneven or slippery terrain while one was due to misjudging a step. Two YA each reported one fall in the past year. Neither fall was due to uneven or slippery ground but was the result of misjudging a step.

3.2 Galvanic Skin Conductance

Testing conditions were designed to increase postural threat and induce physiological arousal. Changes in physiological arousal were indicated by mean GSC. Results from the 2-way RM ANOVA approached significance for Condition ($F(3,12)= 2.81$, $\underline{p}= 0.085$). However, visual inspection of the data indicated a trend of increasing GSC as postural threat increased and a substantial difference in GSC measures between the condition of least postural threat (UCF) and the condition of greatest postural threat (CE) (Figure 5). Follow-up t-test comparisons revealed a significant difference in GSC between the UCF and CE condition ($t(15)= 2.94$, $\underline{p}= 0.01$). GSC was not affected by age ($\underline{p}> 0.05$).

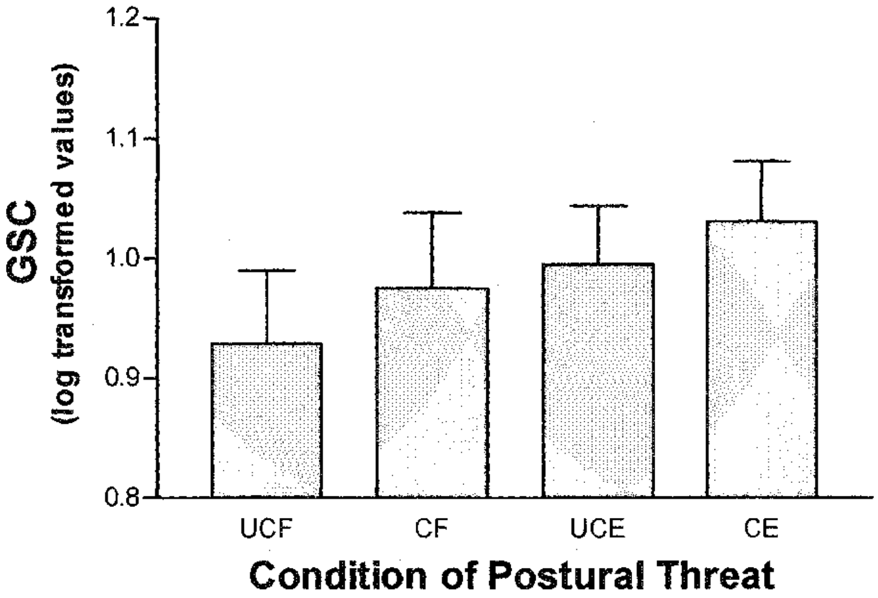


Figure 5: Log transformed galvanic skin conductance (GSC) indicating that participants in both groups experienced decreased GSC in the condition of least postural threat, with GSC increasing as postural threat increased.

3.3 Effects of Postural Threat on the Kinematics of Gait

3.3.1 Video Analysis

Frontal and sagittal view video recordings were analyzed to observe participants negotiating the obstacle during the four conditions of postural threat. For the purpose of this study, results for the number of loss of balance events and obstacle contacts are reported. Chi-squared tests indicated that loss of balance frequency was not affected by age or postural threat since older and younger adults maintained their balance through all trials of obstacle negotiation ($\chi^2(1, N=108) = 0.00$, $\underline{p} > 0.05$). Number of obstacle contacts was also unaffected by age or condition ($\chi^2(1, N=108) = 0.019$, $\underline{p} > 0.05$).

3.3.2 Crossing Step Gait Kinematics

3.3.2.1 Effects of Postural Threat

All crossing step measures were significantly affected by postural threat. Descriptive results for all measures are provided in Table 2. The CSL was 34% shorter in the most threatening condition compared to the least threatening condition (F(3,90)= 10.81, p= 0.000). Follow-up comparison of means revealed that for all subjects, the shortest CSL occurred in the CE condition (CE vs UCF: t(31)=4.63, p=0.000; CE vs CF: t(31)= 3.13, p= 0.004; CE vs UCE: t(31)= 3.52, p= 0.001). Similarly, the CV_{lead}, CV_{trail}, and CV_{COM} decreased significantly with increasing postural threat (CV_{lead}: F(3,90)= 30.79, p= 0.000; CV_{trail}: F(3,90)= 25.05, p= 0.000; CV_{COM} : F(3,90)= 53.68, p= 0.000). Follow-up comparison of means indicated that the CV_{lead} and CV_{trail} both decreased by 16% from the UCF to the CE condition (CV_{lead}: t(31)=7.78, p=0.000; CV_{trail}: t(31)= 5.29, p= 0.000). Additionally, the CV_{COM} decreased by 22% from the UCF to the CE condition (t(31)= 9.25, p= 0.000).

Table 2: Summary of descriptive statistics (mean ± standard error) for crossing step kinematics. Data are collapsed across age groups.

Measure of Interest	UCF	CF	UCE	CE
Crossing step length (m)	0.877 ± 0 .047	0.721 ± 0.035	0.721 ± 0.029	0.584 ± 0.034
Lead crossing velocity (m/s)	2.273 ± 0.060	2.079 ± 0.052	2.189 ± 0.073	1.898 ± 0.062
Trail crossing velocity (m/s)	2.142 ± 0.050	2.096 ± 0.052	2.126 ± 0.047	1.809± 0.061
COM crossing velocity (m/s)	1.129 ± 0.030	1.045 ± 0.027	1.083 ± 0.036	0.879± 0.036
Obstacle-heel strike distance (m)	0.273 ± 0.021	0.240 ± 0.011	0.328 ± 0.014	0.270 ± 0.013
Obstacle-toe approach distance (m)	0.60 ± 0.040	0.481 ± 0.036	0.447 ± 0.035	0.314 ± 0.029
Lead cross height (m)	0.078 ± 0.007	0.095 ± 0.012	0.118 ± 0.010	0.102 ± 0.008
Trail cross height (m)	0.072 ± 0.009	0.070 ± 0.007	0.116 ± 0.011	0.094 ± 0.009

CH_{lead} and CH_{trail} were significantly affected by postural threat (CH_{lead}: F(3,90)= 8.60, p= 0.000; CH_{trail}: F(3,90)= 17.94, p=0.000). In fact, CH_{lead} and CH_{trail} were significantly higher in the CE condition compared to the UCF condition (CH_{lead}: t(31)= 3.77, p= 0.001; CH_{trail}: t(31)= 3.85, p= 0.001), with the CH_{lead} increasing by 24% and the CH_{trail} increasing by 23%.

As postural threat increased, post-obstacle heel strike distance (HSD_{post}) decreased ($F(3,90)= 5.68$, $p=0.001$) and pre-obstacle toe approach distance (TAD_{pre}) decreased ($F(3,90)= 14.07$, $p=0.000$). In the condition of greatest postural threat, TAD_{pre} was 48% shorter than in the condition of least postural threat ($t(31)= 6.02$, $p=0.000$), however no significant differences were found for HSD_{post} between these conditions. Interestingly, the effect of postural threat for the measure of HSD_{post} emerged between the CF and the UCE conditions ($t(31)= 4.10$, $p= 0.000$) as well as between the UCE and the CE conditions ($t(31)= 6.60$, $p= 0.000$). HSD_{post} increased by 27% from the CF to the UCE condition and decreased by 30% from the UCE to the CE condition.

3.3.2.2 Age Interactions

Significant Condition x Age interactions emerged for the measures of CV_{lead}, CV_{trail}, and CV_{COM} (CV_{lead}: $F(3,90)= 30.79$, $p= 0.000$; CV_{trail}: $F(3,90)= 25.05$, $p= 0.000$; CV_{COM}: $F(3,90)= 53.68$, $p= 0.000$). Although both younger and older adults showed significantly slower CV_{lead}, CV_{trail}, and CV_{COM} from the UCF to the CE conditions, the changes in velocity observed among OA were greater than those observed among YA. OA decreased their CV_{lead} by 23% while YA decreased their CV_{lead} by only 10% between the UCF and CE conditions (OA: $t(16)= 8.16$, $p= 0.000$; YA: $t(14)= 4.59$, $p= 0.000$) (Figure 6). OA decreased their CV_{trail} by 23% with YA showing only an 8% decrease (OA: $t(16)= 5.04$, $p= 0.000$; YA: $t(14)= 3.01$, $p=0.009$) (Figure 7). Interestingly, OA showed a 29% decrease in CV_{COM} from the UCF to the CE condition while YA demonstrated a 15% decrease in CV_{COM} (OA: $t(16)= 8.99$, $p= 0.000$; YA: $t(14)= 6.25$, $p= 0.000$) (Figure 8).

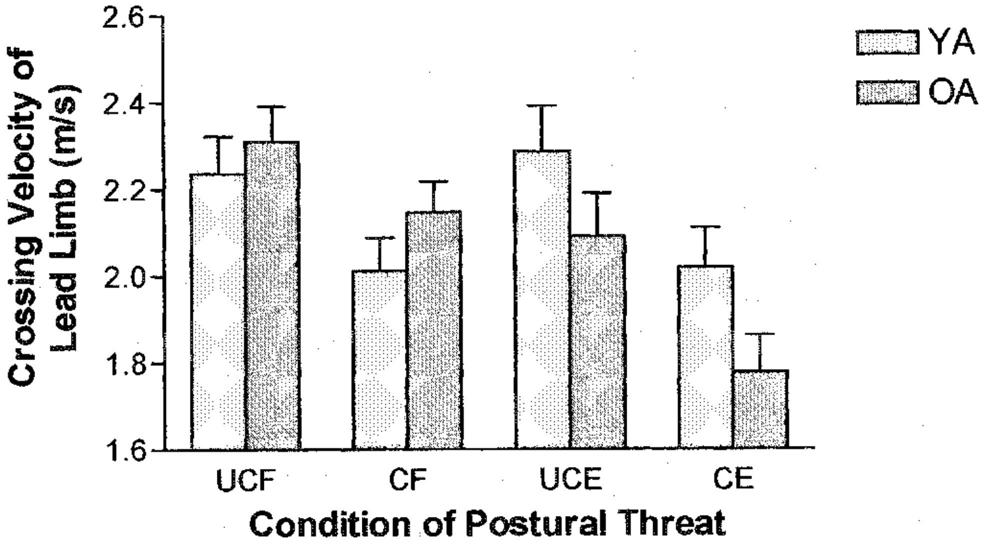


Figure 6: Lead cross velocity (CV_{lead}) for younger and older adults across 4 conditions of postural threat. Note that CV_{lead} decreased as postural threat increased. A significant Condition x Group interactions revealed that OA decreased CV_{lead} more than YA as postural threat increased.

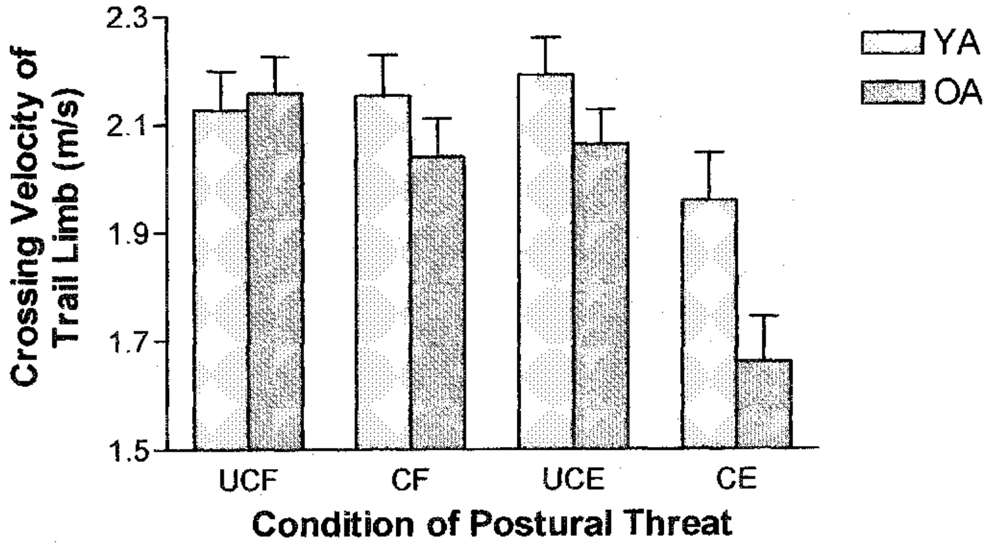


Figure 7: Trail cross velocity (CV_{trail}) for younger and older adults across 4 conditions of postural threat. Note that CV_{trail} decreased as postural threat increased. A significant Condition x Group interactions revealed that OA decreased CV_{trail} more than YA as postural threat increased.

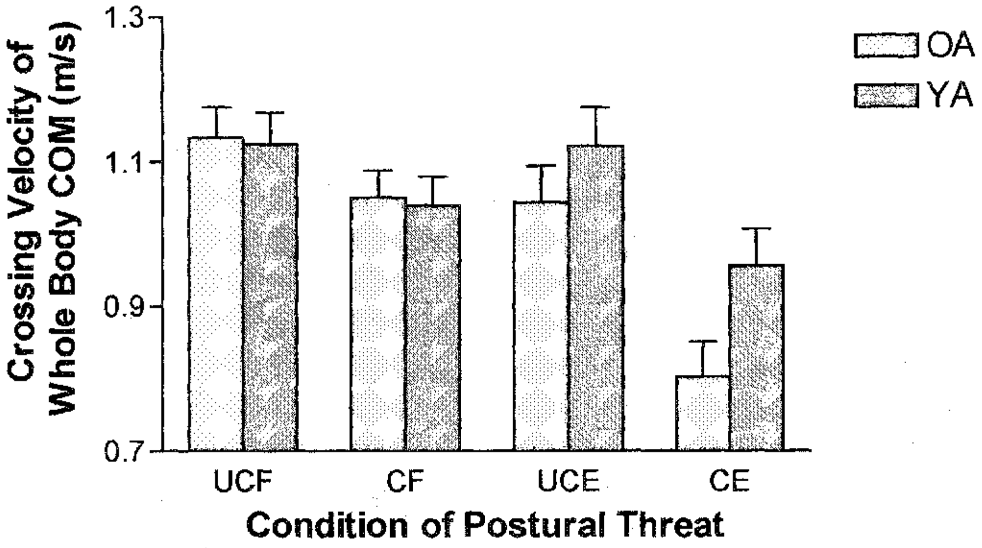


Figure 8: Whole body COM crossing velocity (CV_{COM}) for younger and older adults across 4 conditions of postural threat. Note that CV_{COM} decreased as postural threat increased. A significant Condition x Group interaction revealed that OA decreased CV_{COM} more than YA as postural threat increased.

Although the Condition x Age interaction was not significant for the measure of CH_{trail} (p= 0.070), visual inspection of the data suggested that CH_{trail} values were also affected by postural threat (Figure 9). Interestingly, this trend emerged among YA only. Comparison of means revealed that YA increased their CH_{trail} by 27% and older adults increased their CH_{trail} by 15% from the UCF to the CE condition (OA: t(16)= 1.58, p= 0.135; YA: t(14)= 4.17, p= 0.001). The effect among YA was significant while that among OA was not.

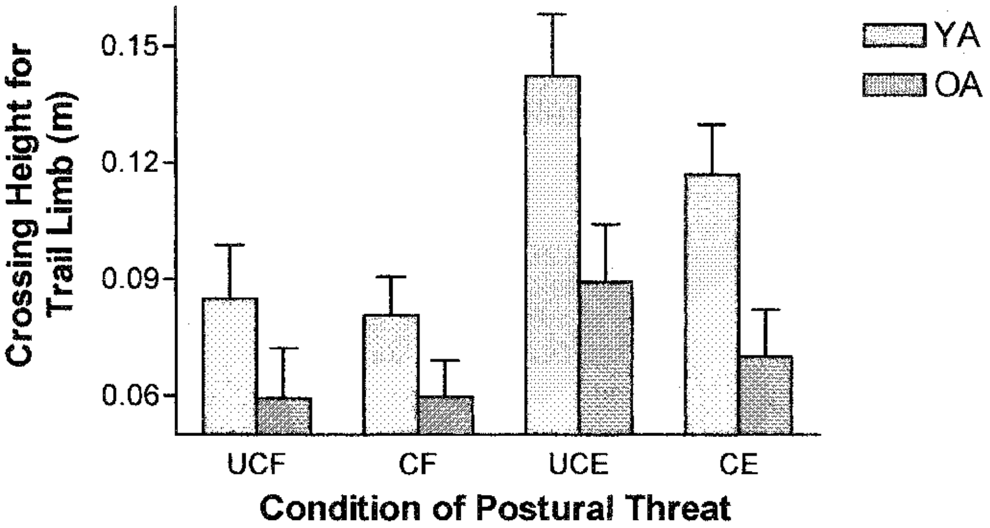


Figure 9: Trail crossing height (CH_{trail}) for younger and older adults across 4 conditions of postural threat. Note that CH_{trail} increased as postural threat increased. A significant Condition x Group interaction revealed that CH_{trail} increased more for YA than for OA as postural threat increased.

4. Discussion

It has already been established that younger and older adults demonstrate conservative control of posture and locomotion when postural threat is heightened (Brown et al., in press; Adkin et al., 2002; Adkin et al., 2000; Carpenter et al., 1999; Brown & Frank, 1997). Our work explored whether conservative patterns of behavior similarly emerged during obstacle negotiation tasks. The premise for our work was to determine whether the kinematic patterns of obstacle negotiation among the elderly that are suggested to increase fall risk (Begg & Sparrow, 2000; Chen et al., 1991) persist when the consequences of instability are more severe. In agreement with our hypothesis, our results indicated that regardless of age, the kinematics of obstacle crossing were affected by postural threat. However, our findings also revealed that although both groups showed similar changes when negotiating an obstacle under conditions of increased postural threat, OA tended to demonstrate more conservative responses than YA under these threatening conditions. We interpret these findings to indicate that OA adopt strategies of compensation to ensure successful obstacle negotiation and reduce fall risk when the consequences of instability are more severe.

Our findings add to current knowledge by extending the work dedicated to the effects of postural threat on postural control and locomotion (Brown et al., in press; Cham & Redfern, 2002; Adkin et al., 2002; Adkin et al., 2000; Carpenter et al., 1999) by contributing the effect of postural threat on obstacle negotiation kinematics. Our work also extends research focusing on the effects of age on obstacle crossing kinematics (Austin et al., 1999; Chen et al., 1994b). Although the effect of age on obstacle negotiation kinematics is beyond the primary purpose of our work, our findings did reveal that OA crossed obstacles more slowly and with smaller steps than YA as postural threat increased. Additionally, OA stepped further from the obstacle during the ascent phase and closer to the obstacle during the descent phases of negotiation and they used smaller vertical crossing heights than YA. These findings are aligned with previous work which has demonstrated that age does influence obstacle negotiation (Chen et al., 1994a; Chen et al., 1991).

4.1 Does postural threat influence crossing kinematics?

In agreement with our hypothesis, our results indicated that regardless of age, the kinematics of obstacle crossing were affected by postural threat. In particular, shorter CSL and decreased CV_{lead}, $CV_{trail,}$ and CV_{COM} were observed among all subjects. Changes in CV_{COM} according to task negotiation constraints have been presented previously. Specifically, Chou and Dragonich (1998b) reported that vertical COM velocity during obstacle crossing decreased as obstacle height increased. In particular, individuals crossed tall (15% of body height) obstacles with a slower vertical COM velocity than when crossing short (2.5% of body height) obstacles. It is possible that the height of the obstacle influences the perceived risk of falling such that a tall obstacle is perceived to present a greater threat for tripping than a shorter obstacle. Consequently, the impending threat of a tall obstacle seems to result in a slow, controlled crossing strategy. Thus, as forwarded by Chen and colleagues (1991), the risk of falling serves to alter the kinematics of obstacle negotiation.

In addition to alterations in CSL, CV_{lead}, CV_{trail}, and CV_{COM}, our findings also revealed that TAD_{pre} position decreased as postural threat increased. This finding reflects a smaller toe-obstacle distance for the trail limb during the crossing step and contradicts our expectations for conservative behavior (Chen et al., 1991). Given that there is potential for obstacle contact during the ascent phase of crossing by the trail limb (Chen et al., 1991), it is possible that decreasing the available horizontal distance between the trail limb and the obstacle may increase the risk for contact during the trail limb swing phase. Furthermore, although the pre-obstacle toe approach distance is closer, the trail limb must still be elevated vertically to ensure obstacle clearance. Moreover, the probability of obstacle contact is further enhanced because the body is progressing forward. Thus, when the magnitude of TAD_{pre} decreases, obstacle contact risk may increase because there is a limited distance available to the trail limb to ensure a sufficient crossing height. Indeed, previous age-related comparisons of obstacle negotiation kinematics demonstrated longer TAD_{pre} distances for OA compared to YA (Chen et al., 1991). This accommodation is inferred to be a conservative response adopted to reduce trip risk. It is curious that this finding emerged because it contradicts our proposed hypothesis that subjects will demonstrate more conservative behaviors and not adopt patterns that will heighten fall risk. One possible explanation is that the obstacle in this study did not pose any threat to balance if contacted. Thus, it may be the case that individuals were not taking as much care as they would had they been crossing an obstacle that may jeopardize safety if contacted.

As postural threat increased participants decreased the distance between the front of the obstacle and the heel of the lead limb. Although a shorter HSD_{post} may increase the risk of obstacle contact during the descent phase of the lead limb, this type of movement may also serve to create a stable BOS near the obstacle and may contribute to controlling the momentum of the COM. This strategy may increase the chance of recovery in the event of a trip. Therefore, it is possible that a short $\mathrm{HSD}_{\mathrm{post}}$ is a safety strategy implemented to decrease the possibility of a LOB by reducing the range of horizontal displacement required by the COM during obstacle crossing. On the contrary, since the obstacle holds no risk to postural threat if contacted, participants may be less concerned about negotiating the obstacle during the descent phase of crossing than they would be under a non-virtual obstacle negotiation task.

Our findings also revealed that $\mathrm{CH}_{\mathrm{lead}}$ and $\mathrm{CH}_{\mathrm{trail}}$ increased as postural threat increased. Previous work by Chen and colleagues (1991) has revealed that foot clearance height increased when negotiating a tall obstacle. Although obstacle height did not change in the current study, all participants adopted higher vertical clearance heights for the lead and trail limbs as postural threat increased. Previous work (Chou & Draganich, 1998; Chen et al., 1994a; Chen et al., 1991) confirms that vertical clearance height is modulated according to obstacle dimensions. Our findings imply that vertical clearance height also depends on the potential consequences of instability imposed by the environmental constraints. We speculate that individuals in this study were more concerned about falling in the more threatening conditions and thus, as also demonstrated by Chou and colleagues (1998a) modified their crossing kinematics to ensure that obstacle contact did not occur.

Interestingly, in line with previous work from our laboratory, (Brown et al., in press) our post-hoc analysis indicated that walking velocity throughout the trial decreased as postural threat increased ($F(3,90)= 31.03$, $p= 0.000$). Since participants were crossing an obstacle that was fixed and visible from trial onset, we propose that modifications were being made throughout the trial to better prepare for obstacle negotiation. These findings are in agreement with those of Adkin and colleagues (2002) who also found that anticipatory adjustments for postural control are magnified in threat conditions.

4.2 Age-dependent differences for the effect of threat

Our findings concur with our proposed hypothesis that OA would be affected differently than YA by conditions of imposed postural threat. The major findings from our work were that the crossing step was shorter and the crossing velocities of the lead and trail limb and the whole body COM were slower for OA compared to YA under conditions of postural threat. Slower crossing steps will minimize the momentum experienced by the COM; limiting the momentum of the COM will serve to reduce the possibility of instability in the event of obstacle contact because the quantity of motion that needs to be overcome will be reduced. Similar strategies of COM momentum control among the elderly have been reported previously. For example, Kaya and colleagues (1998) revealed that healthy OA limit their momentum during gait by decreasing walking speed. Similarly, Pai and colleagues (1994) concluded that constraints on the projection of the COM and horizontal momentum of the COM are necessary for maintaining upright stance at the termination of dynamic weight transfer during the sit-to-stand task.

One question that must be addressed is why OA adopt more conservative patterns of behavior than YA, particularly in the CE condition. Since crossing velocities were relatively similar between OA and YA throughout the other testing conditions, physical limitations do not seem to be the major cause for the differences that emerge in the CE condition. It is possible, however, that the constraints imposed by the testing conditions contribute to the observed age differences in crossing kinematics because OA were more fearful of falling than YA. We speculate that heightened physiological arousal has a more pervasive effect for OA than YA, thus resulting in slower movements and a controlled crossing pattern. Interestingly, this interpretation implies that a heightened arousal may be beneficial to reducing fall risk and may actually be helpful in preventing a fall or recovering from a trip. However, further research is needed to determine the effectiveness of controlled crossing patterns for obstacles that, in fact, will threaten balance if contacted. Furthermore, future studies also need to address whether conservative negotiation kinematics are beneficial in the avoidance of suddenly appearing obstacles. This future work will provide information regarding the ability to avoid obstacles under time constrained conditions rather than a controlled and predictive situation as presented here.

5. Conclusion

Findings from this study show that postural threat differentially affects the obstacle negotiation kinematics of younger and older adults. Specifically, crossing step length, toe approach distance, heel strike distance, crossing velocities, and clearance heights over a virtual obstacle were all affected by increasing postural threat, with OA showing more conservative behaviors than YA. Although OA are demonstrating more conservative strategies than YA, we cannot conclude that this is a detriment to their safety. Perhaps heightened physiological arousal in a given situation prepares OA physically and psychologically for a possible trip or slip. Conceivably, the conservative movements are actually safer, and if performed properly could reduce the risk for falling. On the contrary, the heightened arousal demonstrated by OA could be harmful to their safety. This arousal may increase co-contraction and joint stiffness, which may cause difficulty during trip recovery (Winter et al., 1990), specifically under time constrained conditions. As well, increased arousal may demand the allocation of more attention to postural control making individuals unable to detect sudden environmental risks. It is important to identify the mechanisms that are producing these modifications to determine whether they are helpful or harmful to OA when negotiating obstacles that pose varying levels of threat to their balance. In doing so, we can increase awareness in the elderly population and begin to develop effective strategies for safe obstacle negotiation.

STUDY 2: OBSTACLE NEGOTIATION KINEMATICS FOR DIFFERENT OBSTACLES: AGE-DEPENDENT EFFECTS OF POSTURAL THREAT

1. Introduction

It has been reported that tripping during walking is the primary cause of accidental injury among the elderly (Koroknay, 1995; Tinetti et al., 1988). Specifically, tripping over obstacles is responsible for 53% of falls in older adults (Blake et al., 1988). These falls result in serious injury, immobility, loss of independence, and even death (Tinetti & Williams, 1998). There are a number of factors to provide plausible explanation for the high rate of trip-induced falls among the elderly. Age-related declines in muscle strength (Aniansson et al., 1978), joint range of motion (Maki & McIlroy, 1996; Alexander, 1994), visual acuity (Koroknay, 1995), vestibular system sensitivity (Sloane et al., 1989), reduced proprioceptive sensitivity, and/or cognitive awareness (Hay, Bard, Fleury, & Teasdale, 1996; Teasdale, Stelmach, Breunig, & Meeuwsen, 1991) all alter the ability of OA to maintain balance and thus contribute to an increased risk and number of fall occurrences (Alexander, 1994). In addition to presenting challenge to postural control, age-related deterioration of the sensorimotor system also appears to affect obstacle negotiation kinematics (Pavol et al., 2001; Begg & Sparrow, 2000; Chen et al., 1991). For example, Chen and colleagues (1991) reported that OA negotiate obstacles at a slower crossing velocity than YA. Additionally, OA take shorter crossing steps, have smaller post-obstacle heel strike distances and initiate obstacle crossing further from the obstacle than YA.

Although we are now well informed about the age-related differences in the kinematics of obstacle negotiation, our knowledge remains limited regarding the potential contributions of factors other than age-dependent sensorimotor limitations that may also influence the expression of motor output. One such factor is fear of falling. Fear of falling is a low confidence in mobility tasks (Tinetti et al., 1990) that may lead to a debilitating anxiety regarding balance ability (Lachman et al., 1998).

Fear of falling is now established to be highly prevalent among the elderly, affecting almost 60% of community dwelling seniors (Brouwer et al., 2001). Although fear of falling develops primarily as a consequence of a fall episode (often referred to as the Post Fall Syndrome) (Tinetti et al., 1994), it is now known that fear of falling is prevalent among many seniors who have never experienced a fall. To explore the potential contribution of fear of falling on the control of upright stance and locomotion, research efforts have examined postural control and gait under challenging environmental contexts. The premise of work in this area is to determine whether heightened physiological arousal relating to the potential consequences of imbalance alters the regulation of gait and postural control. Work thus far has indicated that postural threat leads to a tighter regulation of postural control and conservative gait strategies (Brown et al., in press; Adkin et al., 2002; Adkin et al., 2000; Brown & Frank, 1997).

Our previous work (McKenzie, Study 1) explored whether obstacle negotiation is altered when the potential consequences of instability are more severe. Our intention was to investigate whether heightened arousal due to the possibility of an impending fall, such as may occur when there is a fear of falling, may also influence the kinematics of obstacle negotiation. Should the trend of conservative control that is mediated by postural threat (Brown et al., in press; Adkin et al., 2002; Adkin et al., 2000; Carpenter et al., 1999; Brown & Frank, 1997; McKenzie, Study 1) have not emerged during obstacle negotiation tasks, it would then appear that fear of falling contributes to the high incidence of trip related falls among the elderly. On the contrary, should behavioral adaptations that imply more conservative control during obstacle negotiation under postural threat conditions have emerged, it may be inferred that fear of falling regarding the possibility of a fall provides beneficial effects for fall prevention. Our findings demonstrated that regardless of age, obstacle negotiation kinematics were altered under conditions of postural threat. Specifically, lead, trail, and whole body COM crossing velocities decreased as postural threat increased. Additionally, increased postural threat resulted in a decrease in lead and trail toe vertical clearance heights as well as a decrease in the length of the crossing step. We interpreted these findings to indicate that individuals adopt more conservative crossing kinematics when the consequences of an impending fall are more severe. More compelling, however, we also revealed age-dependent differences in obstacle negotiation kinematics under conditions of postural threat. In particular, the imposed postural threat affected OA more than YA, and OA demonstrated slower lead and trail limb and whole body COM crossing velocities, lower vertical crossing heights, and shorter crossing steps than YA under conditions of postural threat. These findings confirmed that OA are more conservative than YA when crossing obstacles under potentially injurious environmental contexts.

Although our findings demonstrated compelling effects for postural threat, and significant age-dependent differences in obstacle negotiation kinematics under conditions of threat, our results emerged when participants negotiated a virtual obstacle, or an obstacle with no consequence for contact. Thus it remains a possibility that the observed kinematics reflect only the effect of postural threat and remain unbiased by the demands of negotiating an obstacle that, as is generally the case, holds the potential for jeopardizing safety if contacted. Thus, the purpose of this study was to investigate whether the alterations in obstacle negotiation kinematics that emerge among younger and older adults under conditions of postural threat are influenced by the potential consequences of obstacle contact.

We expected that obstacle avoidance kinematics would differ as the potential consequences of obstacle contact increased and that these obstacle negotiation kinematics would differ between younger and older adults. More importantly, however, we expected that as the potential consequences of obstacle contact increased, participants would also modify crossing kinematics to achieve longer crossing steps, longer post-obstacle heel strike distances, and longer pre-obstacle toe approach distances. Additionally, negotiation of a real obstacle that heightened fall risk if contacted, was expected to result in increased clearance heights compared to the negotiation of a virtual obstacle that did not pose a risk if contacted (Austin et al., 1999; McKenzie, Study 1). Crossing velocities for the lead and trail limbs, and the whole body COM were expected to decrease as the potential consequences for obstacle contact increased (McKenzie, Study 1). All kinematic measures and strategies were expected to show age-dependent differences with OA showing significantly greater changes than YA adults as the potential consequences of obstacle contact increased.

2. Methods

The protocol used for the current study is the same as that of our previous work and is reported fully in the previous study (McKenzie, Study 1). For the purpose of this study, we present measures of interest and statistical analysis techniques.

2.1 Measures of Interest

Behavioral coding from video records provided data regarding the frequency of obstacle contacts (times an individual touched the obstacle with their feet), and number of times an individual lost their balance. Loss of balance (LOB) was defined as a disruption or alteration in normal gait that required assistance to maintain an upright stance.

Obstacle crossing was defined as the step used to cross the obstacle using the lead limb from the trail toe off position prior to the obstacle to the lead heel contact position following the obstacle. Eight measures were selected to assess the effect of postural threat on the negotiation kinematics of younger and older adults when negotiating the two types of obstacles. Table 3 provides full descriptions and Figure 10 illustrates the measures of interest.

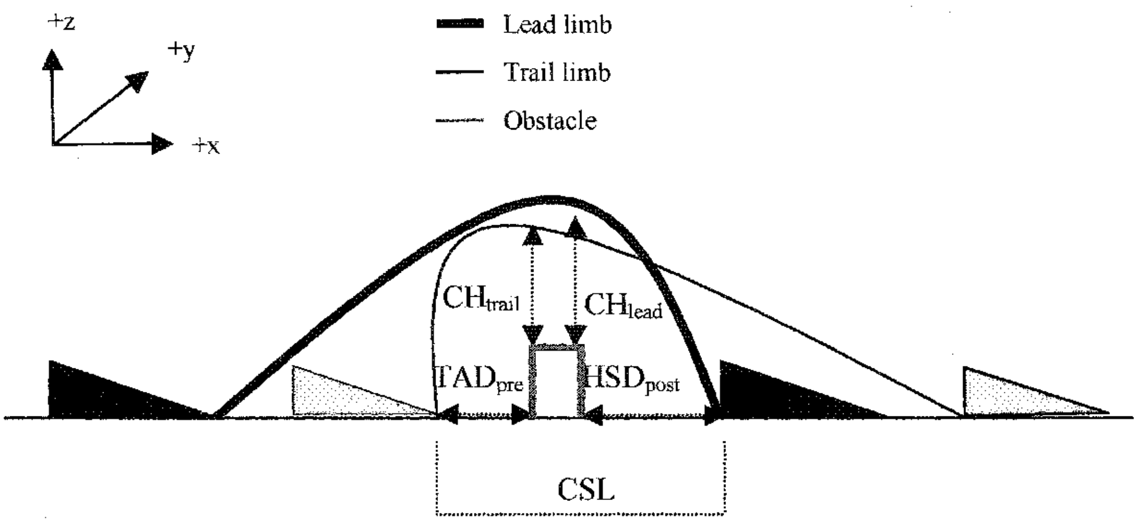


Figure 10: Measures of interest. Bold lines indicate the lead limb trajectory and normal lines indicate the trail limb trajectory during obstacle negotiation. Solid fill indicates the lead foot and grey fill indicates the trail foot. Note: TAD$_{\text{pre}}$ – distance from trail toe to edge of obstacle (x), HSD$_{\text{post}}$ – distance from lead heel to edge of obstacle (x), CSL – distance from the trail toe off to the lead heel contact (x), CH$_{\text{lead}}$, CH$_{\text{trail}}$ – height of lead and trail toe above obstacle (z).

Table 3: Measures of interest and the corresponding abbreviations and definitions.

Measure of Interest	**Acronym**	**Description of Measure**
Crossing step length (m)	CSL	Length of the step involved in crossing the obstacle defined from trail toe approach to lead heel strike
Lead crossing velocity (m/s)	CV$_{\text{lead}}$	Mean horizontal linear velocity of the lead limb during the crossing step
Trail crossing velocity (m/s)	CV$_{\text{trail}}$	Mean horizontal linear velocity of the trail limb during the crossing step
Whole body COM velocity (m/s)	CV$_{\text{COM}}$	Mean horizontal linear velocity of the whole body COM during the crossing step
Obstacle-heel strike distance (m)	HSD$_{\text{post}}$	Horizontal distance from the front edge of the obstacle to the lead heel contact position following crossing
Obstacle-toe approach distance (m)	TAD$_{\text{pre}}$	Horizontal distance from the rear edge of the obstacle to the trail toe off position prior to crossing
Lead cross height (m)	CH$_{\text{lead}}$	Vertical distance between the lead toe and the center of the top of the obstacle during crossing
Trail cross height (m)	CH$_{\text{trail}}$	Vertical distance between the lead toe and the center of the top of the obstacle during crossing

Mean galvanic skin conductance (GSC) was determined by calculating the average galvanic skin conductance values across each trial (Maki & McIlroy, 1996). A logarithmic transformation was applied to meet normal distribution requirements for statistical analysis. Due to technical limitations, GSC from 11 OA and 5 YA were included in this analysis.

2.2 Statistical Analysis

Data from the Falls History form were compiled and converted to percentages for each individual. Results regarding fear of falling and fear of heights were analyzed using separate t-tests to determine differences in the mean total scores of all categories. Time since last fall, and frequency of fall occurrences due to a trip were analyzed by Chi-squared tests to determine any differences in mean total scores for these categories.

The effect of postural threat on physiological arousal levels was assessed using a 2-way [Condition (UCF/CF/UCE/CE) x Group (YA/OA)] Repeated Measures Analysis of Variance (RM ANOVA). The eight kinematic measures of crossing kinematics were analyzed using mixed factor [Condition (UCF/CF/UCE/CE) x Group (YA/OA)] RM ANOVA. These measures were CSL, CV_{lead}, CV_{trail}, CV_{COM}, CH_{lead}, CH_{trail}, TAD_{pre} and HSD_{post}. Post hoc tests were performed using t-tests for the analyses of significant univariate results. To avoid type I errors from ANOVA results, alpha was adjusted to 0.006 using Bonferroni's correction. Significance was set at $p < 0.05$ for all other tests.

3. Results

3.1 Participant Data

Results from independent t-tests on participant history revealed that there was not a significant difference between YA and OA in their perceived fear of falling

(t (30) = 1.58, $p > 0.05$). When participants were asked to rate their fear of heights, more OA responded with a fear of heights than YA ($\chi^2(1, N=32) = 4.96$, $p < 0.05$). Although more OA reported having a fear of heights than YA, OA and YA did not differ in how long it had been since they last fell ($\chi^2(1, N=32) = 1.01$, $p > 0.05$). Of the falls that both groups did experience, there were no age-related differences in the number of falls that were due to tripping ($\chi^2(1, N=32) = 1.12$, $p > 0.05$). Furthermore, of the four OA who reported one fall within the last year, three of these falls were due to uneven or slippery terrain while one was due to misjudging a step. Two YA reported one fall in the past year and neither of these falls were due to uneven or slippery ground but were the result of misjudging a step.

3.2 Galvanic Skin Conductance

Results from the 2-way RM ANOVA approached significance for condition ($F(3,12)= 2.81$, $p= 0.085$). However, visual inspection of the data indicated a trend of increasing GSC as postural threat increased and a substantial difference in GSC measures between the condition of least postural threat (UCF) and the condition of greatest postural threat (CE) (Figure 10). Follow-up t-test comparisons revealed a significant difference in GSC between the UCF and CE condition ($t(15)= 2.94$, $p= 0.01$). GSC was not affected by age ($p> 0.05$).

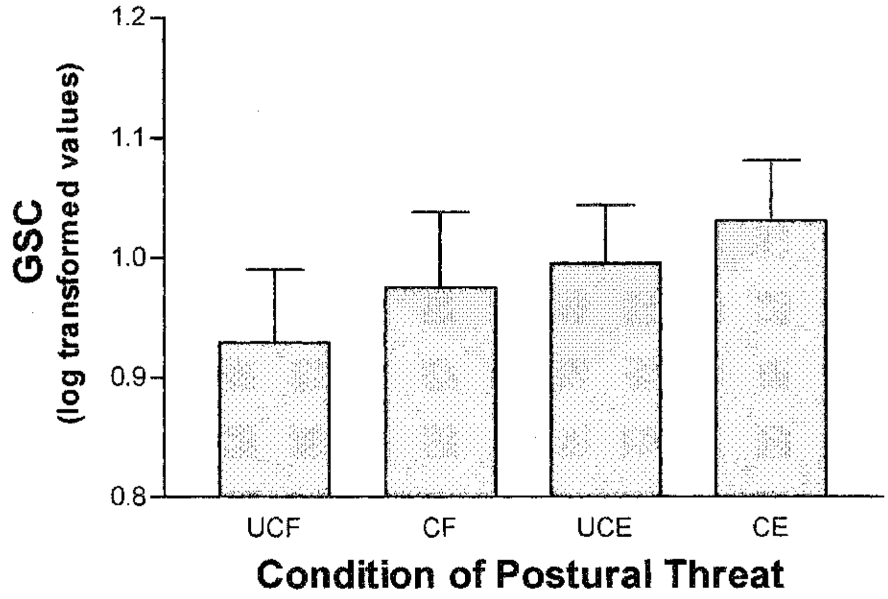


Figure 11: Log transformed galvanic skin conductance (GSC) indicating that participants in both groups experienced decreased GSC in the condition of least postural threat, with GSC increasing as postural threat increased.

3.3 Effects of Postural Threat on the Kinematics of Gait

3.3.1 Video Analysis

Frontal and sagittal view video recordings were analyzed to observe participants negotiating the obstacle during the four conditions of postural threat. For the purpose of this study, results for the number of LOB events, and obstacle contacts are reported. Chi-squared tests indicated that loss of balance frequency was not affected by age or postural threat since YA maintained their balance through all trials of obstacle negotiation and OA experienced only three LOB in the CE condition and two LOB in the CF conditions ($\chi^2(1, \underline{N}=108) = 0.24$, $\underline{p} > 0.05$). Number of obstacle contacts were also unaffected by age or condition ($\chi^2(1, \underline{N}=108) = 0.17$, $\underline{p} > 0.05$).

3.3.2 Crossing Step Gait Kinematics

3.3.2.1 Effects of Postural Threat

Our previous work has demonstrated the effects of postural threat on obstacle negotiation kinematics (McKenzie, Study 1). The findings of the current study confirm our previous work and demonstrate that crossing step kinematics were significantly affected by imposed postural threat. Main effects and descriptive statistics are fully summarized in Table 4. This study revealed a main effect for postural threat as CSL decreased with postural threat (F(3,90)= 16.29, p= 0.000). Additionally, the CV_{lead}, CV_{trail}, and CV_{COM} significantly decreased with increasing postural threat (CV_{lead}: F(3,90)= 44.89, p= 0.000; CV_{trail}: F(3,90)= 22.85, p= 0.000; CV_{COM}: F(3,90)= 133.14, p= 0.000). As in our previous work, increasing postural threat caused significant increases in CH_{lead} and CH_{trail} (CH_{lead}: F(3,90)= 48.16, p= 0.000; CH_{trail}: F(3,90)= 122.63, p= 0.000). Finally, significant effects emerged for the measures of HSD_{post} (F(3,90)= 9.60, p= 0.000), and TAD_{pre} (F(3,90)= 17.34, p= 0.000) and indicated that both measures decreased as postural threat increased.

Table 4: Summary of descriptive statistics (mean ± standard error) for crossing step kinematics. Data are collapsed across age groups.

Measure of Interest	**UCF**	**CF**	**UCE**	**CE**
Crossing step length (m)	0.799 ± 0.034	0.652 ± 0.025	0.665 ± 0.032	0.546 ± 0.028
Lead crossing velocity (m/s)	2.176 ± 0.053	2.044 ± 0.063	1.950 ± 0.052	1.842 ± 0.061
Trail crossing velocity (m/s)	2.234 ± 0.053	2.136 ± 0.055	2.119 ± 0.044	1.968± 0.049
COM cross velocity (m/s)	1.087 ± 0.028	0.981 ± 0.034	0.898 ± 0.028	0.802± 0.033
Obstacle-heel strike distance (m)	0.256 ± 0.015	0.299 ± 0.012	0.229 ± 0.009	0.221 ± 0.008
Obstacle-toe approach distance (m)	0.542 ± 0.031	0.380 ± 0.024	0.434 ± 0.029	0.325 ± 0.026
Lead cross height (m)	0.087 ± 0.009	0.110 ± 0.009	0.177 ± 0.008	0.199 ± 0.010
Trail cross height (m)	0.071 ± 0.008	0.105 ± 0.010	0.222 ± 0.009	0.257 ± 0.011

3.3.2.2 Effects of Potential Consequences of Obstacle Contact

For all subjects, the length of the crossing step was significantly shorter when crossing the real compared to the virtual obstacle ($F(1,30)= 33.40$, $p= 0.000$). Specifically, CSL was 19% shorter when crossing the real obstacle compared to crossing the virtual obstacle. In addition, the CV_{lead} ($F(1,30)= 60.58$, $p= 0.000$), CV_{trail} ($F(1,30)= 20.89$, $p= 0.000$), and the CV_{COM} ($F(1,30)= 86.72$, $p= 0.000$) decreased when the consequences of obstacle contact increased (see Table 5). When crossing the real obstacle compared to the virtual obstacle, all crossing velocities were slower (CV_{lead}: 11%, CV_{trail}: 9%, CV_{COM}: 13%). Main effects for obstacle also emerged for the HSD_{post} and TAD_{pre}, which showed significant decreases as the consequences of obstacle contact increased (HSD_{post}: $F(1,30)= 37.97$, $p= 0.000$; TAD_{pre}: $F(1,30)= 19.19$, $p= 0.000$) (Table 5). In fact, HSD_{post} was 13% shorter and TAD_{pre} was 24% shorter when crossing the real compared to the virtual obstacle. The measures of CH_{lead} and CH_{trail} did not reach significance (CH_{lead} : $F(1,30)= 0.40$, $p= 0.54$; CH_{trail} : $F(1,30)= 5.05$, $p= 0.032$).

Table 5: Summary of descriptive statistics (mean ± standard error) for crossing step kinematics. Data are collapsed across age groups and levels of postural threat.

Measure of Interest	Virtual	Real
Crossing step length (m)	0.734 ± 0.023	0.597 ± 0.024
Lead crossing velocity (m/s)	2.114 ± 0.062	1.892 ± 0.050
Trail crossing velocity (m/s)	2.134 ± 0.046	1.953 ± 0.052
COM cross velocity (m/s)	1.009 ± 0.031	0.875 ± 0.029
Obstacle-heel strike distance (m)	0.269 ± 0.006	0.234 ± 0.007
Obstacle-toe approach distance (m)	0.479 ± 0.025	0.362 ± 0.023
Lead cross height (m)	0.142 ± 0.005	0.144 ± 0.006
Trail cross height (m)	0.169 ± 0.007	0.159 ± 0.007

3.3.2.3 Postural Threat and Potential Consequences of Obstacle Contact Interactions

Significant Condition x Obstacle interactions emerged for CV_{trail}, and CV_{COM} (CV_{trail}: $F(3,90)= 14.01$, $p= 0.000$; CV_{COM}: $F(3,90)= 10.54$, $p= 0.000$) only. Follow-up comparison of means revealed that the CV_{trail} differed significantly between the virtual and real obstacle in the CE condition (t(31)= 4.26, p= 0.000). Specifically, CV_{trail} was 15% slower when crossing the real obstacle compared to the virtual obstacle in the CE condition. The difference between the CV_{COM} when negotiating the real and virtual obstacle also differed significantly for each condition (UCF: t(31)= 12.87, p= 0.000; CF: t(31)= 11.84, p= 0.000; UCE: t(31)= 13.75, p= 0.000; CE: t(31)= 10.85, p= 0.000). Follow-up comparisons also revealed that the CV_{trail} was significantly slower in the CE compared to the UCF condition (virtual: 7% change: (t(31)= 5.29, p= 0.000; real: 17% change: t(31)= 5.29, p= 0.000) (Figure 12). Similarly, the CV_{COM} was 22% slower for the virtual obstacle and 31% slower for the real obstacle in the CE compared to the UCF condition (virtual: t(31)= 9.25, p= 0.000; real: t(31)= 7.78, p= 0.000) (Figure 13).

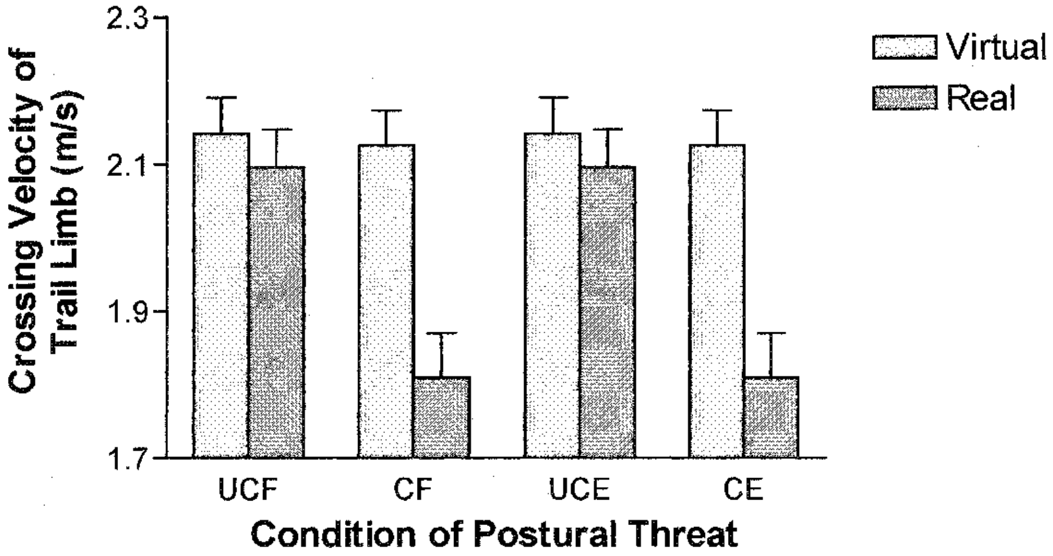


Figure 12: Trail cross velocity (CV_{trail}) for younger and older adults across 4 conditions of postural threat. Note that CV_{trail} decreased as postural threat increased. A significant Condition x Obstacle interaction revealed that CV_{trail} was slower for negotiation of the real obstacle compared to the virtual obstacle as postural threat increased.

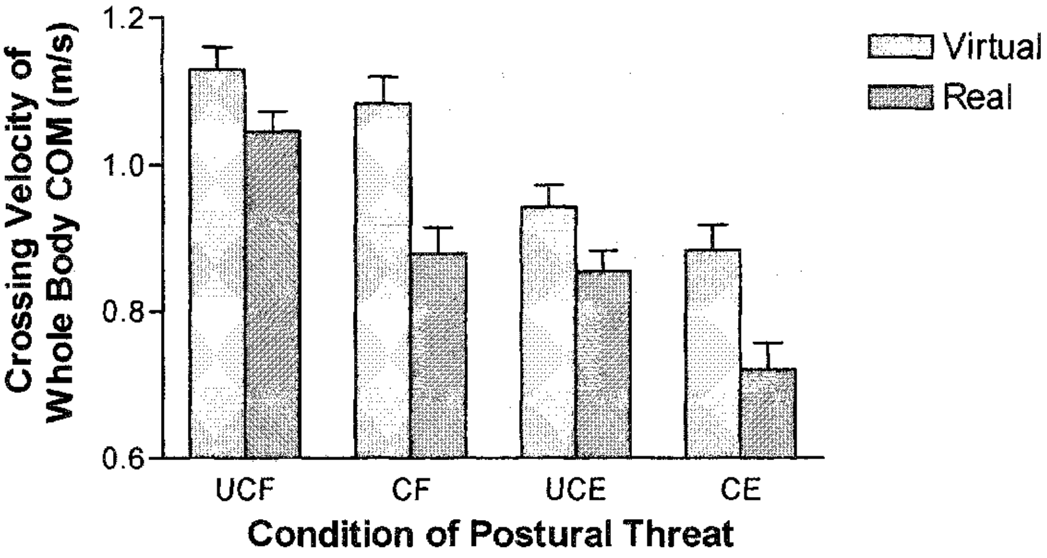


Figure 13: Whole body COM velocity (CV_{COM}) for younger and older adults across 4 conditions of postural threat. Note that CV_{COM} decreased as postural threat increased. A significant Condition x Obstacle interaction revealed that CV_{COM} was slower for negotiation of the real obstacle compared to the virtual obstacle as postural threat increased.

3.3.2.4 Age Interactions

Our findings confirm those of our previous work (McKenzie, Study 1) that CV_{lead}, CV_{trail}, and CV_{COM} were significantly different between younger and older adults as postural threat increased (CV_{lead}: (F(3,90)= 13.84, p= 0.000; CV_{trail}: (F(3,90)= 11.47, p= 0.000; and CV_{COM}: (F(3,90)= 15.63, p= 0.000). Follow-up comparison of means revealed that OA significantly decreased their CV_{lead}, CV_{trail}, and CV_{COM} from the UCF to the CE condition by 22%, 18% and 35% respectively (CV_{lead}: t(33)= 11.04, p= 0.000; CV_{trail}: t(33)= 8.22, p= 0.000; and CV_{COM}: t(33)= 11.80, p= 0.000). However, the results for YA showed substantially lower magnitudes of change in CV_{lead} (t(29)= 5.30, p= 0.000), CV_{trail} (t(29)= 3.87, p= 0.001), and CV_{COM} (t(29)= 7.88, p= 0.000) by reducing velocities by 8%, 6% and 17% respectively from the UCF to the CE condition.

Age-dependent interactions revealed that although CH_{lead} significantly increased among OA and YA as postural threat increased (F(3,90)= 5.11, p= 0.003), OA increased their CH_{lead} more (64%) than YA (46%) in the CE compared to the UCF condition regardless of obstacle contact consequences (Figure 14). None of the measures reached significance for the Obstacle x Age or the Condition x Obstacle x Age interactions.

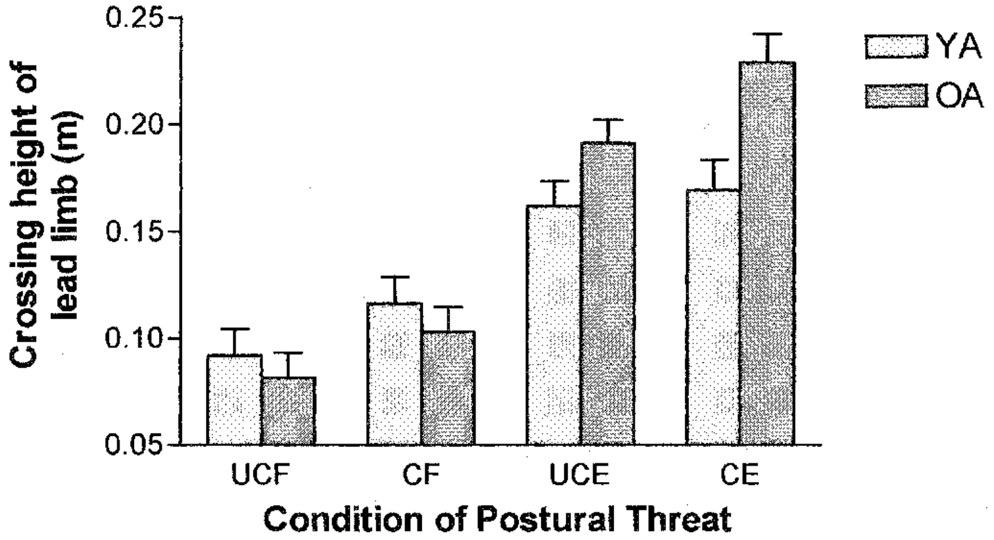


Figure 14: Lead cross height (CH_{lead}) for younger and older adults across 4 conditions of postural threat. Note that CH_{lead} increased as postural threat increased. A significant Condition x Group interaction revealed that CH_{lead} increased more for OA than for YA as postural threat increased.

4. Discussion

Our previous work (McKenzie, Study 1) revealed that younger and older adults adopt conservative patterns of negotiation kinematics under conditions of postural threat. We interpreted these findings to indicate that heightened physiological arousal, which increased as postural threat increased, contributed to the conservative behaviors observed. However, since the obstacle in our previous work did not pose any risk to balance if contacted, our understanding of the effect of postural threat on more natural situations of obstacle negotiation remained incomplete. In particular, it remained possible that the behavioral changes that emerged reflected only the effect of postural threat and remained unbiased by the demands of negotiating an obstacle that, as is generally the case, may threaten balance if contacted. Thus, in our present work, we sought to determine whether the alterations in negotiation kinematics that emerge among younger and older adults under conditions of threat are also influenced by the potential consequences of obstacle contact. Our findings replicated our previous work to confirm that both younger and older adults alter their obstacle negotiation kinematics under conditions of postural threat. Similarly, the changes observed among OA were substantially different than those among YA, with OA adopting more conservative strategies than YA in threatening conditions. As expected, the kinematics of obstacle avoidance were influenced by the type of obstacle being negotiated, and regardless of age, all participants crossed the real obstacle in a more conservative manner than the virtual obstacle. The interesting findings, however, were that the effects of obstacle type differed across conditions of postural threat, and that age did not influence the negotiation kinematics of a real versus a virtual obstacle in any of the conditions of threat. We have interpreted these findings to indicate that regardless of age, the potential consequences of obstacle contact play a significant role in obstacle negotiation. Furthermore, when the consequences of obstacle contact are more severe and postural threat is elevated, both younger and older adults will demonstrate crossing behaviors that may reduce the possibility of instability.

4. 1 Does postural threat influence negotiation kinematics?

The findings of the present study confirm our previous work and demonstrate that postural threat differentially alters obstacle negotiation kinematics among younger and older adults. A thorough report and interpretation of the effects of postural threat on the kinematics of obstacle negotiation is available in our previous work (McKenzie, Study 1. The interesting finding from this study was that regardless of the obstacle being negotiated, postural threat influenced negotiation kinematics of all subjects. The results that emerged in this study replicated our previous findings and are not discussed in this paper.

4.2 Do the potential consequences of obstacle contact influence negotiation kinematics?

Obstacle negotiation kinematics have been examined independently for real (Austin et al., 1999) and virtual obstacles (Chen et al., 1994b). Although Patla and colleagues (1996) compared the locomotor patterns of the lead and trail limbs during solid and fragile obstacle negotiation, no studies to date have focused on comparing the crossing kinematics for real and virtual obstacles. Virtual obstacles permit investigation of negotiation kinematics without posing any risk to balance should contact occur. However, since the inherent risk associated with negotiation of a real obstacle exceeds that of a virtual obstacle, the resulting kinematic trends from a virtual obstacle negotiation task may not be representative of the strategies that emerge in more natural environments. Our findings confirmed that as the potential consequences of obstacle contact increased, negotiation kinematics changed. Interestingly, the alterations that emerged showed trends similar to those that emerged under conditions of postural threat. Specifically, CSL, $\text{TAD}_{pre,}$ HSD_{post} decreased and CV_{lead}, CV_{trail} and CV_{COM} were slowed when crossing the real obstacle compared to the virtual obstacle for both younger and older adults.

It is possible that the observed alterations in negotiation kinematics are not solely attributed to obstacle contact consequences but may also reflect the demands associated with negotiating a higher obstacle. However, contrary to our hypothesis, CSL, $\text{TAD}_{pre,}$ and HSD_{post} decreased as the consequence of obstacle contact increased. From our previous work (McKenzie, Study 1) we found that these measures decreased with increasing postural threat. Thus, we expected that if the potential consequences of obstacle contact were more severe, individuals would modify negotiation kinematics to maximize step length and the horizontal distance between the obstacle and the lead and trail limbs. We expected that, increases in step length and relative horizontal obstacle positioning would emerge for the more demanding task. However, since CSL, TAD_{pre}, and HSD_{post} decreased when negotiating the real obstacle compared to the virtual obstacle, it appears that participants are modifying their crossing strategy to more appropriately reflect the demands associated with crossing an obstacle that may cause a trip if contacted, rather than the demands associated with an obstacle that differs in vertical height. Thus, we believe that the perceived risk associated with contact also contributes to the alterations in crossing kinematics observed among all participants.

Previous research (Chou & Draganich, 1998; Chen et al., 1994a; Chen et al., 1991) demonstrated that vertical clearance height is modulated according to obstacle dimensions. As well, Austin and colleagues (1999) report that vertical clearance heights increase with increasing obstacle height. Thus, we did not expect that CH_{lead} and CH_{trail} would be similar when negotiating the real compared to the virtual obstacle. However, this finding provides support for our theory that the imposed consequences of obstacle contact also affect the kinematics of obstacle negotiation. Since the height of the real obstacle is equivalent to that of a sidewalk curb, it is possible that subjects do not perceive this obstacle to be a threat to their balance and are not adjusting vertical clearance height as we expected. This hypothesis is in agreement with our GSC data that revealed no effect for obstacle type. On the contrary, although it would seem that an increased clearance height over a real obstacle would be a desirable strategy for safety, it may be that moving slowly and lifting the limbs the required minimum height to avoid obstacle contact is actually safer for the negotiation of a real obstacle. These conservative crossing height kinematics may benefit balance by minimizing the momentum of the COM and increasing the probability of recovery should a trip occur. Alternately, perhaps the crossing heights subjects are using for negotiation of the virtual obstacle are perceived to be sufficient for negotiation of the real obstacle. Consequently, we see no modulation of vertical clearance height between obstacles.

Contrary to our hypothesis that OA would be more affected than YA by the potential consequences of obstacle contact, we found that age did not influence the effect of obstacle type. Since OA did display more conservative kinematics compared to YA as postural threat increased, it is possible that the kinematic alterations adopted by OA in a response to the imposed threat are sufficient to tolerate the demands of the different obstacles. On the contrary, it is also possible that OA do not perceive the obstacle to present a threat to their balance because the height does not exceed that of a sidewalk curb. We can also speculate that since OA demonstrate greater conservative behaviors than YA in conditions of postural threat, that OA have reached a ceiling or maximum display of conservative kinematics in the threatening conditions and can not physically express behaviors that are more conservative than those previously observed as postural threat increased.

4.3 Do the effects of the potential consequences of obstacle contact differ across conditions of postural threat?

It has already been established that increasing postural threat (McKenzie, Study 1) and obstacle height (Austin et al., 1999; Chen et al., 1994a; Chen et al., 1991) have an effect on the obstacle negotiation kinematics of younger and older adults. It is not surprising then, that we observe more conservative behaviors among both younger and older adults as postural threat and the potential consequences of obstacle contact increase in the current study. However, the magnitude of change in CV_{trail} and CV_{COM} that emerged under threatening conditions differed between virtual and real obstacles. In particular, the negotiation of a real obstacle resulted in slower CV_{trail} and CV_{COM} compared to the negotiation of a virtual obstacle. Winter (1991) reports that the risk for obstacle contact for the trail limb is during the mid-point of the swing phases because the limb achieves maximum velocity and minimum clearance height at this point. Slowing the crossing of the trail limb and the whole body COM particularly for the real obstacle in the most threatening condition will reduce the probability of obstacle contact by the trail limb. In addition, these modifications will reduce COM momentum and consequently, increase balance recovery ability in the event of a trip.

5. Conclusion

Findings from this study show that the potential consequences of obstacle contact affect the obstacle negotiation kinematics of younger and older adults under conditions of postural threat. Specifically, the crossing step length, velocities, and the horizontal distance prior to and following obstacle crossing were all affected when crossing a real compared to a virtual obstacle. Conceivably, conservative kinematics are safer and may reduce the risk for falling. From our results we can conclude that postural threat and the potential consequences of obstacle threat affect both younger and older adults. Interestingly, although postural threat affects OA differently than YA, threat of obstacle contact affects younger and older adults equally. We speculate that OA do perceive the threatening walking conditions to present a challenge to their balance, but may not perceive the real obstacle to be a risk to postural control. On the contrary, YA may recognize the real obstacle to be a threat to balance, but do not perceive the walking constraints to be hazardous. For this reason, we propose that increased postural threat may result in more conservative behaviors in OA compared to YA, but that increased consequences of obstacle contact do not. Alternately, we propose that OA may perceive both the walking constraints and the impending threat of obstacle contact to be threatening to their balance. However, perhaps OA are performing at a maximum level of conservatism in response to increased postural threat and cannot physically express more conservative kinematics as the potential consequences of obstacle contact increases. Perhaps the perceived risk of postural threat alters the crossing kinematics of OA to a level that is sufficient to tolerate increased potential consequences of obstacle contact. It is important to identify the mechanisms that are producing these modifications to determine whether they are helpful or harmful to OA when negotiating obstacles that pose varying levels of threat to their balance. In doing so, we can increase awareness in the elderly population and begin to develop effective strategies for safe obstacle negotiation.

General Discussion

This thesis examined whether the potential consequences of instability and the potential consequences of obstacle contact alter the age-related kinematics of obstacle negotiation. Two different studies were performed: Study 1 addressed the effects of postural threat on the obstacle negotiation kinematics of younger and older adults; Study 2 examined whether the negotiation kinematics that emerged under conditions of postural threat were influenced by the potential consequences of obstacle contact. Participants were tested under four different conditions of postural threat.

1. Changes in Arousal in Response to Postural Threat

To answer the questions presented in this thesis, it was first necessary to confirm that the conditions of postural threat heightened physiological arousal. Level of arousal was assessed using the measure of galvanic skin conductance (GSC). GSC is a measure of the conductivity of the participants' skin in response to changes in the amount of perspiration on the surface of the skin (Boucsein, Baltissen, & Euler, 1984) and is used as a standard measure of physiological arousal. We expected that the lowest GSC levels would emerge in the UCF condition and the highest levels of GSC would occur in the CE condition. Our results confirmed our expectations and were interpreted to indicate that all subjects experienced heightened levels of arousal as postural threat increased (see Figure 5; pg 30 & Figure 10; pg. 45). Interestingly, we did not observe any age-dependent differences in physiological arousal across any of the testing conditions. This finding was not unexpected because our older participants were all healthy and medically screened to be physically fit. Furthermore, there were no differences in fear of falling levels between our age group populations. We speculate that should this protocol be replicated on a group of OA who identify as experiencing fear of falling during daily activities, group differences in levels of physiological arousal would emerge. Another interesting finding was that levels of arousal did not differ between the virtual and the real obstacle negotiation trials. We interpreted this finding to confirm that subjects did not perceive the real obstacle to present a threat to crossing success. This finding may be explained by the height of the obstacle used in our study. Specifically, the real obstacle was constructed to simulate the height of a sidewalk curb. It is possible that the familiarity of this obstacle height influenced the potential for imposed threat and thus did not heighten physiological arousal among the subjects in this study. We hypothesize that had we presented obstacles that were of novel heights to participants, levels of GSC would differ with obstacle height. Another possible explanation to the lack of age-related differences in GSC is that the safety harness worn by all participants may have softened the effect that the conditions of postural threat were designed to have on arousal. However, in general, GSC results confirmed that the conditions of postural threat were sufficient to increase arousal in all participants.

2. Effects of Postural Threat on the Kinematics of Obstacle Negotiation

Results from this thesis revealed that the kinematics of obstacle negotiation were affected by increased postural threat. Specifically, all subjects demonstrated shorter crossing step lengths, lower vertical crossing heights, and slower crossing velocities as postural threat increased, regardless of the obstacle being negotiated. Specifically, our findings revealed decreased TAD_{pre} and HSD_{post} which were contrary to our hypothesis since we expected that these measures would increase with increasing postural threat to maximize step length and relative horizontal obstacle position during crossing. It would seem that minimizing the horizontal and vertical distances between the feet and the obstacle during crossing is an unsafe strategy and increases the risk for obstacle contact. Upon further evaluation, however, we speculate that these conservative strategies may be an attempt to minimize the momentum of the COM during crossing. Smaller crossing step lengths, demonstrated by shorter TAD_{pre} and HSD_{post}, limit the horizontal momentum of the COM. Likewise, the lower crossing heights observed with increased postural threat may serve to limit the vertical momentum of the COM. The control of momentum results in increased recovery ability in the event of a possible obstacle contact.

The use of slower crossing velocities is another conservative crossing strategy that may be implemented to decrease fall risk. Slower crossing velocities decrease the momentum of the body, and allow for more time to execute safe and effective crossing strategies, thus avoiding obstacle contact and decreasing fall risk. We speculate that the observed changes in negotiation kinematics are an attempt to shift to more conservative movements by all participants. These conservative kinematics may be emerging as a result of increased physiological arousal, and are adopted to reduce trip risk and to increase recovery ability in the event of a possible gait disturbance.

3. Effects of the Potential Consequences of Obstacle Contact on Obstacle Negotiation Kinematics

We examined the effect of increased consequences of obstacle contact on the negotiation kinematics of younger and older adults. For this purpose we asked participants to negotiate fixed virtual and fixed real obstacles. The fixed virtual obstacle presented no threat to balance if contacted, and the fixed real obstacle presented increased height and potential consequences in the event of obstacle contact. Our results indicated that as the potential consequences of obstacle contact increased, participants decreased the length and velocity of their crossing steps. As well, the TAD_{pre} and HSD_{post} decreased as obstacle threat increased. Interestingly, vertical crossing heights did not differ when crossing the real compared to the virtual obstacle. In agreement with past studies that have demonstrated decreased crossing velocities and step lengths with increasing obstacle height (Austin et al., 1999; Chen et al., 1991), we hypothesize that the tall obstacle may be perceived to be more threatening to balance than the virtual obstacle. For this reason, we believe that subjects are adopting slower, smaller crossing movements that are more conservative in an attempt to decrease fall risk.

We did not expect that the toe approach and heel strike distances would decrease with increasing height, since results from Chen and colleagues (1991) report the opposite trend. However, there were differences between our study and that of

Chen and colleagues (1991). In our work, the height of the obstacles as well as the potential consequences of obstacle contact (i.e. virtual versus real) varied. On the contrary, the work by Chen and colleagues (1991) manipulated the height of the obstacle but the potential consequences of obstacle contact remained constant. Therefore, an explanation for the discrepancy between our findings and those of previous research is that it is not the height of the obstacle but rather the imposed threat of contacting the real obstacle compared to the virtual obstacle that results in conservative kinematics.

Interestingly, vertical crossing heights were similar among subjects regardless of the obstacle they were negotiating. We expected that vertical crossing height would increase with increased obstacle height, as found in previous studies (Austin et al., 1999; Chen et al., 1991). Since the height of the real obstacle is equivalent to that of a sidewalk curb, it is possible that subjects do not perceive the real obstacle to be a threat to their balance and are not adjusting vertical clearance height as we expected. This hypothesis is in agreement with our GSC data that revealed no effect for obstacle type. Therefore, we speculate that participants may perceive a threat to balance as a primary concern and perceive a potential obstacle contact as a secondary concern. From these findings, I predict that, had both obstacles been of similar type but different heights, or of similar height but different levels of potential consequence for contact, we could distinguish whether obstacle dimensions, requirements for crossing or potential consequences of obstacle contact are responsible for the interesting results shown in this thesis.

4. Age-Related Changes of Obstacle Negotiation Kinematics

Similar to the results from previous studies (Brown et al., in press; Sleik, Polych, McKenzie, Gage, & Brown, submitted), we found that the potential consequence of falling affect OA differently than YA. Results from this thesis revealed significant Condition x Age interactions when subjects negotiated the virtual and real obstacles. Specifically, crossing velocities and cross step lengths decreased for OA more so than for YA as postural threat increased. It follows that the risk for falling due to the imposed walking constraints has more of an effect on the crossing kinematics of OA compared to YA. Increased postural threat may be resulting in OA displaying more conservative kinematics during obstacle negotiation compared to YA because OA perceive more potential threat in the CE condition than YA do in a similar situation.

An interesting finding that emerged in the second study was the absence of any significant Obstacle x Age or Condition x Obstacle x Age interactions. We speculate that although conditions of postural threat affect younger and older adults differently, there is no difference in the perception of the potential consequences of obstacle contact between younger and older adults. GSC results show both groups are equally threatened by increased obstacle threat, and that the difference between groups lies in the potential consequences of postural threat rather than the potential consequences of obstacle contact. Alternately, we propose that OA have reached a maximal level of arousal under conditions of postural threat and although they perceive the potentially hazardous obstacle to be a threat to their balance, this is not reflected in the GSC or kinematic results. We believe that OA are moving as conservatively as they are physically capable. While the obstacle poses potential threat to the balance of OA if contacted, further modifications to crossing kinematics may not be possible. Following this, since YA are not observed to be adopting conservative behaviors to the same extent as OA under conditions of increased postural threat, perhaps the threat of obstacle contact is more threatening to YA than the threat of the walkway constraints and kinematic adjustments are made only when obstacle threat is increased. Regardless of the reason for the lack of difference between groups as obstacle threat increases, we can hypothesize that postural threat has a more pervasive effect on OA compared to YA, and that the potential consequences of obstacle contact may affect both groups equally.

5. Implications for Fear of Falling

All participants in this thesis were healthy and free from any conditions that could affect their ability to maintain postural control. In addition, none of the participants reported any aversions to heights or reported a fear of falling during daily activities. Thus, conclusions on how obstacle negotiation kinematics are affected by a fear of falling cannot be reported. We can, however, present findings and predictions that may positively influence the health and well being of our elderly population.

Results from this thesis indicated that the kinematics of obstacle negotiation were altered under conditions of postural threat. Additionally, our GSC data indicate that an increase in fear of falling may influence the negotiation kinematics used by both younger and older adults. Specifically, crossing step lengths and crossing velocities decreased with increasing postural threat, particularly in OA. As well, the crossing height of both the lead and trail limbs increased with increasing postural threat, and were shown to increase more for OA compared to YA. An increase in postural threat may lead participants to pay more attention to the position of their body during locomotion to avoid losing their balance. Additionally, slower and smaller movements may be a result of an increased awareness of the external environment, where participants are concentrating on the upcoming obstacle to ensure that contact does not occur. Shorter stride lengths and slower crossing velocities increase the amount of time that is available to implement a safe and effective crossing strategy and thus, eliminate a fall. Additionally, increased crossing heights create a more desirable trajectory to avoid obstacle contact. When crossing height is increased, the lead limb contacts the ground closer to the obstacle, minimizing the movements of the COM relative to the BOS. For OA in particular, this strategy may be beneficial because OA have difficulty generating effective balance responses when they unexpectedly slip or trip compared to YA (Tang & Woollacott, 1998). Therefore, in the event of a trip, momentum of the COM would be controlled easily and recovery for both younger and older adults may be possible. With a longer step, recovery would be more difficult.

On the contrary, the slower, shorter movements may hinder the maintenance of balance in the elderly under conditions of increased postural threat. These conservative movements may cause co-contraction, leading to joint stiffness and difficulty during trip recovery (Winter, et al., 1990). However, findings from previous work (Adkin et al., 2002; Carpenter et al., 2001; Adkin et al., 2000; Carpenter et al., 1999) have revealed that YA adopt a stiffening strategy under conditions of postural threat which may be beneficial to postural control. We speculate that a stiffening strategy may improve the ability to negotiate obstacles, specifically under time restricted situations, because response times to unexpected obstacles may increase due to improved muscular responses around the ankle joint (Winter et al., 1990).

As the potential consequences of obstacle contact increased (i.e. higher, solid), the kinematics of negotiation show similar trends to those observed with increasing postural threat. Specifically, increasing the potential consequence of obstacle contact resulted in all participants taking smaller and slower crossing steps. As well, crossing heights began to decrease with increasing obstacle threat, while the horizontal distance from the obstacle to the trail limb prior to crossing increased and the horizontal distance from the obstacle to the lead limb following crossing decreased. These strategies may result from the increases postural and obstacle threat create for risk for falling, encouraging individuals to adopt more conservative behaviors that minimize the risk for obstacle contact. As well, a threatening obstacle, specifically one that is tall, requires more time for successful negotiation, leading to slower crossing steps. These strategies may serve to decrease the risk for falling as postural and obstacle threat increase. However, these strategies may also prove to be a detriment, specifically in the elderly population, as co-contraction leading to joint stiffness may occur and decrease their ability to react to a suddenly appearing obstacle in their path.

6. Research Applications

The results from this thesis support the idea that the kinematics of obstacle negotiation are affected by increases in postural threat that induce anxiety. Rarely are we faced with a walking surface that is free of obstacles. Many obstacles are fixed in the external environment while others suddenly come to our attention. It is therefore necessary to be able to negotiate an obstacle that is visible from a distance, as well as those that appear suddenly.

From the results of this thesis we can conclude that the kinematics of obstacle negotiation used under conditions of heightened postural or obstacle threat are increasingly conservative and require time to implement. In particular, OA require more time than YA to negotiate an obstacle safely when they are anxious about their balance (Chen et al., 1994b). Therefore, we can speculate that as the potential for instability increases and postural threat is present, OA are at an increased risk for falling if presented with an obstacle that does not allow sufficient time to safely execute a negotiation task.

Although we have determined that increased postural and obstacle threat results in more conservative movements by all participants, and specifically OA, we do not know why this occurs. Further research needs to be performed to determine if physical limitations prevent OA from performing at the same level as YA, or if a fear of falling is the cause of these conservative movements. Once this is established, strategies for safe and effective obstacle negotiation for fixed and suddenly appearing obstacles can be introduced to the elderly population to decrease their risk for falling. As well, strategies for trip recovery also need to be addressed and established.

In a clinical setting, a variety of educational and practical programs should be developed based on the findings of this and other work in this area. Specifically, programs need to be created for the OA population to address the age-dependent differences observed during obstacle negotiation. OA need to be informed of the potential environmental and age-dependent risks associated with falling during obstructed gait. Being aware of these potential dangers may increase the anxiety OA feel regarding their balance to a helpful level without creating a debilitating fear of falling. Also, exercise programs designed to maintain or increase muscular strength and joint ROM are important so that age-related physical declines do not contribute to falling in the elderly. As well, programs that simulate obstacle negotiation are critical for the improvement of fall rates in the elderly. The more that individuals are exposed to a situation requiring negotiation of a fixed or suddenly appearing obstacle, the more comfortable and familiar they will become with these tasks. This will improve older adult's perceived and actual balance ability when encountering obstructed gait during daily activities.

7. Limitations

One limitation for this thesis was our use of a non-established questionnaire to establish balance confidence and fear of falling. We created a novel list of questions for our participants to answer that were designed to test their underlying fear of falling levels as well as their fall history and the underlying causes of these falls. Although we were able to determine fall history and fear of falling levels in our participants, we did not use previously validated scales. Therefore, we should consider including the Activities-specific Balance Confidence Scale (ABC) (Powell & Myers, 1995) as well as the Falls Efficacy Scale (FES) (Tinetti, et al., 1990) in future studies.

The participants in this thesis were healthy and fit OA who were free from any conditions that would affect postural control. None of the participants expressed a fear of falling during their daily activities, or a fear of heights. Thus the conditions of postural threat may not have produced sufficient levels of physiological arousal in our participants, and fear of falling may not have been present. Additionally, participants wore a safety harness during all trials, which may have provided a sense of safety in conditions that would otherwise cause anxiety because of the risk for falling involved. Therefore, even though the risk for tripping and falling in the conditions of highest postural threat was present, a perceived threat of falling by our subjects may have been masked. However, since all participants wore the harness during all trials, levels of physiological arousal regarding balance were relative for each subject because we speculate that the harness had an equal affect on both younger and older adults.

Another limitation of this thesis is that of familiarity. Some of the OA used in the current study have been involved in our previous work (Brown et al., in press). Since participants were already familiar with the walkway constraints designed to induce postural threat, they may not have been as affected as OA for whom the conditions were novel. However, results from the current study regarding levels of arousal were similar to our previous findings (Brown et al., in press) suggesting that the conditions of postural threat were sufficient to induce postural threat regardless of familiarity. Another possible explanation for the observed age-related differences between younger and older adults may be due to the amount of effort displayed by both groups. For example, OA often showed keen interest in completing the tasks "correctly" while some YA were less attentive. We can speculate that some age-related differences found in the crossing kinematics may be due to the care subjects were taking to perform tasks correctly rather than being conservative.

The age-related differences in negotiation kinematics reported in this study are also limited because they may be a reflection of the age-related differences in unobstructed locomotion reported in previous studies. For example, Winter and colleagues (1991, 1990) revealed that OA walk slower, take shorter and wider steps and spend more time in DLS compared to YA. These findings may limit the results of our study because negotiation kinematics could be reflective of the initial speed selected by both younger and older adults. As well, the constrained conditions may induce more threat to the OA population because OA adopt a wider stride compared to YA. This may explain some of the constrained effects found in this study but may also be enhancing age-related differences that would otherwise not emerge. For this reason, future analysis of this work and subsequent studies should attempt to normalize data to the initial speed as well as to the selected stride widths of each group.

An additional limitation to this study was that of obstacle characteristics. We compared the effects of the potential consequences of obstacle contact by asking subjects to negotiate a virtual and a real obstacle. Although we were able to compare the effect of obstacle height on the negotiation kinematics of younger and older adults, the type of obstacle differed. Future research should address the effects of the potential consequences of obstacle contact by asking participants to negotiate two fixed (Austin et al., 1999; Chen et al., 1994a; Chen et al., 1991) or two virtual obstacles (Cao et al., 1998) of varying heights. This would correct for any discrepancies of negotiation kinematics observed between the two obstacles that were not strictly a result of obstacle threat. Our future work is addressing this issue by determining the effects of obstacles of varying heights but similar consequences for contact on the negotiation kinematics of younger and older adults.

Finally, the age-related differences seen in the obstacle negotiation kinematics for the light beam and block obstacle may be due to the level of difficulty that task requirements placed on both groups. Specifically, stepping over a block obstacle may be more physically demanding for OA compared to YA. It is for this reason that we believe the age-related changes found in this thesis may reflect a physical disparity between the two groups of participants rather than the effect of postural threat or obstacle characteristics on the kinematics of crossing. Therefore, an attempt to study the effects of anxiety during obstacle negotiation in an environmental context that is equally demanding to both groups would be beneficial. Fortunately, we feel that examining the negotiation kinematics of younger and older adults for a virtual obstacle in the current study presents an equal challenge to both groups. We also believe that the obstacle characteristics are representative of the obstacles individuals are faced with in real-life situations such as a puddle of water or patch of ice that present undesirable landing surfaces.

8. Future Research

Future work needs to independently address the effects of each of obstacle height and the potential consequences of obstacle contact on the negotiation kinematics of younger and older adults. Findings from research addressing the effects of obstacle height and potential consequences of contact separately will assist researchers in determining the characteristics of obstacles that are threatening to OA, and will help to create safe and effective negotiation strategies for OA when crossing both tall and threatening obstacles. As well, future work should focus on the effect of vision and proprioception on the ability to negotiate obstacles. Since these systems are critical for the maintenance of balance (Spirduso, 1995) and are known to deteriorate with age (Alexander, 1994; Woollacott & Shumway-Cook, 1990; Woollacott, 1989), it is important to determine the involvement of these systems in obstacle negotiation. As well, findings from future work can help develop techniques for obstacle negotiation for individuals who have experienced age-related sensory loss. Research should also focus on the ability of younger and older adults to negotiate virtual obstacles under time-restricted situations. These results will help researchers determine the process involved in the negotiation of suddenly appearing obstacles so that strategies can be developed for, and implemented by the elderly so that recovery from trips can increase and fall risk will decrease.

Conclusion

We have concluded that postural threat and the potential consequences of obstacle contact affect the negotiation kinematics of younger and older adults. Specifically, postural threat affects the negotiation kinematics of OA differently than those of YA, while the potential consequences of obstacle contact affect both groups equally. The results agree with previous research showing that postural threat has a more pervasive effect on the postural control of OA compared to YA (Brown et al., in press; Sleik et al., submitted). As well, although we determined that increased postural threat results in more conservative crossing kinematics, specifically in OA, we cannot conclude that these strategies are helpful or harmful to the control of balance in the elderly.

In regards to the potential consequences of obstacle contact, some novel effects were found in this thesis. We hypothesized that crossing kinematics would become more conservative as the potential consequences of obstacle contact increased, specifically for OA. While our results were in agreement with those of Chen and colleagues (1991) who reported that obstacle height affected crossing kinematics, we did not find any age-dependent effects for the potential consequences of obstacle contact on obstacle negotiation kinematics. Although our results provide insight into the mechanisms involved in maintaining postural control during obstacle negotiation, future work is still needed to determine the specific obstacle characteristics that alter the perception and actual risk presented by various real-life obstacles. We are hopeful that future work will increase awareness in the elderly population and begin to develop effective strategies for safe obstacle negotiation.

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