THE FREQUENCY OF AND FACTORS ASSOCIATED WITH INADVERTENT CONTACTS DURING OBSTACLE CROSSING IN OLDER ADULTS

by

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ABSTRACT

Occasionally healthy older adults trip over stationary objects even when seen well in advance. These are known as "inadvertent" trips. The purpose of this study was to determine the prevalence of inadvertent trips in older males and older females under conditions of normal vision with good lighting. We also determined their relationship with unobstructed gait measures and other risk factors associated with falls during everyday activities. Forty-one subjects stepped over an obstacle (height set to 25% of leg length) 100 times. The obstacle was contacted by 15 participants (37%) in a total of 29 trials (0.7% of all trials). Of the 29 obstacle contacts, 52% occurred with lead limb. There was no difference in the frequency of contacts between males and females. Slower stride speed, shorter stride length, and increased gait cycle time variability during unobstructed walking were associated with contacts during the obstacle crossing trials ($p \leq 0.041$). Inadvertent trips were also associated with the number of prescription medications taken by participants ($p = 0.019$) and participants' maximum reported rating-of-fatigue ($p = 0.022$). Fatigue was an important factor and 36 subjects (88%) reported an increase in their fatigue across trials highlighting the importance of considering fatigue in all obstacle crossing studies using older adults. We conclude that inadvertent trips are not uncommon in older adults and point to useful future areas of research and risk factors that could be targeted by fall intervention programs.

INTRODUCTION

Falls are the number one cause of both fatal and non-fatal injuries among older adults (Bergen, et al., 2016). Falls can be caused by a variety of events such as slipping, a misstep, loss of support, or tripping. Trips are the most frequent, causing 34-53% of all falls in older adults (Blake, et al., 1988), although it should be noted that the cause of the fall is affected by sex (Timsina, et al., 2017). Therefore, quantifying trip-related behavior to understand their causes, factors associated with them, and why they are more frequent in females is an important area to examine.

One important factor associated with falls is sex. When studying falls that resulted in injury, older females have more than twice as many trip-related injuries as older males, and trips accounted for more injuries in older females than older males (23.3% vs 19.3% of fall-related injuries, respectively) (Timsina, et al., 2017). When studying falls with or without injury in long-term care communities, females were more likely fall from a trip or stumble than males (15.1% vs 11.3% of falls, respectively) (Yang et al., 2018). These observations lead to the question: Do females trip more frequently, or are they less likely to recover their balance from a trip?

Most trip-related research has focused on (1) recovery mechanisms following an unavoidable trip or (2) successful obstacle crossing trials. Tripping participants directly, either via covert obstacle, such as a pop-up obstacle, identifies mechanisms of successful versus failed recoveries (Eng, et al., 1994; Weerdesteyn, et al., 2004; Brown, et al., 2006; Pijnappels, et al., 2007). However, since these trips are unavoidable, no information can be gained about the circumstances that lead to a trip. Examination of successful obstacle crossing trials helps understand how gait is proactively adapted to avoid obstacles (Patla & Rietdyk, 1993). In this protocol, the obstacle is stationary and visible during the approach phase. Occasionally, healthy adults trip over the stationary, visible obstacle (Heijnen, et al., 2012). These trips are referred to as 'inadvertent trips' and occur in 1-3% of trials under conditions of normal vision and full lighting (Heijnen, et al., 2012; Muir, et al., 2019; Heijnen & Rietdyk, 2016). Contact rates are higher when vision is obstructed or distorted, emphasizing the importance of visual information to successfully step over obstacles (Chou & Draganich, 1998; Patla & Greig, 2006; Johnson, et al., 2007; Rietdyk & Rhea, 2011; Patla & Rietdyk, 1993; Alexander et al., 2011; Vitorio, et al., 2013). Analyzing inadvertent trips has identified the relevance of limb elevation, of course, but also foot placement before an obstacle (Chen, et al., 1991; Chou, et al., 1995; Heijnen, et al., 2012; Diaz, et al., 2018). Furthermore, failure analyses have revealed the importance of visual information during the approach to the obstacle (Alexander, et al., 2011; Rietdyk & Rhea, 2011; Vitorio, et al., 2013). The research on inadvertent contacts describes the gait parameters (foot placement, limb elevation, elevation variability) that occurred during the trial with the inadvertent contact. However, it is unknown if gait parameters during unobstructed gait are associated with trips.

It is well known that basic gait parameters – obtained while walking on a clear, level walkway – are associated with falls (Campbell, et al., 1989; Maki, 1997; Verghese, et al., 2009; Lord, et al., 2011). However, the relationship between these same basic gait parameters, i.e. from a clear, level walkway, and tripping is unknown. Impairment in sensory, cognitive, and motor systems increase risk of falling; these impairments will also be reflected in gait measures. Therefore, it is not surprising that gait measures are associated with falls. Variables such as stride speed, stride length, or measures of variability in gait have also been used as a simple method to assess general health and function in older adults (Studenski, et al., 2003; Cesari, et al., 2005; Ganz, et al., 2007). Since all of these systems are required for successful obstacle crossing, inadvertent trips will also likely be associated with similar gait markers.

In addition to gait measures, there are multiple other variables associated with fall-risk; we focused on those variables that we could quickly and easily capture within a one hour data collection. Balance confidence and physical activity are associated with falls in older adults (Mazo, et al., 2007; Lajoie & Gallagher, 2004); these variables can be easily quantified with the Activities-specific Balance Confidence scale (ABC) and Godin Leisure-Time Exercise Questionnaire (LTEQ) respectively (Peretz, et al., 2006; Schepens, et al., 2010; Amireault & Godin, 2015). Visual acuity is also related to falls and can be easily assessed (Saftari & Kwon, 2018). A question regarding the number of prescriptions medications taken daily is also useful. Prescription medications are associated with fall risk and may be associated with inadvertent trips as well, in part, due to possible side effects including blurred vision, impaired depth perception, and/or other visuomotor skills (Hilton, et al., 2004; Leendertse, et al., 2008).

Fatigue is also likely an important factor for successful obstacle crossing since increased fatigue increased lower limb variability and impaired motor control (Johnston, et al., 1998; Helbostad, et al., 2007; Barbieri, et al., 2014). The effect of experimentally-induced fatigue on gait tasks is age dependent: Modulations of step speed and step length in response to fatigue were greater in adults aged 40 and older compared to younger participants during level walking and obstacle crossing (Barbieri, et al., 2014). When inadvertent trips have been studied in young adults, the findings did not support fatigue as a cause of contacts (Heijnen, et al., 2012). However, the effect of fatigue on inadvertent contacts in older adults is unknown.

A protocol designed specifically to look at inadvertent trips has been conducted in young adults (Heijnen, et al., 2012) but analysis of inadvertent trips in older adults has been limited to the few trials observed during successful trials (Muir, et al., 2020). In young adults, the vast majority of inadvertent obstacle contacts occur with the trail limb (92%), the second limb to cross the obstacle. There is no visual feedback during trail limb crossing and since it is placed closer to the front edge of the obstacle there is less time to flex the trailing limb adequately (Chou & Draganich, 1998; Heijnen, et al., 2012). These factors may make it more difficult to avoid the obstacle with the trail limb under standard conditions. Although infrequent in young adults, older adults have been shown to have a higher proportion of lead limb trips (Muir, et al., 2015). Furthermore, in studies that have investigated inadvertent obstacle contacts only older adults contacted the obstacle with their lead limb (Muir, et al., 2019; Chen, et al., 1991). Quantifying lead versus trail limb contacts is important since there is a higher fall risk for a lead limb trip versus a trail limb trip (Muir et al., 2015).

The purpose of this study was to determine the prevalence of inadvertent trips, whether there is a difference between sexes, and to what extent they are associated with factors of fall risk in adults aged 65 and older. The following hypotheses will be tested: Females will have a higher frequency of inadvertent obstacle contacts than males (H1). Older adults who display age related declines in unobstructed gait (i.e. reduced stride speed, shorter stride length, or increased variability in gait measures) will have a higher frequency of inadvertent trips (H2). Older adults who report higher fatigue ratings during the study will have a higher frequency of obstacle contacts (H3). We also measured a subset of factors known to be associated with falls (prescription medications, fear of falling, visual acuity, physical activity) and determined if they are associated with inadvertent trips.

METHODS

Participants

Participants were recruited through flyers posted in community centers, local senior centers, and through word of mouth. Forty-one older adults (age: 76.6 + 6.9 years, 25 females) participated. Participants walked without an aid, had no orthopedic or neuromuscular disorders (as verified by self-report), and were independent in daily activities. Participants were screened for cognitive impairments and dementia using a clock-drawing test scored using the method of Watson et al. (Watson, et al., 1993). All participants signed an informed consent approved by the Institutional Review Board.

Materials/Equipment

In the obstacle crossing trials, participants walked down a 6 m grey barber carpet, and stepped over an obstacle placed at 4 m. The obstacle height was 25% of the subject's leg length. Obstacle height range: 19.5-26 cm, in 0.5 cm increments; 100 cm wide, 0.3 cm deep. The obstacles were made of Masonite and painted flat black. To reduce risk of falling, obstacles were designed like a hurdle to tip over if contacted, and an experimenter spotted participants using a gait belt. Two wireless inertial measurement units (GaitUp, Physilog, Lausanne, Switzerland) were placed on participants' feet to measure and analyze gait during unobstructed walking. The GaitUp units remained on the feet during all gait trials (unobstructed walking and when stepping over obstacles) to avoid removing and replacing the units multiple times, but the gait parameters during the obstacle crossing data were not analyzed. Participants feet were videotaped during obstacle crossing to confirm obstacle contact and determine which limb contacted the obstacle (lead or trail).

Protocol

Non-gait Assessments (Figures 1 and 2): Fear of falling was assessed with the Activities-Specific Balance Confidence Scale (ABC-6) (Appendix A), a shortened model of the traditional ABC-16 scale, that has been validated and demonstrated to have similar accuracy as the ABC-16 scale (Peretz, et al., 2006; Schepens, et al., 2010). Physical activity was assessed using the Godin-Shepard Leisure-Time Exercise Questionnaire (LTEQ) (Amireault & Godin, 2015) (Appendix B). Visual acuity was assessed using a Snellen Eye Chart (positioned 20 feet away from participants). Participants were also asked their sex, age, and the number of prescription medications they take daily.

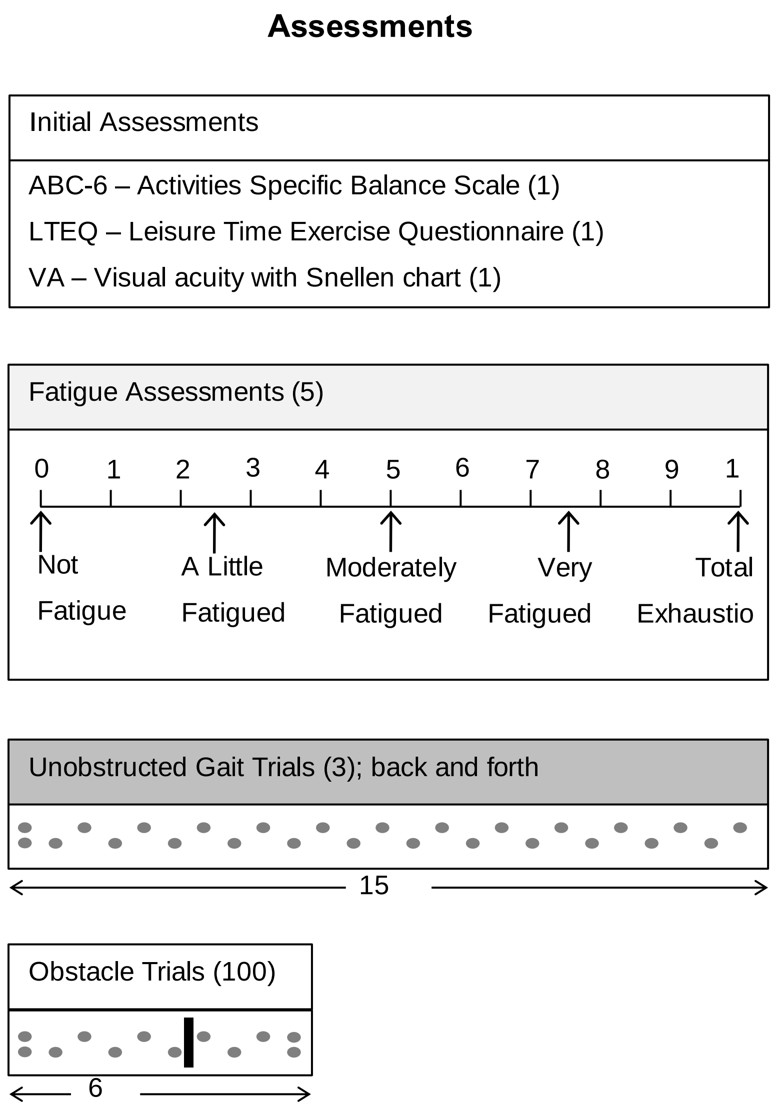

Figure 1: Summary of assessments conducted; number of trials of each assessment in brackets.

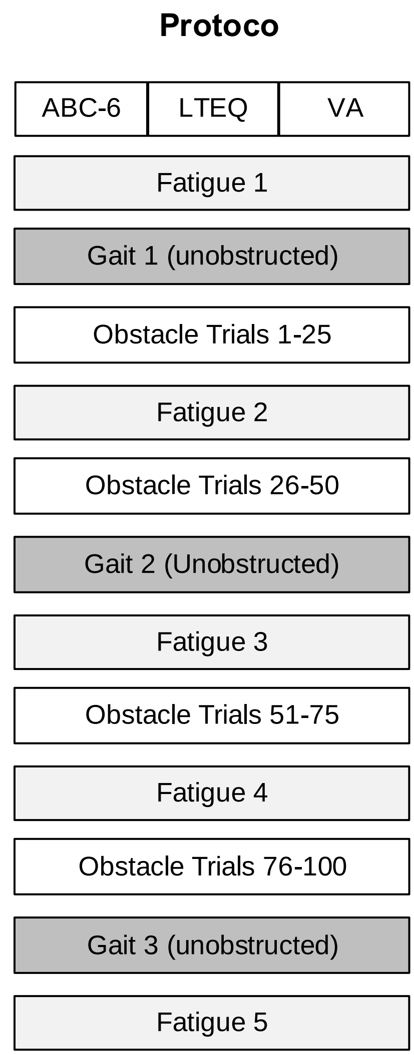

Figure 2: Order of protocol. A two-minute break was given after every 25 obstacle trials. Protocol lasted 40-60 minutes.

Unobstructed Gait Trials: Unobstructed walking was assessed three times: at the beginning, after 50 obstacle crossing trials, and after 100 obstacle crossing trials. The walkway was 15 m long; participants walked 15 m, turned around, and walked back to the start; gait data was collected in both directions (Figures 1 and 2).

Obstacle Crossing Trials: One hundred obstacle crossing trials were completed in four blocks of 25 trials each, with a 2-minute break between each block (Figures 1 and 2). During the break participants were allowed to sit down and drink water if they wanted to. No practice trials were given, and subjects self-selected which leg to lead with during obstacle crossing. Participants were not informed obstacle contacts were of interest and if they asked about the video camera, they were told it served as a backup to analyze obstacle crossing in case the inertial sensors malfunctioned. Participants were instructed "Occasionally a person contacts the obstacle. If you contact the obstacle, it will fall over like a hurdle. Please continue walking and we will pick it up." If an obstacle contact occurred, the experimenter noted the trial number and which limb (lead or trail) contacted the obstacle.

Fatigue: Self-reported fatigue was assessed five times during the protocol: at the beginning and during a 2-minute break that was given at the end of each block of 25 obstacle crossings. Fatigue was assessed using the rating-of-fatigue scale (Figure 1; Appendix C) (Micklewright, et al., 2017). The rating-of-fatigue scale is a 0-10 scale that has high convergence with numerous physiological measures during exercise and recovery (heart rate, blood lactate concentration, oxygen uptake, carbon dioxide production, respiratory exchange ratio and ventilation rate) (Micklewright, et al., 2017). Participants were familiarized with the scale and at each assessment, were shown the rating-of-fatigue scale and asked to select a single value on the scale to describe their current fatigue level.

Data Analysis

Unobstructed Gait Measures: Gait variables were assessed using data recorded with GaitUp during the three unobstructed trials. Trials were filtered to remove (1) turns, (2) the first two steps during gait initiation, and (3) the last two steps during termination (as 90% and 100% of steady-state velocity was achieved during the first step and second step, respectively, and 10% and 90% of steady-state velocity was reduced in the first and last step, respectively (Jian, Winter, Ishac,

& Gilchrist, 1993). A filter was applied to remove data points that were 2 standard deviations (SDs) higher or lower than the median value (Hausdorff, et al., 2001). Five gait variables were assessed during the unobstructed walking trials: stride speed, stride length, stride speed variability, stride length variability, and gait cycle time variability. Variability was quantified as the coefficient of variation (standard deviation/mean x 100). Since the gait measures were recorded at three points in time, we checked if the gait measures were affected by time with a one-way ANOVA. The five gait measures were not affected by time ($F(2,74) \leq 1.26$, $p \geq 0.29$). Therefore, the three values taken at different times were averaged for each variable, for each participant.

Obstacle crossing measures: During data collection, two experimenters independently recorded the trial number of any obstacle contacts. The contact foot (lead or trail: first or last limb to cross the obstacle) was also recorded. The two experimenters had 100% agreement on the contact trials. The contacts and contact limb were later confirmed by video. In addition, a third experimenter reviewed the video of two participants, and 100% agreement was observed on the contact trials.

Physical Activity: LTEQ scores were used to classify participants as sedentary, moderately active, or active (scores of 0-13, 14-23, 24+, respectively) (Godin, 2011).

Group Categorization: Participants were categorized into two groups: 0 inadvertent contacts (no contact group), or 1 or more inadvertent contacts (1+ contact group).

Statistics: Two-sample independent t-tests were used to compare the two groups for the following: gait measures, ABC-6 score, highest reported fatigue rating, and age. Simulated chi-square test (5,000 iterations) were used to compare the two groups for LTEQ classification (sedentary, moderately active, or active) and visual acuity. A Wilcoxon rank sum test was used to compare the two groups for number of prescription medications. Note that a t-test could not be used due to the data not meeting the required normality assumption. Statistical tests were done with SAS version 9.4.

RESULTS

Contacts

The obstacle was contacted 29 times (0.7% of 4075 trials); 15 participants had at least one inadvertent obstacle contact (37% of 41 participants). Of the 29 obstacle contacts, 52% occurred with lead limb. The median trial number for participants first obstacle contact was trial 40 (interquartile range: 12-73), the median trial number for all obstacle contacts was trial 72 (interquartile range: 33-78). There was not a significant difference in the average age of participants who tripped compared to those who did not (t = -1.23, p-value = 0.233). Frequency of obstacle contact was not affected by sex (OR (95% CI): 1.07 (0.27 - 4.24); p = 0.925; Table 1)

Table 1. Distribution of trips (obstacle contacts) in males and females

Gender	Age [95% CI]	Percent with $\geq$ 1 obstacle contact	Total obstacle contacts	Overall Frequency (% of trials)
Female (n = 25)	76.8 $\pm$ 6.2	36% (n = 9)	19	0.8
Male (n = 16)	76.3 $\pm$ 8.1	38% (n = 6)	10	0.6
Total (n = 41)	76.6 $\pm$ 6.9	37% (n = 15)	29	0.7

Number of prescription medications was higher for participants who contacted the obstacle one or more times compared to those who never contacted the obstacle (mean: 4.6 vs 2.3, respectively; W = 108.5; p = 0.019).

Stride length (Figure 3), stride speed (Figure 4), and gait cycle time variability (Figure 5) were different for participants who contacted the obstacle one or more times compared to those who never contacted the obstacle; variability of stride speed and stride length were not different across groups (Table 2).

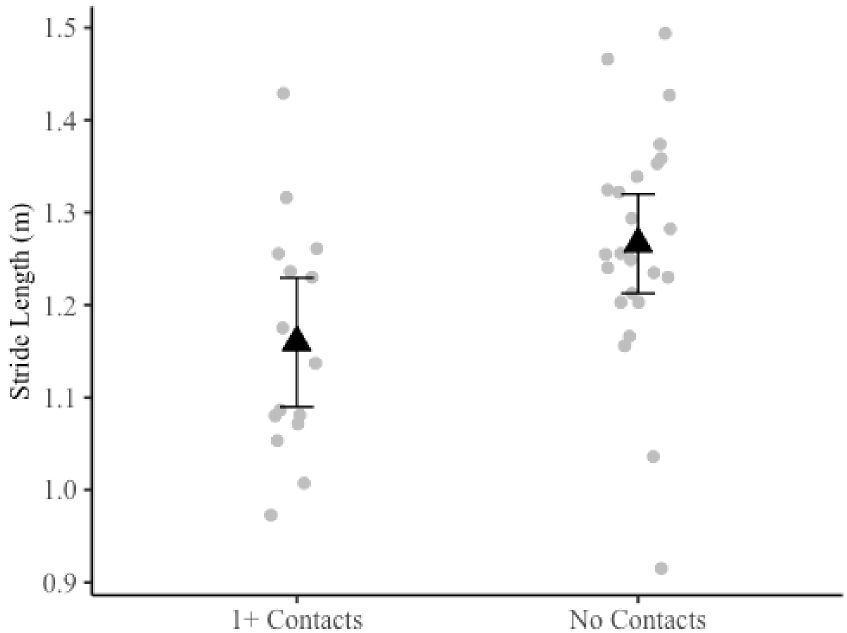

Figure 3: Comparison of stride length in participants with one or more obstacle contact vs participants with no obstacle contacts.

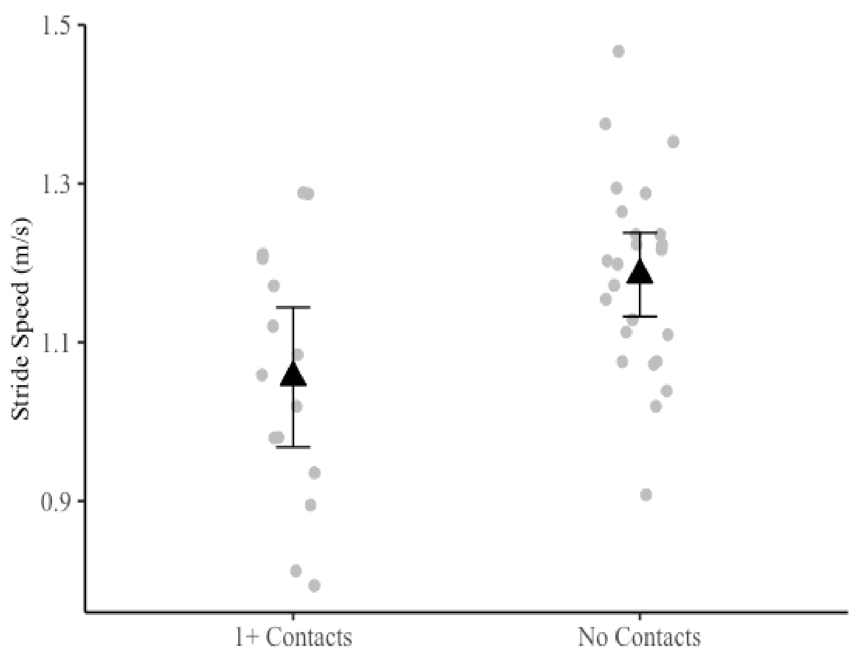

Figure 4: Comparison of stride speed in participants with one or more obstacle contact vs participants with no obstacle contacts.

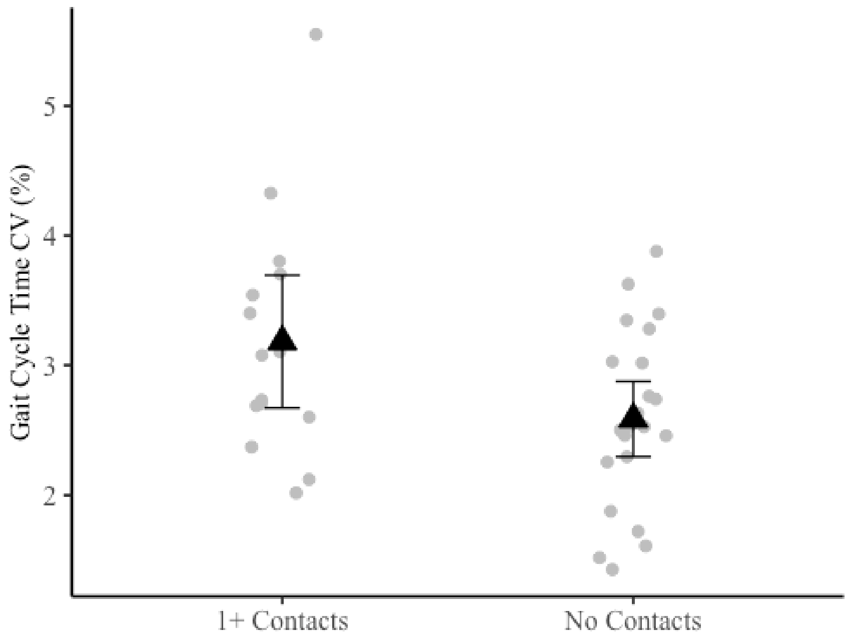

Figure 5: Comparison of the coefficient of variability for gait cycle time in participants with one or more obstacle contact vs participants with no obstacle contacts.

Table 2: Quantitative gait variables in the no contact group vs. 1+ contact group

Gait Variable	No contact [95% CI] (n=26)	1+ contact [95% CI] (n=15)	*p*-Value
Stride Speed (m/s)	1.19±0.13	1.06±0.16	**0.013**
Stride Length (m)	1.27±0.13	1.16±0.13	**0.016**
Gait Cycle Variability (%)	2.59±0.69	3.18±0.92	**0.041**
Stride Speed Variability (%)	6.14±2.31	6.32±1.87	0.792
Stride Length Variability (%)	4.76±1.49	5.06±1.28	0.521

Fatigue rating increased throughout the obstacle crossing trials ($F(4,167) = 45.33$, $p < 0.001$; Figure 6); post hoc tests revealed that the fatigue rating at each time interval increased significantly in the next 25 or 50 trials. Thirty-six participants (88%) reported an increase in their fatigue rating compared to their initial fatigue rating. The maximum fatigue rating reported by participants who contacted the obstacle one or more times compared to those who never contacted the obstacle (mean: 4.7 vs 3.0; $t = -2.49$; p-value = 0.022). For qualitative comparisons, participants who reported maximum fatigue ratings of 3+ (n = 26) were compared to those with lower maximum fatigue ratings (n=15) (Figure 7); participants with higher fatigue rating were more than twice as likely to contact the obstacle.

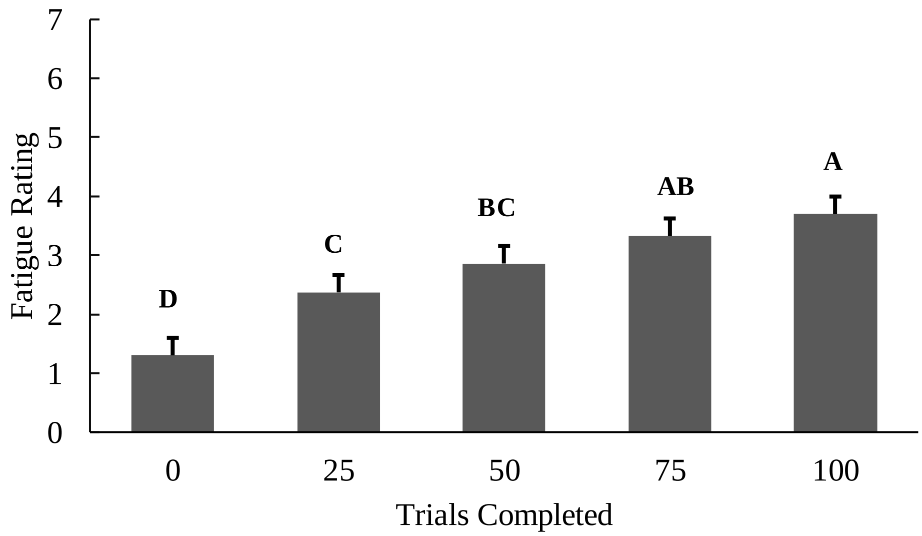

Figure 6: Fatigue rating as a function of number of obstacle crossing trials completed. Error bars are standard error. Different letters (A, B) indicate statistically significant differences.

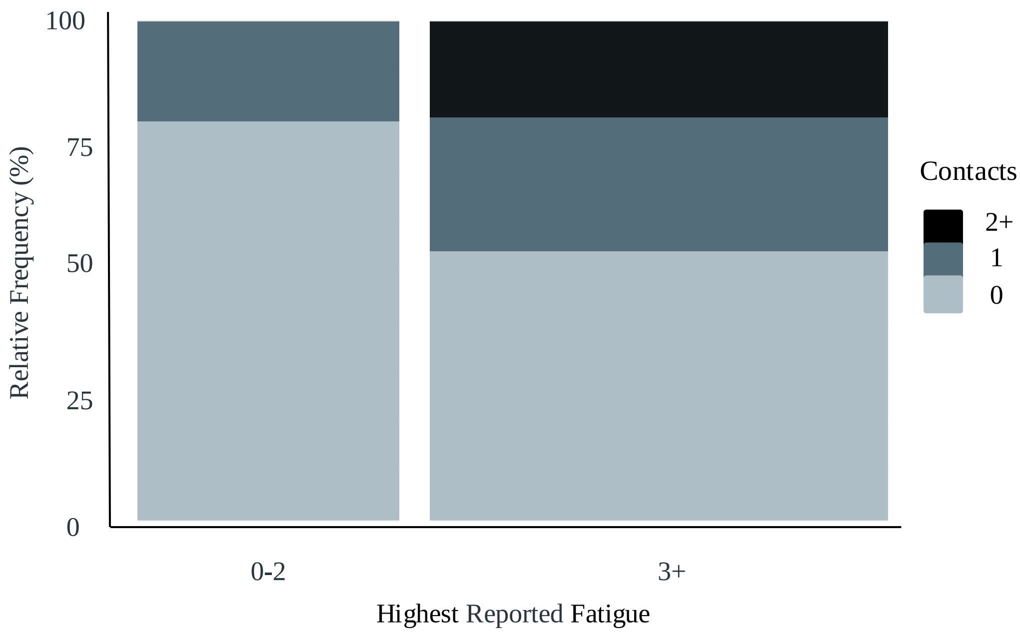

Figure 7: Mosaic plot of the relative frequency of obstacle contacts as a function of the highest reported rating of fatigue of each participant. The width of each rectangle is proportional to the number of participants within that group.

DISCUSSION

The goal of this study was to quantify the frequency and circumstances of inadvertent obstacle contacts in older adults. Current knowledge was extended using an obstacle crossing protocol that (1) quantified inadvertent obstacle contacts in older adults under standardized conditions, and (2) examined factors associated with inadvertent trips, such as unobstructed gait characteristics. We observed that inadvertent trips were not uncommon in older adults (37% of participants tripped at least once), and that 52% of contacts occurred with the lead limb. We rejected our first hypothesis – there were no sex-related differences in the frequency of inadvertent trips, suggesting other factors are responsible for why trips account for a greater percentage of fall-related injuries in females. We accepted the hypotheses that inadvertent obstacle contacts were associated with unobstructed gait parameters (stride speed, stride length, gait cycle time variability), self-reported fatigue, and number of prescription medications. However, inadvertent contacts were not associated with balance confidence nor physical activity.

Inadvertent trips were not uncommon in older adults and the trips frequently occurred with lead limb, which increases risk of falling (Chen, et al., 1991; Heijnen et al., 2012; Muir et al., 2019; 2020). Fifteen healthy older adults (37%) contacted the obstacle in 29 trials (0.7%) highlighting the importance of investigating inadvertent trips in older adults. Furthermore, of the 29 obstacle contacts, 52% were lead limb trips. When inadvertent trips were investigated in young adults in an earlier study where the obstacle position and height was consistent with our protocol (obstacle position was 4 m from the start position, and obstacle height was 25% of the subject's leg length) only 8% of all trips were lead limb trips (Heijnen et al., 2012). Contacting an obstacle doesn't always result in a fall; balance can be recovered with a quick and coordinated response. However, trips that occur with the lead limb trips are more difficult to recover from than trail limb trips. To prevent a fall, a new base of support needs to be established by either lowering or elevating the swing limb that contacted the obstacle (Eng, et al., 1994). Keeping the center of mass within this new base of support is more difficult when a trip occurs with the lead limb because at the time of contact, the center of mass moving away from base of support (stance foot) unlike when trips occur with the trail limb where the center of mass is moving towards a new base of support. Since lead limb trips are more likely to result in a fall, the higher frequency of lead limb trips observed in older adults may explain why a greater percentage of fall-related injuries are caused by trips in older adults when compared to other age groups and emphasizes the importance of continued research on inadvertent trips in older adults (Blake, et al., 1988; Timsina, et al., 2017)

The increased proportion of lead limb contacts for older adults is likely related to the shorter step length, and perhaps also to vision changes. Compared to young adults, older adults have a shorter step length (Menz, et al., 2003). Despite this, older adults trail foot placement prior to obstacle crossing is the same as young adults trail foot placement (Lowrey, et al., 2007; Muir, et al., 2015; Chen, et al., 1991; Muir, et al., 2019). Since the placement of the trail foot is the same, the shorter step length in older adults' necessitates closer foot placement after obstacle crossing, increasing the risk of lead limb contacts (Chen, et al., 1991). Although normally rare in young adults, lead limb trips are more frequent than trail limb trips under the following conditions: vision is obstructed during approach (Patla, 1998; Mohagheghi, et al., 2004; Patla & Greig, 2006) or distorted through multi-focal lenses (Johnson, et al., 2007). Unlike the trail limb, visual guidance is available while crossing with the lead limb so it is logical that visual manipulations result in an increase in the proportion of lead limb trips (Rietdyk & Rhea, 2011; Heijnen, et al., 2012; Rietdyk & Rhea, 2006). These findings suggest the higher proportion of lead limb trips observed in older adults may, at least in part, reflect an impairment of older adults' visual guidance of the lead limb trajectory. Although visual acuity itself was not associated with obstacle contacts in our study, a previous study observed that depth perception was a significant determinant of obstacle contacts but visual acuity and edge contrast sensitivity were not (Menant, et al., 2010). Additionally, interventions designed to improve eye and stepping coordination have been demonstrated to be effective at improving stepping control and mitigating fall risk (Hollands, et al., 2017).

In epidemiological research, trips accounted for a larger proportion of fall related injuries in older females (23.3%) than in older males (19.3%) (Timsina, et al., 2017), which leads to the question: Do females trip more frequently, or are they less likely to recover their balance from a trip? Our protocol can answer the first question, and we found no evidence of a higher frequency of obstacle contacts for females when the environment was the same (Table 1). Rather, other factors are likely responsible for the sex differential. As noted above, it is possible that when a trip occurs, women are less likely to recover. Lab-based protocols have found that women fall more than four times more frequently as males when trips are induced using a concealed mechanical obstacle (Pavol, et al., 1999). This may be partially explained by women having less muscle mass and a longer reaction time than men, (Neder, et al., 1999; Der & Deary, 2006), both of which are important to recover from a trip. It is also possible that females spend more time in environments where trips are more likely to occur. Understanding these differences and obtaining more information about the circumstances of trips will likely be relevant for developing effective interventions to prevent falls.

Inadvertent obstacle contacts were related to participants' gait measures during unobstructed walking, similar to the relationship between gait characteristics and falls during everyday activity. (Campbell, et al., 1989; Maki, 1997; Verghese, et al., 2009; Lord, et al., 2011; Hamacher, et al., 2011). Participants with one or more obstacle contact had both a slower stride speed and a shorter stride length compared to participants with no obstacle contacts. They also had greater variability in gait cycle time; however, there was no difference in variability of either stride speed or stride length. Initially, we expected all three measures of variability to be related to inadvertent trips since they are all commonly used to assess fall risk. However, our findings are consistent with a growing body of evidence suggesting measures of stride speed and stride length may be better predictors of age related differences than fall risk itself. In contrast, gait cycle time variability is a strong predictor of fall risk independent of age differences (Hamacher, et al., 2011).

Inadvertent trips were also associated with the number of prescription medications taken daily by participant. Compared to participants with no obstacle contacts, participants with one or more contacts took twice as many prescription medications, suggesting a relationship between prescription medications and trip-related falls. The number of medications taken can be a simple predictor of someone's overall health but there is also evidence that some drug classes significantly increase the likelihood of falling and these medications are preventable risk factors for falling (Woolcott, et al., 2009). Evidence supporting a structured approach to drug discontinuation (or deprescribing) is emerging in large part due to the observed reduction in falls (Scott, et al., 2012). However, while effective in reducing the number of falls, the exact method of falls being reduced is still unclear (i.e. trips, slips, etc.). The lack of clarity results for several reasons: 1) relatively few medication studies use falls as an outcome measure, 2) the method of falls is often not reported in studies, and 3) few randomized controlled trials have looked at the impact of deprescribing. Understanding the true effect of deprescribing drugs associated with fall risk is important as it allows physicians and pharmacists to make better decisions when prescribing medications or when re-evaluating medications patients are currently taking. Although further research is needed, our results indicate that the reduction in falls seen from deprescribing medications may, at least in part, be due to a reduction of trips.

Fatigue may impair older adults' ability to safely negotiate obstacles over repeated trials. In our study, the 100 obstacle crossing trials were enough to increase fatigue in most participants. Compared to their initial rating of fatigue, thirty-six participants (88%) reported an increase in their fatigue rating during the study. Overall, more obstacle contacts occurred in the second half of the study (median contact trial = 72) and participants with one or more contacts reported higher maximum fatigue ratings than participants without any contacts (Figure 7). Conversely in young adults, although fatigue was not directly assessed, inadvertent obstacle contacts did not increase in the second half of the protocol, which suggests fatigue had little effect on young adults (Heijnen et al., 2012). The effect of fatigue on obstacle contacts in older adults is not surprising, as experimentally induced fatigue resulted in age-dependent changes such as increased lower limb variability and impaired motor control (Johnston et al., 1998; Barbieri et al., 2014). Compared to experimentally induced fatigue (induced via an isokinetic dynamometer and a sit-to-stand chair task at 30 cycles/min in research cited above), the fatigue we induced during repeated obstacle was more ecological. The obstacle crossing trials lasted around 30-40 minutes and breaks were given every 25 trials (about every 10 minutes) to sit and drink water. The fatigue reported during our study is more similar to fatigue during an everyday shopping trip, relative to fatigue induced by a dynamometer or a sit-to-stand task. Overall, the association between fatigue – induced by walking – and inadvertent contacts highlights the importance of measuring fatigue in future gait studies. Furthermore, endurance training should be considered as a potential intervention for people who trip frequently.

This study had several limitations. First, repeatedly stepping over the same obstacle with a 4 m approach distance is not a situation typically encountered. However, obstacles with a consistent height, such as stairs or curbs, are regularly encountered. Furthermore, in private houses, nursing homes, and offices, shorter distances are expected due to room size constraints. Second, obstacle avoidance may not have been prioritized since safety was not threatened due to the presence of a spotter and the obstacle easily collapsing if contacted. Thus, we may have observed a higher frequency of contacts than might be observed under more typical situations. Lastly, the method to identify obstacle contacts was visual observation, confirmed by two experimenters in real time and later by video. We are confident that any contacts noted by the experimenters were actual contacts and there were not any false positives. However, it is possible that an obstacle contact, where the participant 'grazed' the top edge of the obstacle, went unnoticed (resulting in a false negative). While it is unlikely that contacts minor enough to go unnoticed in the research protocol would have impeded participants walking during everyday activities, these grazing contacts may indicate people who are at risk of tripping. The current protocol did not allow us to determine any factors associated with grazing contacts.

In summary, inadvertent trips were not uncommon in older adults. These contacts share many of the same risk factors associated with falls during everyday activity including gait measures during unobstructed walking. We also found that when the task and environment are held constant, the frequency of inadvertent trips in males was not different than the frequency in females, which suggests other factors are responsible for why females have a higher proportion of trip-related injuries. Fatigue was an important factor for successful obstacle crossing, despite regular breaks, which demonstrates the need to consider fatigue in all obstacle crossing studies. Furthermore, interventions designed to reduce falls in older adults may benefit from targeting the factors associated with inadvertent trips such as improving endurance and improving eye and stepping coordination.

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APPENDIX A- ACTIVITIES-SPECIFIC BALANCE CONFIDENCE SCALE.

The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0%	10	20	30	40	50	60	70	80	90	100%
no confidence						completely confident				

"How confident are you that you will not lose your balance or become unsteady when you…

…stand on your tiptoes and reach for something above your head? ____%

…stand on a chair and reach for something? ____%

…are bumped into by people as you walk through the mall? ____%

… step onto or off an escalator while you are holding onto a railing? ____%

… step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%

…walk outside on icy sidewalks? ____%

APPENDIX B- GODIN LEISURE-TIME EXERCISE QUESTIONNAIRE

Godin Leisure-Time Exercise *Questionnaire*

During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

Weekly leisure activity score = (9 × Strenuous) + (5 × Moderate) + (3 × Light)

	Times per week		Totals
a) **STRENUOUS EXERCISE (HEART BEATS RAPIDLY)** (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)		**X9**	
b) **MODERATE EXERCISE (NOT EXHAUSTING)** (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)		**X5**	
c) **MILD/LIGHT EXERCISE (MINIMAL EFFORT)** (e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)		**X3**	
WEEKLY LEISURE-TIME ACTIVITY SCORE			

APPENDIX C- RATING-OF-FATIGUE SCALE.