Title: Associations Between Gait-Related Falls and Gait Adaptations when Stepping onto a Curb: A Prospective Falls Study

Authors: Steven van Andel[1], Michael H. Cole[1], Gert-Jan Pepping[1]

1. School of Exercise Science, Australian Catholic University, Banyo, Queensland, AU

Address for Correspondence:

Steven van Andel

Steven.vanAndel@acu.edu.au

Abstract

Objectives. Examine gait regulation during the approach to stepping onto a curb for older adults who did or did not report gait-related falls over a 12-month follow-up.

Methods. Ninety-eight participants aged 60 years and older were analyzed. Primary outcomes were step length adaptations (lengthening or shortening) during a curb approach and the occurrence of a gait-related fall during a 12-month follow-up.

Results. Linear-mixed effects modelling indicated stronger adaptations towards the end of the approach. Participants who reported experiencing a gait-related fall showed a stronger relationship between the adjustment required and adjustment produced; indicating different gait adaptations during the step leading onto the curb.

Discussion. The link between prospective gait-related falls and gait-adaptations indicated that older adults with reduced capabilities require stronger adaptations to complete tasks reminiscent of everyday life. This finding may provide insight into the mechanisms of falls in older adults and should inform new falls prevention interventions.

Keywords

Perceptual-Motor Coupling; Locomotor Pointing; Functional Approach to Ageing; Falls Risks; Prospective Falls Diaries;

Introduction

It is estimated that about one in three older adults fall at least once each year (Campbell, Reinken, Allan, & Martinez, 1981; Tinetti, Speechley, & Ginter, 1988; World Health Organization, 2007), making accidental falls a significant physical, psychological and financial burden on society (Hartholt et al., 2011). Falls-related medical costs are significant and predicted to grow further with the increasing number of older adults (Burns, Stevens, & Lee, 2016; Hartholt et al., 2012; Hendrie, Hall, Arena, & Legge, 2004). As the majority of falls occur during gait (Berg, Alessio, Mills, & Tong, 1997), the current study aimed to establish the relationship between perceptual-motor control in gait and the high incidence of gait-related falls measured prospectively in a cohort of older adults.

Recent studies have proposed that falls might be related to a decline in an individual's ability to perceive their own action capabilities (Luyat, Domino, & Noël, 2008; Sakurai et al., 2013). For instance, research has shown that, older participants were unaware of the age-related declines that affected their ability to stand on inclined surfaces (Luyat et al., 2008). These findings call for an approach to falls risk assessment that considers the entire perceptual-motor system and the intrinsic scaling of perception and action (Andel, Cole, & Pepping, 2017).

A locomotion task in which perceptual-motor regulation has been well studied is the task of approaching and placing a foot on a target on the ground, known as *locomotor pointing* (Lee, Lishman, & Thomson, 1982). The mechanisms of locomotor pointing have been established in research concerning the long jump approach (De Rugy, Montagne, Buekers, & Laurent, 2000; De Rugy, Taga, Montagne, Buekers, & Laurent, 2002; Lee et al., 1982; Montagne, Cornus, Glize, & Quaine, 2000) and later generalized to walking tasks (Andel, Cole, & Pepping, 2018; Cornus, Laurent, & Laborie, 2009). Collectively, this body of evidence shows that adjustments in step length during the approach to a target are informed by the athlete's perception; showing evidence of a *perceptual-motor coupling*. Montagne and colleagues (2000) operationalized this informational coupling as the relationship between athletes' perception of their current position and the adjustments made in a following step. They showed that, for instance, if long jumpers in a certain phase of their approach (n steps from the take-off bar) perceive themselves to be closer to the bar than normally at step n; they will compensate by shortening their following step. In other words, they perceive an 'adjustment required' in their position and couple this to the change their step length ('adjustment produced'). The strength of this coupling (i.e. the steepness of the regression line between adjustment required and adjustment produced) was shown to increase as people drew closer to their target in both the long jump and other locomotor pointing tasks (Andel et al., 2018; Cornus et al., 2009; De Rugy et al., 2000, 2002; Lee et al., 1982; Montagne et al., 2000).

The strength of perceptual-motor coupling has been shown to change when a person is confronted with different tasks that pose different demands for locomotor pointing (Montagne, Buekers, De Rugy, Camachon, & Laurent, 2002). For instance, when investigating locomotor pointing to step over an obstacle, Cornus and colleagues (2009) showed that the strength of perceptual-motor coupling increased both when the walking speed and the obstacle size were increased. These results illustrate that, when individuals are confronted with higher task demands in a locomotor pointing task, they show stronger perceptual-motor coupling (Andel, Cole, & Pepping, in press).

It is important to realize that task demands in locomotor pointing are determined not only by the task, but also by the person completing the task; that is, if a person with limited capabilities completes a locomotor pointing task, the relative task demands are increased. In the example of stepping up a curb, this task is more challenging for a person with weaker legs, compared to a well-trained athlete. It is well established that decreases in muscle mass for older adults lead to a functional decline in the locomotor system (Larsson, Grimby, & Karlsson, 1978; Oberg, Karsznia, & Oberg, 1993). Furthermore, such impairments to the locomotor system have been identified as risk factors for falls (Ambrose, Paul, & Hausdorff, 2013). It could be reasoned that the functional declines in the locomotor system that are associated with an elevated risk for falls, lead to higher task demands in locomotor pointing. The current study, therefore, hypothesized that an elevated incidence of gait-related falls would be associated with increased perceptual-motor coupling requirements during the approach to stepping up a curb.

Methods

Participants. One hundred and six participants volunteered to enter the study (number of females: 77, mean age: 71.4 yr, standard deviation: 5.6 yr). Participants were eligible to be included if they were 60 years or older, were able to stand and walk without a walking aid for the entire length of the experiment, had no signs of cognitive decline (Mini Mental State Examination score >23) and had normal or corrected to normal vision (Bailey-Lovie High Contrast Sensitivity <0.30 LogMAR). No participants were excluded based on these criteria. The protocol of the study gained written approval by the institutional human research and ethics committee and all participants signed an informed consent form.

Materials and protocol. An 8.5-meter long GAITRite pressure-sensitive walkway (GAITRite®, CIR Systems, Inc., Franklyn, NJ, USA) was positioned in front of a purpose-built platform similar in dimensions to a regulation-sized curb (L: 200 cm, W: 100 cm, H: 15 cm). Participants were instructed to use their natural walking pace to walk along the walkway toward the platform and were required to step onto the curb, continue to the end of the landing and flick a switch (Height 135 cm). The GAITRite system recorded foot placements during the approach and the positioning of the first footfall on top of the curb was collected using a digital video camera (CASIO, EX-FH100) that was positioned 2.35m from the edge of the platform, perpendicular to the direction of walking. The use of a video camera to collect data for the first footfall on top of the curb was necessary, as the GAITRite system does not allow gait to be measured on two surfaces of differing heights. Video footage of the first step on top of the curb was digitized by the first author and two research assistants using Kinovea Video analysis software (version 0.8.15, ©2006-2011 Joan Charmant & Contrib.). The gait measures derived from the digitisation process by the three raters for two participants (n = 66 trials) were shown to have very high inter-rater reliability (ICC = 0.993) and the outcomes of this process are reported elsewhere (Andel et al., 2018).

Prior to commencing the experiment, participants were asked to perform three walks over the set-up to: i) familiarize themselves with the protocol; and ii) collect an a-priori measure of their average step length. The three trials used to determine the a-priori step length measure were used to inform the set up of the different conditions in the experiment and, hence, were not used to derive any of the reported outcome measures. As the task was foreign to the participants, some approached the first of the familiarization trials with some caution, which resulted in biased average step length. If this was the case, a fourth walk was requested for the calculation of the a-priori step length to ensure a representative average.

The experiment aimed to assess how participants minimize variability in their foot placements in stepping onto the curb. It was, therefore, important to introduce a higher degree of variability in the foot placements early in the approach. To this end, participants were required to place one of their early footfalls on a non-slip mat (L: 30 cm, W: 150 cm) that was positioned in ten different positions ranging 1 to 2.5 times the step length measured a-priori from a fixed starting position. An 11th condition was included in which no mat was presented and participants walked unconstrained. All conditions were repeated three times in random order, resulting in the total of 33 trials per participant.

Participants received instructions for the completion of a 12-month follow-up assessment to screen for the occurrence of falls. The following definition of a fall was provided: ‘an unintentional coming to the ground or some lower level not as a result of a major intrinsic event (e.g., stroke or syncope) or overwhelming hazard’ (Tinetti et al., 1988). Participants were prompted to submit information on all falls, also when in doubt with this definition, in order to prevent under reporting. Only gait-related falls were considered in the analysis. Falls occurring in non-steady-state gait and falls occurring during other activities which might involve short or atypical bouts of gait, such as ‘gardening’ or ‘treadmill walking’ were excluded. All participants were given the option to either complete these calendars on paper-based forms that they returned via post, or electronically using a web-based survey (‘Google Forms’, Google LLC, Mountain View, CA, USA). Wording of the questions in both versions of the calendars was identical with participants asked questions like “Did you experience any falls this month?” and “Did you suffer any injuries?”. All participants were instructed to return one calendar at the start of each month (for which the web-based participants received an email reminder). In situations where a participant did not submit a response to the questionnaire, they were reminded to do so halfway through the subsequent month via email or phone (depending on personal preference) and then weekly until a response was received. If a response was not received after six weeks, the participant was considered to have withdrawn from the study. If, at the moment of withdrawing, the participant had already reported one or more gait-related fall, the participant’s data were included in the analyses (unless requested otherwise by the participant). However, if no fall had yet occurred, data was excluded from further analyses, as it was not possible to confidently classify the participant as a faller or non-faller based on the available data.

Outcome Variables and Statistical Analyses. The primary outcome variable of the statistical analyses was the degree to which gait-adaptability, i.e. the step-length adjustment, was based on the participant's position before that step. This was measured as the relationship between the 'adjustment required' (AR) and the 'adjustment produced' (AP); AR being the difference between the current footfall's location and the average location for that footfall per participant over all 33 trials; and AP was measured as the difference between the length of each step and the average step length for that step per participant over all trials (Figure 1). Following previous locomotor pointing protocols (Andel et al., 2018; Cornus et al., 2009; Montagne et al., 2000), this relationship was calculated in all trials that showed at least one step with a significant adjustment in step length. For this study, a significant adjustment in step length was defined as being more than two standard deviations different from the average step calculated over four steps in the middle of the walk (over all trials, 84% of the trials met this criterion with no significant differences in percentage between non-fallers and fallers). This relationship was analyzed for the last six steps leading to the curb, with the last being the step onto the platform.

INSERT FIGURE 1 ABOUT HERE

A Linear Mixed Effects (LME) modelling analysis was performed using Matlab (R2018A) to assess differences between groups in terms of the relationship between AR and AP when approaching the curb. AP was included as the dependent variable, while AR was included as a fixed factor. To assess whether this relationship was different for non-fallers and fallers, the prospective falls classification was included as a random factor and slopes were allowed to vary per step number. Furthermore, the interaction between the falls category and step number was included as a random factor in the LME model. Step numbers were defined with ‘Step0’ being the step leading onto the curb and ’Step-n’ being the nth step before stepping onto the platform. The resulting coefficients from the model were interpreted with an alpha of 0.05 and the full model is specified below.

$$AP \sim AR + (-1 + AR|Step) + (-1 + AR|FallsCategory) + (-1 + AR|Step * FallsCategory)$$

Results

Of the 106 participants, ninety (85%) chose to complete the 12-month follow-up using the web-based form (mean age: 71.3 yr, SD: 5.8), while 16 (15%) chose the paper-based method (mean age: 71.8, SD: 4.8). Three participants withdrew from the follow-up after failing to respond to any communication; one of these participants was still included in the analyses as the withdrawal occurred after reporting a gait-related fall prior to the withdrawal. In a small number of trials, it was not possible to derive the outcomes from the video data due to technical errors arising during the data collection process. Pilot measures showed that mean values and error measures were not severely affected if the missing data were less than 10% of the total collection (i.e. maximum 3 trials) and, hence, participants who were missing the video-based outcomes for 3 or fewer trials were kept in the analysis, otherwise participants were excluded (N=6).

After exclusions, 98 participants were left in the analysis and these participants reported a total of 77 falls in the prospective follow-up. Two of these falls did not fit the definition of a fall as used by the current study (i.e. were caused by overwhelming hazards) and were thus excluded, leading to 75 reported falls in total in the analysis, experienced by 36 participants. Of these falls, participants reported 28 to be without injury, 39 falls led to minor injuries (e.g. small bruises, cuts or swelling, not requiring medical attention), six falls caused moderate injuries (e.g. severe bruising, cuts or sprains, not requiring medical attention) and two falls caused severe injuries requiring medical attention (e.g. fractures, dislocation, head injury). Of the 75 falls in total, 40 were classified as gait-related falls, experienced by 28 participants; these participants were marked as fallers in the statistical analysis. Table 1 summarizes the mean age, mobility, vision and mental state of the two study groups, with independent samples t-tests indicating no significant differences between the fallers and non-fallers.

INSERT TABLE 1 ABOUT HERE

As introduced in the Methods section, perceptual-motor coupling can be measured during the approach to a target (i.e. the curb) by analyzing how participants minimize their footfall variability as they draw closer to the target. For this reason, the variable placement of a ‘target step’ was introduced early in the approach, to induce variability. Figure 2A shows that this manipulation was successful, illustrated by the high variability of footfalls early in the approach, which was systematically lowered as participants drew closer to stepping up and onto the curb (marked ‘footfall 0’ in Figures 2A and 2B). Furthermore, Figure 2B confirms the homogeneity between the groups in terms of how they completed the task. A similar strategy was shown in terms of changing step length in the approach to the curb by both groups.

INSERT FIGURE 2 ABOUT HERE

Table 2 summarizes the results of the Linear Mixed Effects Modelling analysis. A significant main effect was found for AR (beta = 0.196, pred. SE = 0.066, p = 0.003), showing the relationship between AR and AP over the entire walk. Furthermore, a significant random effect for step number was identified, with positive coefficients at Step0 and Step-1, and negative coefficients at Step-5 and Step-6. These effects illustrate that the relationship between AR and AP increases as one moves closer to the curb. Analyzing all steps in the walk together, the main effect for grouping was not statistically significant (beta < 0.001, pred. SE < 0.001, p = 1.000), showing no difference between groups over all steps. However, a significant Group*Step interaction was found, which indicated that fallers showed a stronger relationship between AR and AP during the last step up and onto the curb (beta =0.035, pred. SE =0.016, p = 0.032). The results for the final four steps are summarized in Figure 3.

INSERT TABLE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

Discussion

The aim of the current study was to investigate gait adaptations in older adults who did and did not experience a gait-related fall during a 12-month follow-up period and to test whether the incidence of gait-related falls is associated with specific gait adjustments. The results showed that gait adaptations in any step during the approach were related to the required adjustment, based on the foot placement before that step. The strength of this relationship increased as participants drew closer to stepping onto the curb. It was shown that during the final step onto the curb, participants who had experienced a gait-related fall exhibited significantly stronger relationships between the required adjustment and the produced gait adaptation than participants who did not report a gait-related fall.

The results confirm our hypothesis that gait-related falls are associated with increased perceptual-motor coupling requirements during the approach to stepping up a curb, and that the required perceptual-motor coupling increases with increasing task demands (Montagne et al., 2002). It is important to note that stronger or weaker perceptual-motor coupling should not be interpreted as inherently better or worse in terms of falls risk. That is, all participants in this study successfully completed the task of stepping up the curb, without tripping and falling. As such, it should be concluded that all participants produced an adequate degree of perceptual-motor coupling to safely perform the task. However, these results were recorded in a laboratory-based experiment with a simple task and no distracting factors. If older adults with an elevated falls risk need to produce a stronger coupling in this simple task, it seems reasonable to assume that their required coupling is also higher in more complex locomotor pointing tasks in the natural world. Previous studies have already shown that older adults at risk for falls generally use a sub-optimal gaze strategy in these type of situations (Chapman & Hollands, 2006; Young &

Hollands, 2010). Future reasearch is required to investigate whether the mechanism behind falls during walking is actualy related to not meeting the elevated demands for perceptual-motor coupling in a natural, complex environment, with many potential distractors.

The functional declines in the locomotor system that are associated with a reduced muscle mass (Larsson et al., 1978; Oberg et al., 1993), could have made the task of approaching a curb more demanding for older adults that are prone to falling, which might have led to greater perceptual-motor demands in this task. Theoretically, in coping with these higher demands, it would be more efficient to produce a slightly stronger coupling over multiple steps in the approach, instead of producing one step with relatively large adaptations. However, older adults who reported falling seemed to use this latter strategy and left the relatively large adaptations to be made in the very last step. It is important to consider why fallers did not ‘spread out’ making the required adjustments over multiple steps. Future studies are required to distinguish whether it is this ‘late timing’ of adjustments that is the mechanism behind the higher incidence of falling. Potentially, this interpretation of gait adaptability could provide new insights into falls prevention interventions.

The current study used a perceptual-motor control framework to explain falls risk. According to this framework, risk needs to be interpreted as a relational concept; that is, as the relationship between the individual and their environment (Cordovil, Araújo, Pepping, & Barreiros, 2015). Too often, the field of gerontology focuses on just the individual (e.g. this person is at risk of falling) or the environment (e.g. this situation is dangerous), rather than on the relationship between them (i.e. this person is at risk of falling when placed in a specific environment). A functional approach to healthy ageing broadens the field to consider the person within the environment (Vaz, Silva, Mancini, Carello, & Kinsella-Shaw, 2017). For instance, rather than prescribing lower limb strength training for falls prevention, practitioners could prescribe a functional alternative, in order to strengthen the limbs as well as challenge the perceptual-motor system. In these tasks, participants should be required to couple perception and action with each step. An example of this could be a guided bushwalking intervention, where the environment demands an accurate foot placement with each step to limit the risk of tripping or slipping resulting from inaccurate placement. The demands of such a task require a strong coupling between perception and action for each step, which could be effective practice for older adults to engage in strong coupling in any situation. Future reasearch is required to study the effectiveness of such an intervention for falls prevention.In agreement with previous findings (Berg et al., 1997), the current study found that the majority of falls (53%) occurred during gait-related activities. The percentage of participants who reported at least one fall (37%) was slightly higher than the commonly reported 33% for adults aged 65 years and older (Campbell et al., 1981; Tinetti et al., 1988; World Health Organization, 2007). Given that the current study included slightly younger participants over the age of 60 years, slightly lower falls rates were expected. The elevated falls rate might be linked to the participant recruitment, which was organized in cooperation with a local community for healthy aging. This might have resulted in a sample that was more active compared to the general older population. Increased activity levels might have led our participants to engage in more risky behaviors and risky situations, leading to an elevated falls rate. Even though the falls rate in the current study was higher than expected, this only led to the report of two falls (3%) that required medical attention. Further studies should identify whether a higher physical activity level in older adults is related to a greater familiarity with their perceptual-motor system (Andel et al., 2017), which might have helped them to minimize the negative consequences of these falls.

The methods of falls assessment can be considered a strength of the current study. A daily falls diary that is returned monthly is generally regarded as the gold standard for recording falls (Peel, 2000; Stark, Silianoff, Kim, Conte, & Morris, 2015). To our knowledge, the current study was the first to have used an electronic, web-based survey to collect falls information. The finding that 85% of participants chose to use the online version of the diaries was unexpected, as it is often assumed that older adults prefer to use conventional media. This is a promising finding, as methods using paper-based calendars are considered to be strenuous and labor intensive (Hannan et al., 2010).

In conclusion, the current study investigated gait adaptability in older adults in a walking approach towards and stepping onto a curb. Older adults who had experienced a gait-related fall during the 12-month follow-up exhibited significantly tighter regulation of gait adaptations in the step leading onto the curb. This finding underlines the importance of a functional approach to assessing physical function and falls risk in older populations and should be used to design novel falls prevention interventions.

Funding

This work was supported by an Australian Government Research Training Program Scholarship awarded to SvA

Acknowledgements

We thank our team of research assistants for their efforts in data collection: Kane Nadasdy, Dominic Kristafor, Olivia Collins, Tom Williams and Hope McMurray. We thank Nancy Low Choi and the School of Physiotherapy for lending us the equipment used in this study. We acknowledge the Burnie Brae community for their invaluable efforts in participant recruitment.

Reference List

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: A review of the literature. *Maturitas*, *75*(1), 51–61. https://doi.org/10.1016/j.maturitas.2013.02.009

Andel, S. van, Cole, M. H., & Pepping, G.-J. (in press). Regulation of locomotor pointing across the lifespan: Investigating age-related influences on perceptual-motor coupling. *PLoS ONE*.

Andel, S. van, Cole, M. H., & Pepping, G.-J. (2017). A systematic review on perceptual-motor calibration to changes in action capabilities. *Human Movement Science*, *51*, 59–71. https://doi.org/10.1016/j.humov.2016.11.004

Andel, S. van, Cole, M. H., & Pepping, G.-J. (2018). Perceptual-motor regulation in locomotor pointing while approaching a curb. *Gait & Posture*, *60*, 164–170. https://doi.org/https://doi.org/10.1016/j.gaitpost.2017.12.006

Berg, W. P., Alessio, H. M., Mills, E. M. E. M., & Tong, C. (1997). Circumstances and consequences of falls in independent community-dwelling older adults. *Age and Ageing*, *26*(4), 261–268. https://doi.org/10.1093/ageing/26.4.261

Burns, E. R., Stevens, J. A., & Lee, R. (2016). The direct costs of fatal and non-fatal falls among older adults — United States. *Journal of Safety Research*, *58*, 99–103. https://doi.org/10.1016/j.jsr.2016.05.001

Campbell, A. J., Reinken, J., Allan, B. C., & Martinez, G. S. (1981). Falls in old age: A study of frequency and related clinical factors. *Age and Ageing*, *10*(4), 264–270. https://doi.org/10.1093/ageing/10.4.264

Chapman, G. J., & Hollands, M. A. (2006). Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. *Gait and Posture*, *24*(3), 288–294. https://doi.org/10.1016/j.gaitpost.2005.10.002

Cordovil, R., Araújo, D., Pepping, G.-J., & Barreiros, J. (2015). An ecological stance on risk and safe behaviors in children: The role of affordances and emergent behaviors. *New Ideas in Psychology*, *36*, 50–59. https://doi.org/10.1016/j.newideapsych.2014.10.007

Cornus, S., Laurent, M., & Laborie, S. (2009). Perception-movement coupling in the regulation of step lengths when approaching an obstacle. *Ecological Psychology*, *21*(4), 334–367. https://doi.org/10.1080/10407410903320991

De Rugy, A., Montagne, G., Buekers, M. J., & Laurent, M. (2000). The study of locomotor pointing in virtual reality: the validation of a test set-up. *Behavior Research Methods, Instruments, & Computers*, *32*(4), 515–520.

De Rugy, A., Taga, G., Montagne, G., Buekers, M. J., & Laurent, M. (2002). Perception - Action coupling model for human locomotor pointing. *Biological Cybernetics*, *87*(2), 141–150. https://doi.org/10.1007/s00422-002-0325-2

Hannan, M. T., Gagnon, M. M., Aneja, J., Jones, R. N., Cupples, L. A., Lipsitz, L. A., … Kiel, D. P. (2010). Optimizing the tracking of falls in studies of older participants: Comparison of quarterly telephone recall with monthly falls calendars in the MOBILIZE Boston study. *American Journal of Epidemiology*, *171*(9), 1031–1036. https://doi.org/10.1093/aje/kwq024

Hartholt, K. A., Polinder, S., Van Der Cammen, T. J. M., Panneman, M. J. M., Van Der Velde, N., Lieshout, E. M. M. van, … Van Beeck, E. F. (2012). Costs of falls in an ageing population: A nationwide study from the Netherlands (2007–2009). *Injury*, *43*(7), 1199–1203. https://doi.org/10.1016/j.injury.2012.03.033

Hartholt, K. A., van Beeck, E. F., Polinder, S., van der Velde, N., van Lieshout, E. M. M., Panneman, M. J. M., … Patka, P. (2011). Societal consequences of falls in the older population: injuries, healthcare costs, and long-term reduced quality of life. *The Journal of Trauma: Injury, Infection, and Critical Care*, *71*(3), 748–753. https://doi.org/10.1097/TA.0b013e3181f6f5e5

Hendrie, D., Hall, S. E., Arena, G., & Legge, M. (2004). Health system costs of falls of older adults in Western Australia. *Australian Health Review : A Publication of the Australian Hospital Association*, *28*(3), 363–373.

Larsson, L., Grimby, G., & Karlsson, J. (1978). Muscle strenght and speed of movement in relation to age and muscle morphology. *J. Appl. Physiol.*, *46*(3), 451–456.

Lee, D. N., Lishman, J. R., & Thomson, J. A. (1982). Regulation of gait in long jumping. *Journal of Experimental Psychology: Human Perception and Performance*, *8*(3), 448–459. https://doi.org/10.1037/0096-1523.8.3.448

Luyat, M., Domino, D., & Noël, M. (2008). Surestimer ses capacités peut-il conduire à la chute? Une étude sur la perception des affordances posturales chez la personne âgée [Can overestimating one’s own capacities of action lead to fall? A study on the perception of affordance in the elderly]. *Psychologie & Neuropsychiatrie Du Vieillissement*, *6*(4), 287–297.

Montagne, G., Buekers, M., De Rugy, A., Camachon, C., & Laurent, M. (2002). Control of human locomotion under various task constraints. *Experimental Brain Research*, *143*(1), 133–136. https://doi.org/10.1007/s00221-001-0990-8

Montagne, G., Cornus, S., Glize, D., & Quaine, F. (2000). A perception-action coupling type of control in long jumping. *Journal of Motor Behavior*, *32*(1), 37–43. https://doi.org/10.1080/00222890009601358

Oberg, T., Karsznia, A., & Oberg, K. (1993). Basic gait parameters: reference data for normal subjects, 10-79 years of age. *Journal of Rehabilitation Research and Development*, *30*(2), 210–223. https://doi.org/10.1080/19397030902947041

Peel, N. (2000). Validating recall of falls by older people. *Accident Analysis & Prevention*, *32*(3), 371–372. https://doi.org/10.1016/S0001-4575(99)00066-4

Sakurai, R., Fujiwara, Y., Ishihara, M., Hirguchi, T., Uchida, H., Imanaka, K., … Imanaka, K. (2013). Age-related self-overestimation of step-over ability in healthy older adults and its relationship to fall risk. *BMC Geriatrics*, *13*(44), 1–9. https://doi.org/10.1186/1471-2318-13-44

Stark, S. L., Silianoff, T. J., Kim, H. L., Conte, J. W., & Morris, J. C. (2015). Tailored calendar journals to ascertain falls among older adults. *OTJR : Occupation, Participation and Health*, *35*(1), 53–59. https://doi.org/10.1177/1539449214561764

Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *The New England Journal of Medicine*, *319*(26), 1701–1707.

Vaz, D. V., Silva, P. L., Mancini, M. C., Carello, C., & Kinsella-Shaw, J. (2017). Towards an ecologically grounded functional practice in rehabilitation. *Human Movement Science*, *52*, 117–132. https://doi.org/10.1016/j.humov.2017.01.010

World Health Organization. (2007). *WHO Global Report on Falls Prevention in Older Age.* World Health Organization. https://doi.org/978 92 4 156353 6

Young, W. R., & Hollands, M. A. (2010). Can telling older adults where to look reduce falls? Evidence for a causal link between inappropriate visual sampling and suboptimal stepping performance. *Experimental Brain Research*, *204*(1), 103–113. https://doi.org/10.1007/s00221-010-2300-9

Figures

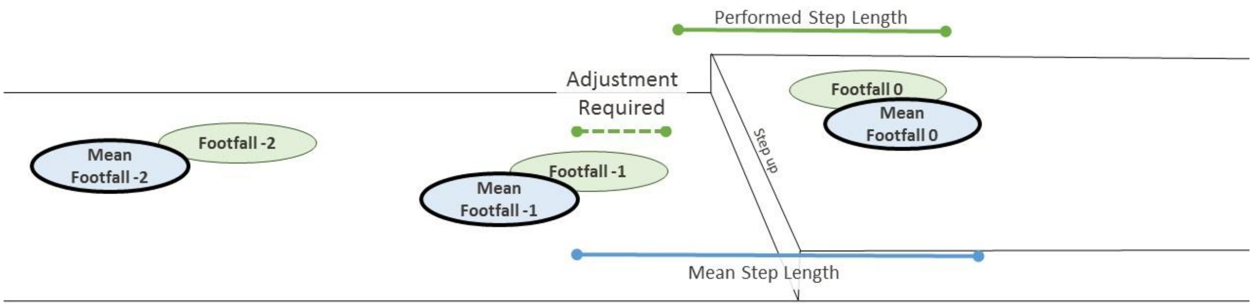

Figure 1: Figure depicts the measures collected to compute AR and AP per step. AR (dashed line) is the difference between any footfall's location and the mean location of that footfall overall trials per participant. AP is the difference between any step length and the mean step length for that step in the approach, per participant (difference between solid lines). AR = adjustment required; AP = adjustment produced.

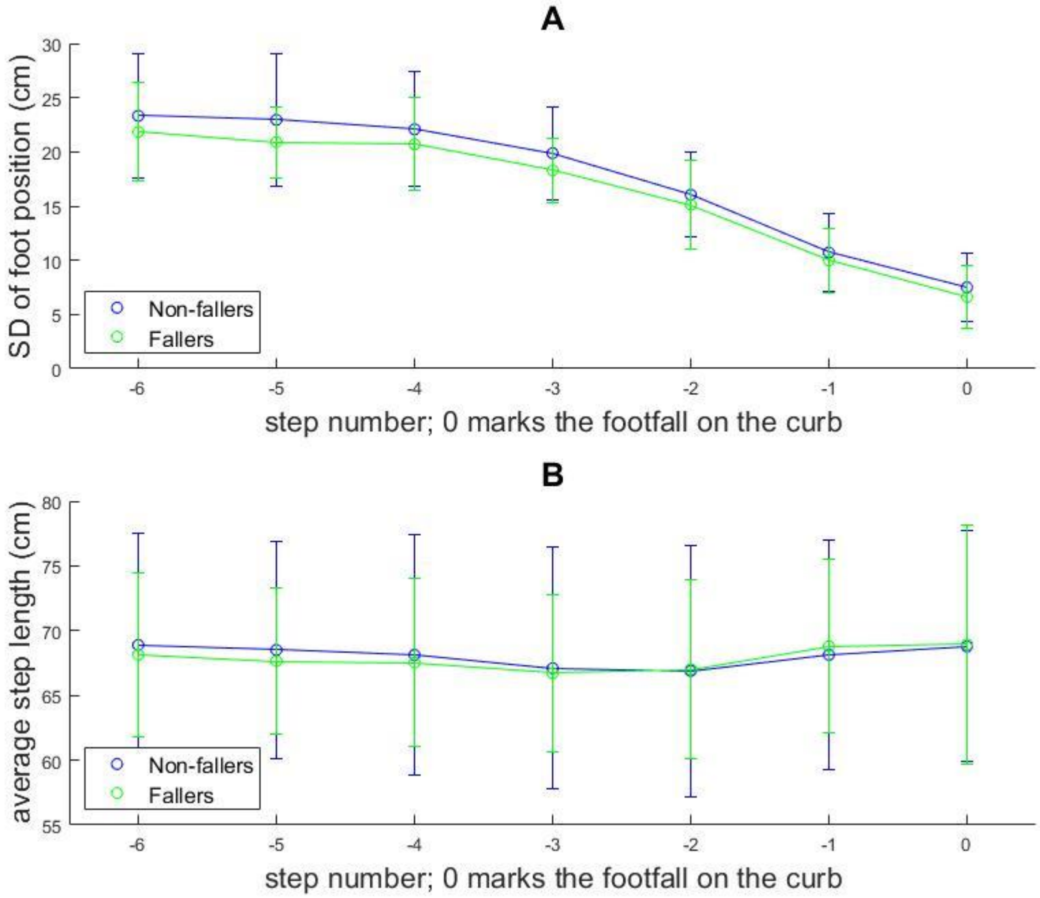

Figure 2: Panel (a) depicts the variability in footfall location as participants get closer to stepping onto the curb (step 0 being the step onto the curb landing). It is apparent that both fallers and nonfallers reach minimal variability in foot placement with their step onto the curb. Panel (b) shows the average step length produced by participants of both groups in their approach to step-up. *Note.* 0 marks the football on the curb.

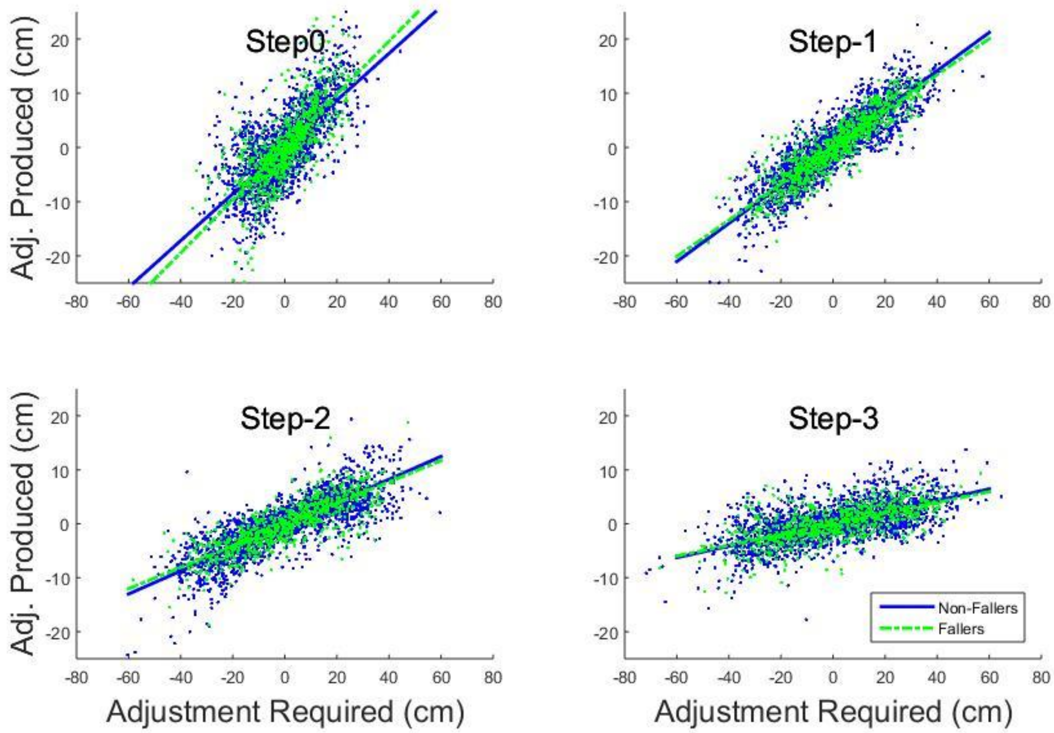

Figure 3: Panels depict the relationship between adjustment required and adjustment produced per step; Step 0 indicating the step onto the curb and step N indicating the N'th step before reaching the curb. Solid line depicts nonfalling older adults and dashed line depicts fallers. Significant differences between groups in relationship are apparent only at Step 0. AR = adjustment required; AP = adjustment produced.

Tables

Table 1. *Descriptive Statistics; means (SD) for non-fallers (N = 70) and fallers (N=28)*

	Non-Fallers	Fallers
Age (years)	71.5 (5.7)	70.4 (4.6)
Timed Up and Go (s)	9.3 (1.6)	9.0 (1.3)
Bailey-Lovie High Contrast Visual Acuity (LogMAR)	0.06 (0.11)	0.09 (0.12)
Mini Mental State Examination (score out of 30)	29.1 (1.1)	29.0 (0.6)
Percentage step ups with right foot	52 (0.25)	51 (0.22)

NOTE. Between group differences were assessed using an independent samples t-test, no significant differences were found.

Table 2. *Results of the Linear Mixed Effects Modelling Analysis Comparing Participants with and without a Gait-Related Fall*

		Fixed Factors		
		Beta	SE	p value
Intercept		-0.004	0.026	0.874
Adjustment Required		0.196	0.066	**0.003**

		Random Factors		
		Beta	Pred. SE	p value
	Falls Grouping	< 0.001	< 0.001	1
Step0	Main effect step number	0.264	0.068	< **0.001**
	Interaction with Gait Fall	-0.03	0.016	0.063
	Interaction without Gait Fall	0.035	0.016	**0.032**
Step-1	Main effect step number	0.148	0.067	**0.028**
	Interaction with Gait Fall	0.005	0.016	0.729
	Interaction without Gait Fall	-0.003	0.016	0.856
Step-2	Main effect step number	0.01	0.067	0.883
	Interaction with Gait Fall	0.005	0.015	0.744
	Interaction without Gait Fall	-0.005	0.015	0.753
Step-3	Main effect step number	-0.092	0.067	0.171
	Interaction with Gait Fall	0.001	0.015	0.95
	Interaction without Gait Fall	-0.003	0.015	0.867
Step-4	Main effect step number	-0.15	0.067	**0.026**
	Interaction with Gait Fall	0.009	0.015	0.577
	Interaction without Gait Fall	-0.011	0.015	0.467
Step-5	Main effect step number	-0.18	0.067	**0.008**
	Interaction with Gait Fall	-0.01	0.015	0.505
	Interaction without Gait Fall	0.007	0.015	0.643

Note. P-values significant at an alpha of 0.05 are presented boldfaced