The Role of Reinvestment in Conservative Gait in Older Adults

Toby C.T. Mak[a], William R. Young[b], Thomson W.L. Wong[a,c,d]

[a] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong SAR, China.

[b] College of Life and Environmental Sciences, University of Exeter, United Kingdom.

[c] Department of Physiotherapy, School of Nursing and Health Studies, The Open University of Hong Kong, Hong Kong SAR, China.

[d] Department of Rehabilitation Sciences, Faculty of Health and Social Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China.

*Corresponding author:
Dr. Thomson W.L. WONG
E-mail: wongtwl@hku.hk

Abstract

Previous research suggests that reinvestment (i.e. conscious control of movements) is associated with inefficient information processing and compromised movement strategies in older adults during walking. We examined whether reinvestment propensity is associated with conservative gait behaviour in older adults. Trait Reinvestment propensity was measured using the Movement Specific Reinvestment Scale (Chinese version) (MSRS-C). Thirty-eight older adults were categorized into 'Low Reinvestor Group' (LRG) (MSRS-C <27) and another 38 were categorized into 'High Reinvestor Group' (HRG) (MSRS-C >38). There were no significant differences in physical and cognitive abilities between groups. Participants were asked to walk along a 6-meter straight level-ground walkway at a self-selected pace under conditions of no instruction (Baseline), instruction related to self-focus on body movements (BI), and instruction related to the external environment (EI). No significant difference was found in gait behaviour between LRG and HRG at Baseline. However, significant changes, indicative of conservative gait patterns, were found in LRG when given instructions that prompted them to consciously control their body movements. No changes were observed in HRG under external-related instructions that are assumed to reduce conscious motor processing and improve motor performance. Our findings contradict previous views on the association between trait reinvestment propensity and compromised motor performance in older adults, which potentially reduces justification for reducing trait reinvestment propensity in older adults. We also suggest that MSRS is insensitive to reflect the degree of conscious control during gait tasks. Our findings also implicate the potential detrimental effect of applying inward-focus-related instructions in healthcare rehabilitation settings.

Keywords: Attention, Reinvestment, Conscious Processing, Gait, Conservative Behaviour

1. Introduction

The most commonly reported cause for falls is slipping/tripping when walking (Talbot, Musiol, Witham, & Metter, 2005). Previous studies have demonstrated associations between changes in gait (e.g., reduced gait speed, increased stance time and shorter stride length) and falls (Kwon, Kwon, Park, & Kim, 2018; Talbot et al., 2005), mobility impairment (Brach, Studenski, Perera, VanSwearingen, & Newman, 2007; Guralnik et al., 2000), and mortality (Studenski et al., 2011) among older adults. These changes in gait that occur through the ageing processes have commonly been described as a 'conservative' gait strategy (Gschwind, Bridenbaugh, & Kressig, 2010; Muir, Haddad, Heijnen, & Rietdyk, 2015; Ronthal, 2019), aimed at maintaining walking stability and preventing future falls (Kang & Dingwell, 2008).

In the field of gait and posture, several studies suggest that individuals operate a different form of motor control when under increased anxiety/pressure (see review from Masters & Maxwell, 2008). In general, walking movements can be performed with relative automaticity among healthy older adults (Malone & Bastian, 2010). When under pressure to avoid falling and experiencing anxiety, however, individuals will typically allocate attention towards processes associated with movement execution instead of the performance goal (Masters & Maxwell, 2008; Wulf, McNevin, & Shea, 2001). The shift from relative automaticity to allocating cognitive effort into consciously monitoring and controlling movement mechanics is often termed 'reinvestment'; a phenomenon previously associated with compromised automatic motor control processing and compromised performance (Masters & Maxwell, 2008).

Several researchers have argued that when individuals 'reinvest' cognitive effort into consciously controlling movement mechanics, various neuromuscular degrees of freedom will be unintentionally 'frozen', resulting in inefficient recruitment of motor units and disruption of movement automaticity (Higuchi, Imanaka, & Hatayama, 2002; Mullen & Hardy, 2000; Vance, Wulf, Töllner, McNevin, & Mercer, 2004). Freezing degrees of freedom within the motor system is associated with increases in muscle co-contractions and reduction in motor efficiency (Lohse, Sherwood, & Healy, 2011; Vance et al., 2004; Zachry, Wulf, Mercer, & Bezodis, 2005). As increased muscle co-contractions contribute to joint stiffness (Reynolds, 2010), it is plausible that reinvestment might, at least in part, be responsible for older adults adopting a conservative gait strategy. Paradoxically, such defensive and conservative adaptations do not necessarily result in safer and more stable gait. Herman, Giladi, Gurevich, & Hausdorff (2005) demonstrated that increased stride-to-stride variability is present as a characteristic of older adults with a description of conservative gait (represented by reduced gait speed, widened base of support and shorter steps). This is also supported by Mak and colleagues (Mak, Young, Chan, & Wong, 2018) who discovered similar characteristics, with the addition of increased body sway in community-dwelling older adults who walked with a so-called ‘conservative’ gait pattern. Extant literature shows that stride-to-stride variability is positively associated with future falls risk (Hausdorff, Rios, & Edelberg, 2001). Maki (1997) suggested that increased variability may be a marker of increased foot placement error that serves to increase the risk of missteps, trips or slips during gait. Several prospective studies have also identified features of conservative gait as a risk factor for falls in older adult populations (Gschwind et al., 2010; Ho, Woo, Chan, Yuen, & Sham, 1996; Ronthal, 2019).

Aside from being a function of situational contexts (e.g. psychological pressure/anxiety), the likelihood of cognitive involvement (i.e., relating to reinvestment and conscious control mechanisms) can relate to individual differences in personality. Masters and colleagues (Masters, Polman, & Hammond, 1993) suggested that an individual’s propensity for movement specific reinvestment is a characteristic of personality trait and can be quantified by the Movement Specific Reinvestment Scale (MSRS) (Masters, Eves, & Maxwell, 2005). The MSRS assesses two distinct dimensions of reinvestment (movement self-consciousness and conscious motor processing). Different scores have been reported between specific populations (e.g., older fallers (Wong, Masters, Maxwell, & Abernethy, 2008), patients with stroke (Orrell, Masters, & Eves, 2009) and Parkinson's disease (Masters, Pall, MacMahon, & Eves, 2007)) and their age-matched controls. For instance, Wong and colleagues (Wong, Masters, Maxwell, & Abernethy, 2009) have shown that older repeat fallers have a higher predisposition to 'reinvest' and consciously control their movements than non-fallers. Uiga and colleagues (Uiga, Capio, Wong, Wilson, & Masters, 2015) have also shown that when performing a walking task with obstacles, older adults with higher reinvestment tendency showed greater awareness of their limb movements and reduced awareness of surrounding environmental features, compared to older adults with lower reinvestment tendency (Wong et al., 2009).

Our current knowledge of the processes underlying associations between reinvestment and conservative gait is limited. The purpose of the present study was to further evaluate this association by comparing gait characteristics between groups of older adults categorized as being either high or low 'reinvestors'. Given the widespread assumption that reinvestment can compromise motor performance across a range of motor tasks (Masters & Maxwell, 2008), we also sought to investigate if reinvestment-related verbal instructions can induce changes in cognitive motor processing. The evaluation of any corresponding within-subject changes in gait characteristics would provide a means of potentially demonstrating (or refuting) a causal link between the two.

Exploring the potential impact of cognitive motor processing on gait performance could provide insights for the future development of therapeutic interventions (e.g., through training practitioners to use suitable verbal instructions). Previously, Ellmers and colleagues used explicit verbal cues that directed attention to body movement in postural and gait tasks (Ellmers et al., 2016; Ellmers & Young, 2019). They demonstrated that even a simple verbal instruction led to an increase in conscious control during movements (Ellmers et al., 2016). This study attempted to apply verbal instructions (comparable to Ellmers & Young (2019)) that prompt individuals to 'reinvest' in their body movements or increase their internal awareness related to body movements. We examined whether older adults who display a low propensity for movement specific reinvestment might demonstrate stronger features of a conservative gait pattern when given body-related instruction compared to Baseline. In a separate condition, we also applied verbal instructions that prompt individuals to direct their attention away from their body movements by focusing on the movement effects on the environment (e.g. the destination of the walkway) (Wulf & Prinz, 2001). We also examined whether such environment-related instruction can reduce features of conservative gait in older adults who display a high propensity for movement specific reinvestment compared to Baseline.

2. Method

2.1. Participants

One hundred and twenty healthy older adults aged 65 or above participated in this study. The study was approved by the institutional review board of the University of Hong Kong (EA1501054) and informed consent was obtained from all participants prior to the experiment. Participants were recruited from a number of community centres in Hong Kong and were checked for their eligibility by the inclusion criteria of: (a) aged 65 or above; (b) able to walk independently indoors; and exclusion criteria of: (a) history of neurological disorders; (b) visual impairment (a static visual acuity of below 20/40 assessed by Tumbling-E eye chart); (c) cognitive impairment (a score of less than 24/30 on the Chinese version of the Mini Mental State Examination (MMSE-C)) (Chiu, Lee, Chung, & Kwong, 1994).

Demographic data was then acquired from each eligible participant including gender, age, medical history, fall history, education level and other socio-economical information.

2.2. Baseline Assessments

Timed Up & Go Test (TUG) was used to determine functional walking ability of older adults (Podsiadlo & Richardson, 1991). A duration of longer than 14 seconds to complete the test indicates high fall risk for community-dwelling frail older adults (Shumway-Cook, Brauer, & Woollacott, 2000). Berg Balance Scale (BBS), a 14-item balancing assessment, was used to evaluate balance ability of community-dwelling older adults (Berg, Wood-Dauphine, Williams, & Gayton, 1989). The scale was used widely in clinical testing and has been regarded as the gold standard of functional balance assessment (Blum & Korner-Bitensky, 2008). Falls Efficacy Scale (FES–13 items) (Chinese version) was used to measure older adults' falls efficacy (Lui, 2005). Falls efficacy was considered as the level of perceived self-confidence to take part in typical daily activities without falling (Tinetti, Mendes de Leon, Doucette, & Baker, 1994). A higher score indicates greater confidence or efficacy. The Chinese version of Movement Specific Reinvestment Scale (MSRS-C) was used to assess the reinvestment propensity of the participants (Masters et al., 2005, 1993; Wong, Abernethy, & Masters, 2015; Wong et al., 2008). It comprises two subscales (five items each) of a) conscious motor processing and b) movement self-consciousness. Examples of conscious motor processing include: ''I am always trying to think about my movements when I carry them out''. An example of movement self-consciousness includes: "I'm concerned about my style of moving''. Participants were required to rate 10 items (statements that described them) on a 6-point Likert scale ranging from "*strongly disagree*" to "*strongly agree*". Scores range from 10 to 60 overall, with higher scores representing a higher predisposition to reinvest or consciously control their body movements.

This study constitutes a retrospective analysis of data collected as part of a previously published study (Mak et al., 2018). For the current analysis, participants were allocated into two groups of either High Reinvestor Group (HRG) or Low Reinvestor Group (LRG) by tertile split of the MSRS-C (Masters et al., 2005, 1993; Wong et al., 2015; Wong et al., 2008). Thirty-eight older adults were categorized into LRG (MSRS-C < 27) and another 38 were categorized into HRG (MSRS-C > 38) (see Table 1). Forty-four participants who had the MSRS total score between 27 and 38 were excluded from group allocation and data analysis.

	Mean (SD) or N (%)		
Variables	Low Reinvestor Group (LRG)	High Reinvestor Group (HRG)	*p*-value
N (numbers)	38	38	-
Gender (female)	25 (65.8%)	27 (71.1%)	-
Age (years)	70.2 (4.8)	71.1 (4.8)	.43
Faller (numbers)	11 (28.9%)	8 (21.1%)	-
MSRS-C - Total	17.9 (5.4)	45.6 (5.7)	< .001*
MSRS-C - CMP	9.4 (3.6)	22.8 (4.2)	< .001*
MSRS-C - MSC	8.5 (3.2)	21.7 (4.7)	< .001*
MMSE-C	29.3 (0.9)	28.8 (1.5)	.10
BBS	54.8 (1.5)	54.6 (1.4)	.48
TUG (seconds)	10.6 (2.6)	11.5 (2.1)	.13
FES-13	121 (9)	116 (14)	.08

Table 1. Participants' Baseline Characteristics (N=76).

Note: MSRS-C = Movement Specific Reinvestment Scale (Chinese version) (Range: 10 – 60); CMP = Conscious Motor Processing subscale; MSC = Movement Self-consciousness subscale; MMSE-C = Mini-Mental State Examination (Chinese version) (Range: 0 – 30); BBS = Berg Balance Scale (Range: 0 – 56); TUG = Timed Up & Go Test; FES-13 = Falls Efficacy Scale (13 items) (Range: 0 – 130). * denotes significant difference.

2.3. Task and Procedure

Participants were instructed to walk at their comfortable pace along a 6-m level-ground walkway under conditions of no instruction (Baseline), instruction related to body movements (BI) and instruction related to the movement effect on external environment (EI). After three practice walking trials, each participant performed nine walking trials, with three repetitions of each condition. Trials were presented in randomized order across participants. The specific instruction for BI was ‘Please focus on your lower limb movements during walking’ while for EI, it was ‘Please focus on a random sequence of digits ranging from 1 to 9 which can be seen on a computer monitor in front of you during walking’. For Baseline, no specific instruction was given to the participants.

2.4. Measurements

Kinematic data was obtained through a 6-camera ProReflex 3-D Motion Capture system (Motion Capture Unit 170 120, Qualisys, Sweden) operating with a sampling rate of 120 Hz. Nineteen retro-reflective markers were attached onto specific anatomical landmarks of participants. Gait parameters were computed from the locations of the markers and filtered with a low pass 3rd order Butterworth filter at 20 Hz with a customized analysis programme in Matlab (R2015b, Mathworks Inc., USA). We calculated outcome measures of stride length, step length and step width (represent spatial characteristics), along with stride time, double support time, stance time and swing time (representing temporal characteristics).

We also calculated gait speed and the amplitude of medial-lateral (M-L) sternum and pelvis sway. Gait speed was calculated by dividing the distance walked by the ambulation time. Stride length was defined as the anterior-posterior (A-P) displacement between two successive heel contacts of the same foot. Step length was defined as the A-P displacement between two successive footsteps, calculated from the heel of one footstep to the heel of the next footstep. Step width was defined as the M-L displacement between the heel of one footstep and the heel of the next footstep. Stride time was defined as the time between two successive heel contacts of the same foot. Double support time (DST) was defined as the time when both feet were touching the floor at the same time (represented by percentage of 2 x DST / stride time). Swing time was defined as the time when the foot was off the floor, measured from toe off to heel contact of the same foot. Stance time was defined as the time when the foot was touching the floor, measured from heel contact to toe off of the same foot. Sternum sway was represented by the mean range of M-L excursion from a sternum marker calculated from each step. Pelvis sway was represented by the mean range of M-L excursion from a virtual marker (created by averaging the locations of the left and right greater trochanters) calculated from each step. Means of all spatial and temporal gait parameters were calculated from each step across the three trials within each condition.

2.5. Statistical analysis

Statistical analysis was performed using SPSS version 23.0. One-way Analysis of Variance (ANOVA) was firstly used to compare baseline characteristics (i.e. functional balance, mobility, fear of falling etc.) between the two groups of HRG and LRG (see Table 1). Then, one-way ANOVA was again used to compare Baseline gait parameters between HRG and LRG. We carried out two one-way Repeated Measures ANOVAs to compare gait parameters between two within-subject conditions (see Table 2). For LRG, we compared BI to Baseline, and for HRG, we compared EI to Baseline. Other potential comparisons were beyond the scope of our investigation since our aim is to manipulate conscious control against the trait disposition of each group. The level of significance for all statistical tests was set at $p < .05$.

3. Results

3.1. Baseline Characteristics

No significant differences were found in age, scores of MMSE-C, BBS, TUG and FES-13 between HRG and LRG (all $p > .05$). As expected due to our group categorisations, MSRS-C scores differed significantly between HRG and LRG ($p < .001$).

	Baseline		BI condition		EI condition	
	LRG	HRG	LRG	HRG	LRG	HRG
Pelvis sway (mm)	41.56 (9.02)	37.78 (9.69)	41.12 (9.82)	39.67 (10.6)	41.57 (9.37)	36.37 (9.90)
Sternum sway (mm)	30.64 (7.82)	28.06 (8.91)	32.26 (7.58)	30.20 (9.63)	31.60 (9.65)	27.61 (9.61)
Gait speed (m/s)	1.11 (0.19)	1.04 (0.19)	1.04 (0.19)	0.99 (0.19)	1.08 (0.20)	1.03 (0.19)
Stride time (s)	1.09 (0.13)	1.12 (0.09)	1.13 (0.15)	1.15 (0.10)	1.10 (0.15)	1.11 (0.09)
DST (%)	30.54 (3.05)	31.20 (3.90)	31.22 (3.13)	31.63 (4.06)	30.93 (3.13)	31.12 (3.73)
Swing time (s)	0.376 (0.046)	0.381 (0.028)	0.384 (0.049)	0.389 (0.030)	0.376 (0.0499)	0.379 (0.029)
Stance time (s)	0.713 (0.092)	0.734 (0.076)	0.741 (0.108)	0.756 (0.082)	0.720 (0.105)	0.730 (0.070)
Stride length (mm)	1176 (126)	1168 (159)	1148 (136)	1139 (158)	1155 (135)	1158 (159)
Step length (mm)	589.3 (62.0)	584.5 (79.1)	580.0 (80.2)	569.9 (78.8)	578.3 (67.0)	579.5 (79.1)
Step width (mm)	68.66 (24.74)	66.60 (25.90)	71.65 (25.59)	69.96 (26.25)	68.41 (23.99)	68.06 (24.53)

Table 2. Gait parameters in Baseline, BI and EI conditions between LRG and HRG.

Note: BI = Body movement instruction; EI = External environment instruction; HRG = High Reinvestor group; LRG = Low Reinvestor group; DST = Double support time.

3.2. Postural Sway

No significant differences in sternum and pelvis sway were found between HRG and LRG at Baseline (all $p > .05$). For LRG, results showed a significantly higher degree of sternum sway under BI compared to Baseline (F [1, 37] = 8.69, $\eta^2 = .19$, $p = .006$) (see Figure 1). Degree of pelvis sway did not differ between BI and Baseline ($p > .05$). For HRG, no significant differences were found in sternum or pelvis sway between EI and Baseline (all $p > .05$).

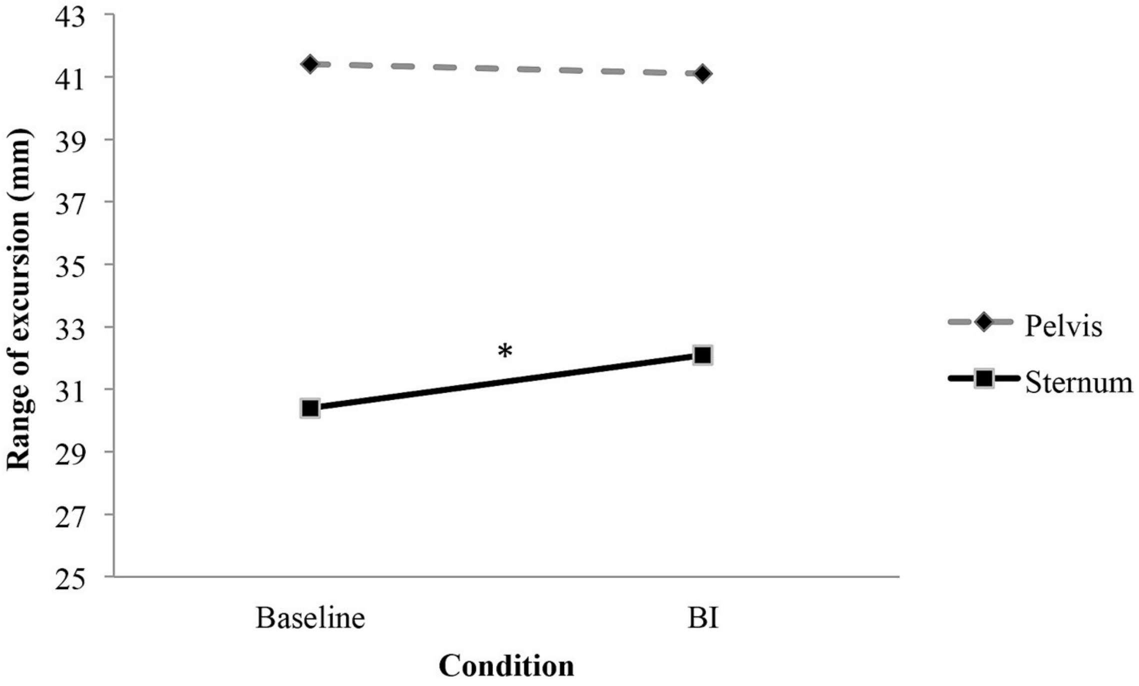

Figure 1. Range of M-L excursion of sternum and pelvis region (mm) of Low Reinvestor Group (LRG) under BI and Baseline. *p < .05.

3.3.1. Gait Pattern – Gait Speed

No significant differences in gait speed were found between HRG and LRG at Baseline ($p > .05$). For LRG, results showed significantly slower gait speed under BI compared to Baseline (F [1, 37] = 56.11, $\eta^2 = .60$, $p < .001$). For HRG, no significant differences were found between EI and Baseline ($p > .05$).

3.3.2. Gait Pattern – Temporal parameters

No significant differences in any temporal gait parameters were found between HRG and LRG at Baseline (all $p > .05$). For LRG, results showed significantly longer durations in all the temporal parameters under BI compared to Baseline (stride time: F [1, 37] = 34.17, $\eta^2 = .48$, $p < .001$; DST: F [1, 37] = 15.69, $\eta^2 = .30$, $p < .001$; swing time: F [1, 37] = 21.97, $\eta^2 = .37$, $p < .001$; stance time: F [1, 37] = 37.17, $\eta^2 = .50$, $p < .001$) (see Figure 2). For HRG, no significant differences were found in any temporal parameters between EI and Baseline (all $p > .05$).

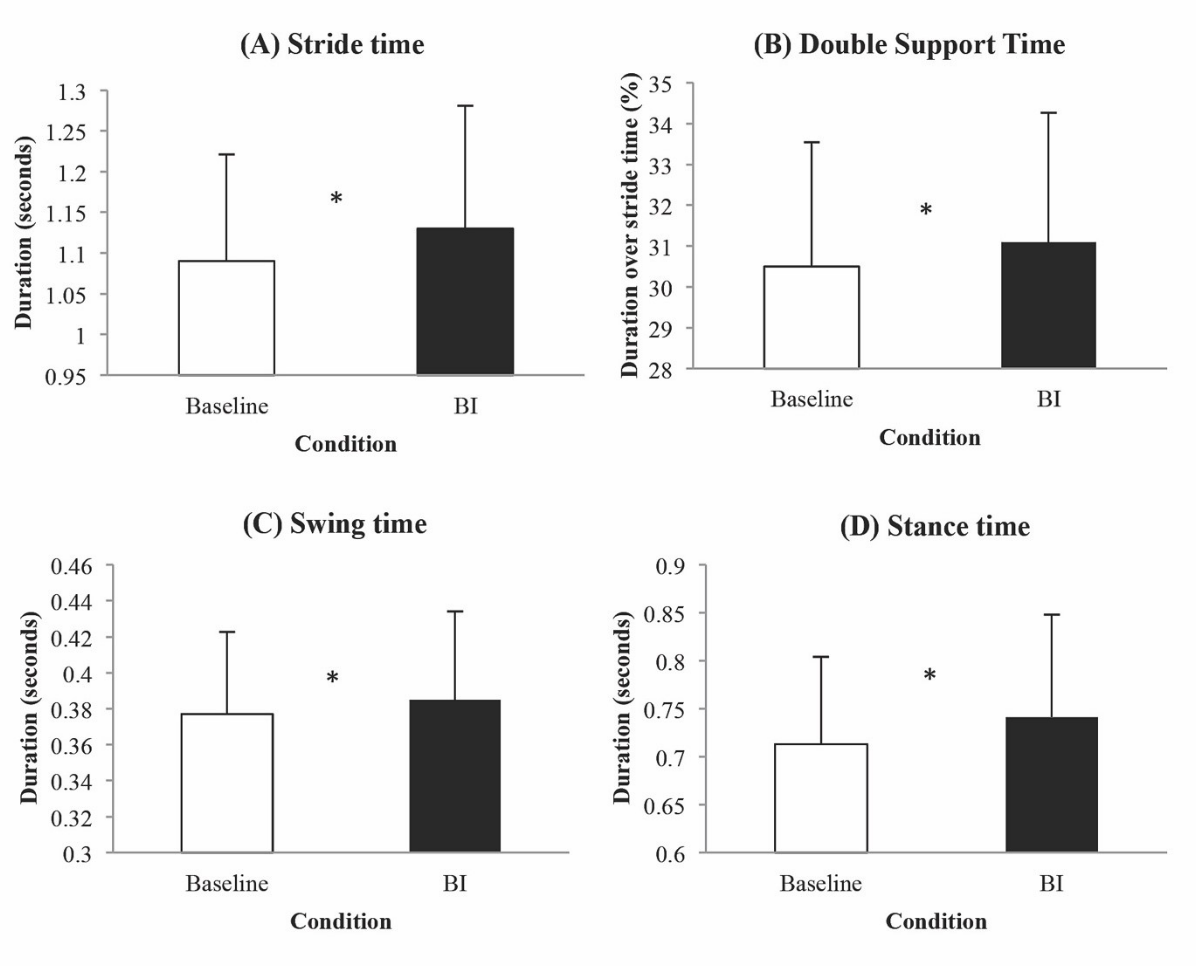

Figure 2. Temporal parameters including (A) stride time, (B) double support time, (C) swing time and (D) stance time (in seconds) of Low Reinvestor Group (LRG) under BI and Baseline. $^*p < .05$. Error bars represent standard deviations.

3.3.3. Gait Pattern – Spatial parameters

No significant differences in any spatial gait parameters were found between HRG and LRG under Baseline condition (all $p > .05$). For LRG, results showed significantly shorter strides under BI compared to Baseline (stride length: F [1, 37] = 32.83, $\eta^2 = .47$, $p < .001$). No significant changes were observed in step length and step width (all $p > .05$). For HRG, no significant differences were found in any spatial parameters between EI and Baseline (all $p > .05$).

4. Discussion

The current study first compared gait patterns between older adults with high (HRG) and low self-reported trait reinvestment (LRG) at Baseline. Given that baseline characteristics (i.e. physical function and fear of falling etc.) were broadly similar between HRG and LRG (see Table 1), the only statistical difference was their reinvestment propensity reflected by MSRS scores. We observed no significant differences between the two groups in any gait measure. The lack of significant differences between groups, independent from physical and cognitive factors, indicates that changes in level-ground gait associated with prior or future falls (Talbot et al., 2005; Tinetti, Speechley, & Ginter, 1988) (generally conceptualised as a conservative gait pattern) might not be associated with trait reinvestment propensity in healthy older adults. This conclusion directly contradicts previous conceptual conclusions drawn from observed associations between reinvestment and motor performance (Masters & Maxwell, 2008; Uiga et al., 2018). Previous literature suggests that previous falls or increased movement difficulties may lead to an increase in self-reported reinvestment. However, our results raise the possibility that this emergent reinvestment may not necessarily compromise movement; at least not in the context of postural control and level-ground walking.

The current results also suggest that the MSRS, an instrument to quantify the propensity for reinvestment as a personality trait, might not be sensitive enough to detect differences in conscious control of walking movements in healthy older adults. Previous studies have revealed differences in MSRS scores between stroke patients and age-matched controls (Orrell et al., 2009), and between older repeat fallers and non-fallers (Wong et al., 2008). However, in healthy older adults, movement-specific reinvestment is usually and only invoked by elevated anxiety/fear of falling or increased awareness of movement difficulties (Wong et al., 2008, 2009). At Baseline, across HRG and LRG, the current task constituted a simple gait task that was, for the current cohort, both physically and cognitively undemanding (Malone & Bastian, 2010). As such, the task may not have induced conscious effort in controlling movement in those who self-reported high trait reinvestment within the MSRS. Future research should employ alternative measures to detect between-subject differences in the degree to which walkers consciously control gait, be it via a revised self-reported measure or through electrophysiological methods such as electroencephalography (EEG) (Chu & Wong, 2018). Ellmers and colleagues validated the use of EEG coherence between T3 (verbal-analytical region) and Fz (motor planning region) as a real-time objective measure of conscious control in a postural task (Ellmers et al., 2016). Increased T3-Fz coherence was found when young adults adopted an inward focus and consciously controlled their body movements during a postural sway task.

To the best of our knowledge, this is the first attempt to evaluate the effect of verbal instructions (to allocate attention either internally or externally to environmental features) on gait characteristics in older adults with different reinvestment tendencies. LRG showed significantly stronger conservative adaptations in their gait pattern under BI. Such changes were observed not only for stride time and length but also in the amplitude of M-L sternum sway, potentially indicating reduced stability (Perrin, Jeandel, Perrin, & Béné, 1997). This finding provides further support to an emergent notion in motor control and learning literature; that a causal link may exist between increased conscious control and conservative gait patterns.

We suggest that in BI trials, LR were able to retrieve and utilise self-generated gait-relevant explicit knowledge relevant to walking actions (Masters & Maxwell, 2004; Poolton, Masters, & Maxwell, 2005). In accordance with The Theory of Reinvestment (Masters & Maxwell, 2008), this information was then used in effortful monitoring and control processes that interfered with the automaticity of this well-learned skill, presumably contributing to a more cautious and potentially less stable gait (Vance et al., 2004; Wulf & Prinz, 2001; Young & Williams, 2015).

Uiga and colleagues previously demonstrated that older adults with a self-reported low propensity to reinvest are less aware of their limb movements when walking, meaning that greater attentional resources are available to be allocated to the external environment (Uiga et al., 2015). As such, according to the rationale that increased awareness of movement will induce more conservative gait, one would expect group differences in gait characteristics between LRG and HRG. Aside from the potential insensitivity of the MSRS to detect changes in conscious monitoring and control of gait-specific movements, the current results also point to a qualitative difference in the manner of internal movement awareness/control evident in older adults reporting high scores on the MSRS (that is associated with increased awareness of movement (Wulf & Prinz, 2001), but not altered gait characteristics) and those with low self-reported reinvestment who are instructed to attend to their body movements when walking (where changes in gait characteristics are evident).

While the specific nature of the conscious control adopted by the LRG cohort is unlikely to be directly comparable with that adopted by older adults with fear of falling or people with neurological impairments, one would anticipate that the 'drive' to consciously control movement in an attempt to avoid falling would be much stronger in these high-risk fearful individuals; thereby presumably having a more pronounced impact on the motor performance compared to that observed here. In other words, certain gait variables known to be associated with anxiety and fear of falling (e.g., stride length and double support time (Donoghue, Cronin, Savva, O'Regan, & Kenny, 2013)) may not have been significantly affected in BI due to the nature of the specific instruction. Nevertheless, the current results do provide clear evidence that adopting a strategy of consciously monitoring and controlling walking actions potentially influences gait characteristics in a manner that resembles conservative gait patterns repeatedly observed in older adults who are deemed to be at a high-risk, and are fearful of falling. It is also important to note that, during BI trials, reductions in gait speed were observed in conjunction with changes in other ‘conservative’ gait parameters. Fukuchi, Fukuchi, & Duarte (2019) suggested that many spatiotemporal gait parameters are largely contingent on gait speed (i.e., walking slower is often associated with reduced step length). As such, we must acknowledge that the broad range of gait changes observed in this study may be, at least in part, an artefact of altered gait speed.

The current data did not show any indication that instruction to focus on the external environment induced any significant ‘beneficial’ difference in gait pattern among HRG. This finding contradicts traditional conceptualisations in the literature. For example, Wulf and colleagues suggested that unconscious or automatic motor processes allow the motor system to regulate and control movements with less conscious involvement, leading to greater movement fluidity and better performance (Wulf & Prinz, 2001). As discussed above, we speculate that this result could be a consequence of the insensitivity of the MSRS to detect high levels of gait-specific conscious control or monitoring during our specific task. We argue that HRG maintained relatively low levels of conscious monitoring and allocated sufficient attentional resources to the external environment during Baseline trials (i.e., comparable to EI) and that this may have been a consequence of the low level of task complexity.

There are limitations to our study. We did not include any depression or state anxiety scale during the experiment. Given that performance anxiety is commonly associated with increased conscious control of movement, such measures would have provided further insight into the way participants allocated attention between conditions. Since participants in this study represent a high functioning group of community-dwelling older adults, caution should be taken when generalizing our findings to broader populations of older adults, such as those with balance deficits. The findings of the present study may also be limited by the lack of kinematic data measurement regarding joint motion in the lower limbs. Such information could provide insight into the association between joint stiffness and conservative or cautious gait characteristics. Moreover, our current kinematic data were determined from a relatively low number of steps due to the limited length of the walkway. Recording a greater number of steps with a longer walkway might provide more accurate and reliable estimates. We also cannot rule out the possibility that participants did not entirely adhere to each specific instruction (i.e., focus on the random digits or lower limb movements).

To conclude, our study does not support the association between self-reported trait reinvestment propensity and level-ground gait performance, as evaluated by variables indicating conservative walking patterns in older adults. While interpretations of this finding in isolation might indicate a contradiction with previous literature, the current data also revealed that a manipulation of attentional focus towards greater internal awareness of movement in LRG induced conservative gait adaptations indicative of increased fall-risk; behaviours that we had expected to observe in HRG at Baseline. These findings collectively provide evidence for a causal link between increased conscious movement processing and conservative gait adaptations in older adults. Consequently, the lack of between-group differences at Baseline might be interpreted with reference to the potential insensitivity of the MSRS at detecting gait-specific levels of conscious control. As such, efforts should be made to develop new gait-specific measures capable of measuring such between-group differences. The current findings have practical implications as they highlight potentially maladaptive consequences of older adults adopting an internal focus of attention when walking; consequences that are likely to reduce walking stability and increase fall risk. As such, our current findings can facilitate the planning of rehabilitation gait training for older adults as they suggest that healthcare practitioners should be cautious when using verbal cues that could potentially induce conscious motor processing. Further work is necessary to establish whether specific internally focused verbal instructions would compromise gait rehabilitation in patient populations.

Acknowledgements

The authors would like to thank Prof Rich Masters, Dr Kenneth Cheng, Dr Gilbert Lam, Dr Andy Tse, Miss May Leung, Miss Connie Chen, Miss Victoria Chow, Miss Janice Chui, Miss Marcia Wong, and Mr. Marco Ng for the support in this study.

Conflict of Interests

The authors list no conflict of interests.

Funding

This work was supported by Early Career Scheme from the Research Grants Council of the Hong Kong Special Administrative Region, China [grant number 27608815].

References

Berg, K., Wood-Dauphine, S., Williams, J. i., & Gayton, D. (1989). Measuring balance in the elderly: Preliminary development of an instrument. *Physiotherapy Canada*, *41*(6), 304–311. https://doi.org/10.3138/ptc.41.6.304

Blum, L., & Korner-Bitensky, N. (2008). Usefulness of the Berg Balance Scale in stroke rehabilitation: A systematic review. *Physical Therapy*, *88*(5), 559–566. https://doi.org/10.2522/ptj.20070205

Brach, J. S., Studenski, S. A., Perera, S., VanSwearingen, J. M., & Newman, A. B. (2007). Gait variability and the risk of incident mobility disability in community-dwelling older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *62*(9), 983–988.

Chiu, H. F. K., Lee, H. C., Chung, W. S., & Kwong, P. K. (1994). Reliability and Validity of the Cantonese Version of Mini-Mental State Examination-A Preliminary Study. *Hong Kong Journal of Psychiatry*, *4*(2), 25.

Chu, C. K. H., & Wong, T. W. L. (2018). Conscious Postural Control During Standing on Compliant Surface by Older Adults. *Journal of Motor Behavior*, 1–8. https://doi.org/10.1080/00222895.2018.1481820

Donoghue, O. A., Cronin, H., Savva, G. M., O'Regan, C., & Kenny, R. A. (2013). Effects of fear of falling and activity restriction on normal and dual task walking in community dwelling older adults. *Gait & Posture*, *38*(1), 120–124. https://doi.org/10.1016/j.gaitpost.2012.10.023

Ellmers, T. J., Machado, G., Wong, T. W.-L., Zhu, F., Williams, A. M., & Young, W. R. (2016). A validation of neural co-activation as a measure of attentional focus in a postural task. *Gait & Posture*, *50*, 229–231. https://doi.org/10.1016/j.gaitpost.2016.09.001

Ellmers, T. J., & Young, W. R. (2019). The influence of anxiety and attentional focus on visual search during adaptive gait. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(6), 697–714. https://doi.org/10.1037/xhp0000615

Fukuchi, C. A., Fukuchi, R. K., & Duarte, M. (2019). Effects of walking speed on gait biomechanics in healthy participants: A systematic review and meta-analysis. *Systematic Reviews*, *8*(1), 153. https://doi.org/10.1186/s13643-019-1063-z

Gschwind, Y. J., Bridenbaugh, S. A., & Kressig, R. W. (2010). Gait disorders and falls. *GeroPsych: The Journal of Gerontopsychology and Geriatric Psychiatry*, *23*(1), 21–32. https://doi.org/10.1024/1662-9647/a000004

Guralnik, J. M., Ferrucci, L., Pieper, C. F., Leveille, S. G., Markides, K. S., Ostir, G. V., … Wallace, R. B. (2000). Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *55*(4), M221-231.

Hausdorff, J. M., Rios, D. A., & Edelberg, H. K. (2001). Gait variability and fall risk in community-living older adults: A 1-year prospective study. *Archives of Physical Medicine and Rehabilitation*, *82*(8), 1050–1056. https://doi.org/10.1053/apmr.2001.24893

Herman, T., Giladi, N., Gurevich, T., & Hausdorff, J. M. (2005). Gait instability and fractal dynamics of older adults with a “cautious” gait: Why do certain older adults walk fearfully? *Gait & Posture*, *21*(2), 178–185. https://doi.org/10.1016/j.gaitpost.2004.01.014

Higuchi, T., Imanaka, K., & Hatayama, T. (2002). Freezing degrees of freedom under stress: Kinematic evidence of constrained movement strategies. *Human Movement Science*, *21*(5–6), 831–846.

Ho, S. C., Woo, J., Chan, S. S. G., Yuen, Y. K., & Sham, A. (1996). Risk Factors for Falls in the Chinese Elderly Population. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *51A*(5), M195–M198. https://doi.org/10.1093/gerona/51A.5.M195

Kang, H. G., & Dingwell, J. B. (2008). Effects of walking speed, strength and range of motion on gait stability in healthy older adults. *Journal of Biomechanics*, *41*(14), 2899–2905. https://doi.org/10.1016/j.jbiomech.2008.08.002

Kwon, M.-S., Kwon, Y.-R., Park, Y.-S., & Kim, J.-W. (2018). Comparison of gait patterns in elderly fallers and non-fallers. *Technology and Health Care*, *26*(Suppl 1), 427–436. https://doi.org/10.3233/THC-174736

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2011). Neuromuscular effects of shifting the focus of attention in a simple force production task. *Journal of Motor Behavior*, *43*(2), 173–184. https://doi.org/10.1080/00222895.2011.555436

Lui, W. M. (2005). *Validity of the Chinese version of modified falls efficacy scale in predicting falls among community-dwelling elderly in Hong Kong*. The University of Hong Kong, Hong Kong.

Mak, T. C. T., Young, W. R., Chan, D. C. L., & Wong, T. W. L. (2018). Gait Stability in Older Adults during Level-ground Walking: The Attentional Focus Approach. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*. https://doi.org/10.1093/geronb/gby115

Maki, B. E. (1997). Gait changes in older adults: Predictors of falls or indicators of fear. *Journal of the American Geriatrics Society*, *45*(3), 313–320.

Malone, L. A., & Bastian, A. J. (2010). Thinking About Walking: Effects of Conscious Correction Versus Distraction on Locomotor Adaptation. *Journal of Neurophysiology*, *103*(4), 1954–1962. https://doi.org/10.1152/jn.00832.2009

Masters, R., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology*, *1*(2), 160–183. https://doi.org/10.1080/17509840802287218

Masters, R. S. W., Eves, F. F., & Maxwell, J. P. (2005). *Development of a movement specific Reinvestment Scale*. Presented at the 11th World Congress of Sport Psychology, Sydney, Australia. Retrieved from http://hub.hku.hk/handle/10722/115113

Masters, R. S. W., & Maxwell, J. P. (2004). Chapter 10: Implicit motor learning, reinvestment and movement disruption: what you don’t know won’t hurt you. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory, and practice* (pp. 207–228). Retrieved from http://ezproxy.library.uq.edu.au/login?url=http://www.tandfebooks.com/isbn/978-0-415-27074-8

Masters, R. S. W., Pall, H. S., MacMahon, K. M. A., & Eves, F. F. (2007). Duration of Parkinson disease is associated with an increased propensity for “reinvestment.” *Neurorehabilitation and Neural Repair*, *21*(2), 123–126. https://doi.org/10.1177/1545968306290728

Masters, R. S. W., Polman, R. C. J., & Hammond, N. V. (1993). ‘Reinvestment’: A dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences*, *14*(5), 655–666. https://doi.org/10.1016/0191-8869(93)90113-H

Muir, B. C., Haddad, J. M., Heijnen, M. J. H., & Rietdyk, S. (2015). Proactive gait strategies to mitigate risk of obstacle contact are more prevalent with advancing age. *Gait & Posture*, *41*(1), 233–239. https://doi.org/10.1016/j.gaitpost.2014.10.005

Mullen, R., & Hardy, L. (2000). State anxiety and motor performance: Testing the conscious processing hypothesis. *Journal of Sports Sciences*, *18*(10), 785–799. https://doi.org/10.1080/026404100419847

Orrell, A. J., Masters, R. S. W., & Eves, F. F. (2009). Reinvestment and movement disruption following stroke. *Neurorehabilitation and Neural Repair*, *23*(2), 177–183. https://doi.org/10.1177/1545968308317752

Perrin, P. P., Jeandel, C., Perrin, C. A., & Béné, M. C. (1997). Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults. *Gerontology*, *43*(4), 223–231. https://doi.org/10.1159/000213854

Podsiadlo, D., & Richardson, S. (1991). The Timed "Up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons. *Journal of the American Geriatrics Society*, *39*(2), 142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x

Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science*, *24*(3), 362–378. https://doi.org/10.1016/j.humov.2005.06.006

Reynolds, R. F. (2010). The ability to voluntarily control sway reflects the difficulty of the standing task. *Gait & Posture*, *31*(1), 78–81. https://doi.org/10.1016/j.gaitpost.2009.09.001

Ronthal, M. (2019). Gait Disorders and Falls in the Elderly. *The Medical Clinics of North America*, *103*(2), 203–213. https://doi.org/10.1016/j.mcna.2018.10.010

Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy*, *80*(9), 896–903.

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., … Guralnik, J. (2011). Gait speed and survival in older adults. *JAMA*, *305*(1), 50–58. https://doi.org/10.1001/jama.2010.1923

Talbot, L. A., Musiol, R. J., Witham, E. K., & Metter, E. J. (2005). Falls in young, middle-aged and older community dwelling adults: Perceived cause, environmental factors and injury. *BMC Public Health*, *5*, 86. https://doi.org/10.1186/1471-2458-5-86

Tinetti, M. E., Mendes de Leon, C. F., Doucette, J. T., & Baker, D. I. (1994). Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *Journal of Gerontology*, *49*(3), M140-147.

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. https://doi.org/10.1056/NEJM198812293192604

Uiga, L., Capio, C. M., Wong, T. W. L., Wilson, M. R., & Masters, R. S. W. (2015). Movement specific reinvestment and allocation of attention by older adults during walking. *Cognitive Processing*, *16*(1), 421–424. https://doi.org/10.1007/s10339-015-0685-x

Uiga, Liis, Capio, C. M., Ryu, D., Young, W. R., Wilson, M. R., Wong, T. W. L., … Masters, R. S. W. (2018). The Role of Movement Specific Reinvestment in vIsuo-motor Control of Walking by Older Adults. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*. https://doi.org/10.1093/geronb/gby078

Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG Activity as a Function of the Performer’s Focus of Attention. *Journal of Motor Behavior*, *36*(4), 450–459. https://doi.org/10.3200/JMBR.36.4.450-459

Wong, T. W. L., Abernethy, B., & Masters, R. S. W. (2015). Enhancement of the Chinese Movement Specific Reinvestment Scale in Older Adults. *GeroPsych*, *28*(3), 137–141. https://doi.org/10.1024/1662-9647/a000130

Wong, W. L., Masters, R., Maxwell, J., & Abernethy, B. (2008). Reinvestment and Falls in Community-Dwelling Older Adults. *Neurorehabilitation and Neural Repair*. https://doi.org/10.1177/1545968307313510

Wong, W. L., Masters, R. S. W., Maxwell, J. P., & Abernethy, B. (2009). The role of reinvestment in walking and falling in community-dwelling older adults. *Journal of the American Geriatrics Society*, *57*(5), 920–922. https://doi.org/10.1111/j.1532-5415.2009.02228.x

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology Section A*, *54*(4), 1143–1154. https://doi.org/10.1080/713756012

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, *8*(4), 648–660. https://doi.org/10.3758/BF03196201

Young, W. R., & Mark Williams, A. (2015). How fear of falling can increase fall-risk in older adults: Applying psychological theory to practical observations. *Gait & Posture*, *41*(1), 7–12. https://doi.org/10.1016/j.gaitpost.2014.09.006

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin*, *67*(4), 304–309. https://doi.org/10.1016/j.brainresbull.2005.06.035