The role of conscious processing of movements during balance by young and older adults

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Abstract

We examined the effect of verbalization of a phylogenetic motor skill, balance, in older and young adults with a low or a high propensity for conscious verbal engagement in their movements (reinvestment). Seventy-seven older adults and 53 young adults were categorized as high or low reinvestors, using the Movement Specific Reinvestment Scale, which assesses propensity for conscious processing of movements. Participants performed a pre- and post-test balance task that required quiet standing on a force-measuring plate. Prior to the post-test, participants described their pre-test balancing performance (verbalization) or listed animals (non-verbalization). Only young adults were affected by verbalization, with participants with a high propensity for reinvestment displaying increased medio-lateral entropy and participants with a low propensity for reinvestment displaying increased area of sway and medial-lateral sway variability following the intervention. The possible explanations for these results are discussed.

Keywords: movement specific reinvestment; postural control; verbalization; older adults

1. Introduction

Research has challenged the prevailing understanding that postural control is automatic, requiring minimal conscious information processing. For example, decrements in balance performance are observed when participants are required to simultaneously carry out a secondary cognitive task (e.g., Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; for a review, see Woollacott & Shumway-Cook, 2002). Cognitively demanding secondary tasks use information processing capacity, which can deplete resources available for the primary motor task (Abernethy, 1988). Disrupted balance performance in secondary-task conditions, therefore, suggests that postural control requires cognitive input. These effects have been shown to be larger among the aged (e.g., Bergamin et al., 2014; Qiu & Xiong, 2015; for a review, see Boisgontier et al., 2013), possibly because of age-related reductions in sensorimotor and cognitive functions (e.g., Lacour, Bernard-Demanze, & Dumitrescu, 2008).

Studies that have manipulated focus of attention during balancing have often shown that focusing internally (i.e., on lower limb movements), rather than externally (i.e., on movement effects), disrupts postural stability (e.g., Wulf, McNevin, & Shea, 2001; Wulf, Mercer, McNevin, & Guadagnoli, 2004). For example, Wulf et al. (2001) demonstrated that following training young adults who had adopted an external focus of attention (i.e., keep the markers besides your feet horizontal) generated smaller balance errors than young adults who had adopted an internal focus of attention (i.e., keep your feet horizontal). Chow, Ellmers, Young, Mak, and Wong (2019) have recently compared balance performance between young adults who received internal focus instructions and young adults who received no instructions. The authors confirmed the disadvantages of adopting an internal focus of attention by showing increased body sway in young adults who were instructed to focus internally compared to participants who received no instructions. It has been argued that adopting an internal focus of attention promotes conscious movement processing, which interferes with automatic control mechanisms and, therefore, reduces fluency of movement (Wulf et al., 2001; Chow et al., 2019). Indeed, Chow et al. (2019) provided objective evidence of this by demonstrating that participants who were instructed to focus internally displayed increased cortical communication between the verbal-analytical (T3) and motor planning (Fz) areas of the brain (indicative of conscious processing of the motor task; see Zhu, Poolton, Wilson, Maxwell, & Masters, 2011) compared to participants who received no instructions. In line with these results, Wulf et al. (2001) showed that participants instructed to focus externally exhibited lower probe reaction times[1] than participants instructed to focus internally, for whom balancing seemed to require more conscious effort.

Proponents of the Theory of Reinvestment (Masters, 1992; Masters & Maxwell, 2008) have proposed analogous line of arguments. According to the theory, movement specific reinvestment occurs when there is "manipulation of conscious, explicit, rule based knowledge, by working memory, to control the mechanics of one's movements during motor output" (Masters & Maxwell, 2004, p.208). Masters and Maxwell (2008) argued that reinvestment represents a "shift" from efficient procedural processing towards inefficient step-by-step conscious processing of previously automated movements. The movements are likely to be disrupted, because the process of conscious movement processing is slow, attention demanding and utilizes working memory resources (Beilock & Carr, 2001; Masters & Maxwell, 2008; Meier, Morger, & Graf, 2003; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

The Theory of Reinvestment further argues that some people have a higher propensity for movement specific reinvestment than the others (e.g., Masters et al.,1993; Masters & Maxwell, 2008). Research has shown that people with a high propensity for movement

[1] Probe reaction times measure available attention capacity once necessary resources are allocated to the primary task (Abernethy, 1988; Posner & Keele, 1969).

specific reinvestment tend to engage in conscious motor processing during task execution, accumulate more task-relevant declarative knowledge during learning than people with a low propensity for reinvestment (Maxwell, Masters, & Eves, 2000), and are most likely to be negatively impacted by pressure and cognitive task loading (e.g., Chell, Graydon, Crowley, & Child, 2003; Jackson, Ashford, & Norsworthy, 2006; Malhotra, Poolton, Wilson, Ngo, & Masters, 2012; Masters et al., 1993).

A majority of the research examining movement specific reinvestment has focused on ontogenetic movement skills (i.e., skills that extend fundamental movements for specialized purposes). Masters (1992; Masters & Maxwell, 2008) has argued that for ontogenetic skills, verbal knowledge is more readily available. Recently, however, it has been shown that phylogenetic skills (i.e., fundamental movement skills), such as balancing can also be affected by reinvestment. For example, Huffman, Horslen, Carpenter, and Adkin (2009) and Zaback, Cleworth, Carpenter, and Adkin (2015) demonstrated that young adults with a high propensity for movement specific reinvestment leaned further away from a platform edge in height-induced postural threat conditions (i.e., on a platform 3.2m above the ground).

Significantly less, however, is known about how conscious self-focused attention affects balance performance of older adults. Chiviacowsky, Wulf, and Wally (2010) required older adults to stand on a balance platform (stabilometer) under internal focus or external focus conditions. They found that older adults who were instructed to focus externally were better able to keep the platform close to horizontal than older adults who were instructed to focus internally. On the other hand, Chow et al. (2019) found no differences in balance performance between older adults who were instructed to focus internally or who were uninstructed, when performing a complex balance task. Furthermore, they found no differences in cortical connectivity between the verbal-analytical (T3) and motor planning (Fz) areas of the brain, suggesting that internal focus instructions did not cause older adults to engage more in conscious movement processing than no instructions. Chow et al. (2019) acknowledged, however, that a manipulation check was not conducted in their study, so it was difficult to know where attention was directed.

In our previous research, we required older and young adults to stand as still as possible on a force measuring platform (Uiga, Capio, Ryu, Wilson, & Masters, 2018). We found that for young adults a high propensity for movement specific reinvestment was associated with larger sway amplitude and a more constrained (i.e., less complex, more regular) mode of balancing. This association, however, was not found for older adults. We argued that older adults may not have access to declarative knowledge about simple postural tasks (given their phylogenetic nature) or that the propensity for movement specific reinvestment may not correctly represent the extent of conscious movement processing by older adults. Indirect support for the latter possibility has been recently provided by Chu and Wong (2019), who found no difference in cortical connectivity between the T3 and Fz areas of the brain in older adults with a high compared to a low propensity for movement specific reinvestment. However, Chu and Wong (2019) did find that older adults engaged in more conscious motor processing as task difficulty increased.

In sum, sufficient evidence has been provided to conclude that movement specific reinvestment plays a role in balance performance by young adults. However, the findings with older adults have been less straightforward, possibly because older adults do not have access to declarative knowledge about balancing. Therefore, in the present study, we employed a verbalization intervention to purposefully provide an opportunity for older and younger adults to create or access declarative knowledge that could potentially be used for conscious movement processing during a simple balance task. We aimed to examine the interaction between age, movement specific reinvestment, and verbalization.

1.1. Present study

Our verbalization intervention was similar to the verbal overshadowing paradigm (Schooler & Engstler-Schooler, 1990), which has previously been used in sport. Flegal and Anderson (2008), for example, showed that high skilled golfers who were asked to verbally describe the mechanics of their putting stroke took twice as many putts to reach a criterion of three consecutive successful putts as high skilled golfers who were not asked to describe the mechanics of their putting stroke. In contrast, low skilled golfers who described the mechanics of their putting stroke performed better than low skilled golfers who did not.

The verbal overshadowing effect has been hypothesized to occur when the perceptual/procedural experience is so rich or complex that it exceeds what can be communicated in words (Melcher & Schooler, 1996). In these circumstances, a shift from automatic to controlled processing occurs (Schooler, 2002; Schooler, Fiore, & Brandimonte, 1997). Flegal and Anderson (2008) argued that the putting stroke of highly skilled golfers is controlled by a non-verbal procedural processing system, so it was not surprising that they demonstrated decrements in performance following verbalization. For low skilled golfers, however, the putting stroke was already under verbal declarative control, so verbalization promoted effective processing (see also, Lewis & Dawkins, 2015).

We divided young and older adults into high and low reinvestors, based on their scores on a psychometric measure of their propensity for movement specific reinvestment (the Movement Specific Reinvestment Scale; Masters, Eves, & Maxwell, 2005). We asked them to perform a quiet standing balancing task before and after engaging in a verbalization intervention. Verbalization was expected to affect performance of quiet standing balance (a well-practiced motor skill), because procedural knowledge underlying balancing tremendously exceeds declarative, verbal knowledge about the skill. We hypothesized, however, that low reinvestors would show greater decrements in balance performance following the intervention than high reinvestors, because low reinvestors are less accustomed to conscious verbal processing of their movements (i.e., relying more on procedural knowledge than high reinvestors, who tend to rely on both procedural and declarative knowledge). As the verbalization intervention provides an opportunity to access or create declarative knowledge about balancing, we expected to see similar trends among both young and older adults.

2. Method

2.1. Participants

G*Power 3.1 power calculation software indicated that the experiment was sufficiently powered (.95) to address our research question and would enable us to detect at least a medium effect (ηp^2=.06) if we recruited N=84 participants (42 young adults and 42 older adults). These calculations were performed by adopting an alpha of .05, non-sphericity correction of 1, and autocorrelation of 0.5 for verbalization, age, reinvestment, and time interaction by mixed model ANOVA.

Fifty-three healthy young adults (mean age = 20.92, SD = 2.53; 49.1% women) and 89 healthy self-ambulatory older adults (mean age = 69.24, SD = 3.72; 79.5% women) participated in the experiment. Young adults were undergraduate students who were asked to participate for course credits. Older adults were recruited via local elderly community centers and by word-of-mouth. Older adults were excluded from the study when they had static visual acuity worse than 20/40 vision, scored less than 24/30 on the Cantonese version of the Mini Mental State Examination (Chiu, Lee, Chung, & Kwong, 1994; Folstein, Folstein, & McHugh, 1975), used walking aids, or reported any physical or neurological impairment. Visual acuity worse than 20/40 has been shown to affect physical functioning and activities of daily living among older adults (West et al., 1997). A score lower than 24 in the Mini Mental State Examination is generally considered to be an indicator of cognitive impairment

(Tombaugh & McIntyre, 1992). Ethical approval was obtained from the local ethics committee and written informed consent was collected from each participant.

2.2. Cognitive measures

Describing something in words, especially something as abstract as balance performance, is not an easy task. Age-related declines in cognitive functions (see Murman, 2015) might influence the ability of older adults to successfully complete the 'verbalization' intervention. We therefore assessed the cognitive functions of older adults and excluded participants who displayed lower levels of functioning.

The Backwards Digit Span test (see Ramsay & Reynolds, 1995) was used to asses verbal working memory performance by older adults. They were presented with a sequence of numbers, which they subsequently had to report in reversed order. The length of the sequence increased by one item until the participant failed to recite the reverse order correctly on two consecutive attempts.

The executive functioning of older adults was assessed using the Trail Making Test Part A and Part B (TMT-A and TMT-B; Partington & Leiter, 1949). TMT-A required participants to draw a line connecting a series of encircled Arab numbers from 1 to 25 on a sheet of paper as quickly and accurately as possible. TMT-B required participants to draw a line connecting a series of encircled Arab numbers and Chinese numbers (e.g., 1 to一, 一 to 2, 2 to 二, 二 to 3, 3 to 三) as quickly and accurately as possible (see Lu & Bigler, 2000). Task performance was reflected by the amount of time it took for a participant to complete the task.

In order to ensure that participants were able to complete the 'verbalization' intervention, those who failed to recite a three-item sequence during the Backwards Digit Span test and took more than 80 seconds and 130 seconds, respectively, to complete the

TMT-A and TMT-B, were excluded from subsequent analysis[2]. In total, 12 older adults were excluded.

2.3. Movement Specific Reinvestment

All remaining participants were required to complete the Movement Specific Reinvestment Scale (MSRS-English/MSRS-Chinese) (Masters & Maxwell, 2008; Masters et al., 2005; Wong et al., 2008, 2009). The scale consists of 10 statements designed to evaluate an individual's concerns about perceptions of their movements (e.g., "I am concerned about my style of moving") and their process of movement (e.g., "I try to think about my movements when I carry them out"). The items are rated on a 6-point Likert scale ranging from "strongly disagree" to "strongly agree". Cumulative scores range from 10 to 60 points, with lower scores indicative of low propensity for reinvestment and higher scores indicative of greater propensity for reinvestment. The MSRS has been shown to have high internal consistency and test-retest reliability (Laborde et al., 2015; Masters & Maxwell, 2008). The internal consistency of the Scale in the present study, as measured using Cronbach's alpha, was found to be good ($\alpha = .903$).

Participants were classified as low or high reinvestors using a median split[3] of their MSRS scores (Jackson et al., 2006; Malhotra et al., 2012). The median score for young adults was 41 and the median score for older adults was 33. Five young adults and two older adults whose MSRS scores were the same as the median score for their respective age groups were excluded from data analysis. An independent samples t-test for young adults showed a significant difference between the mean scores of the low reinvestors (n = 24, mean score = 34.25, SD = 5.75) and high reinvestors (n = 24, mean score = 47.08, SD = 3.82), t(46) =

[2] 80 and 130 seconds were determined by visually screening the data using box plots for 'extreme values' (i.e., values more than 3 times the interquartile range).
[3] Similarly to the study by Laborde et al. (2015), young adults in our study had significantly higher MSRS scores compared to older adults, t(123) = 3.681, $p < .001$. We therefore computed medians separately for each population.

9.106, $p < .001$. Similarly, a significant difference was evident for older adults: low reinvestors (n = 38, mean score = 20.21, SD = 6.21), and high reinvestors (n = 37, mean score = 45.08, SD = 7.13), t(73) = 16.121, $p < .001$.

2.4. Apparatus

Postural stability was measured using a force-measuring plate (Zebris FDM 1.5, Germany; 55cm x 40cm x 2.1 cm; 50 Hz sampling rate).

2.5. Procedure

Participants within each reinvestment group were randomly assigned to a verbalization condition or a non-verbalization condition. All participants performed two 1-minute balancing tasks that took place before or after the verbalization intervention. The balancing task required participants to attempt to stand as still as possible for 1 minute on the force-measuring plate by adopting their most comfortable stance while keeping their hands by their sides and looking straight ahead at an empty wall. Participants in the verbalization condition were allowed 4 minutes to provide a description of their balancing performance. Specifically, participants were instructed to *"Think back to the 'standing still' task that you just completed. State everything you focused on in order to stand still on the force plate. In other words, think about everything that made you not move. Try to report every detail that you can remember, regardless of how insignificant it might seem to you."* Participants in the non-verbalization condition were given 4 minutes to report as many animal names as they could think of.

2.6. Outcome measures and data analysis

Three traditional center of pressure (COP) measures of ellipsoidal area (85.35%) (Area), standard deviation of medial-lateral (SD-ML) and anterior-posterior (SD-AP) axes were calculated using the force-measuring plate data. Additionally, sample entropy (Borg & Laxåback, 2010; Richman & Moorman, 2000) was calculated to analyze the COP dynamics on the medial-lateral (SampEn-ML) and anterior-posterior (SampEn-AP) axes. The traditional measures quantify the average amount of sway variability; however, as the COP is constantly moving, nonlinear methods (such as entropy) provide information about the dynamic structure and regularity of the COP time series.

Sample entropy was calculated as follows (see Ko & Newell, 2016):

$$SampEn(m,r,N) = -ln\frac{C^{m+1}(r)}{C^{m}(r)}$$

where *m* represents the length of the repetition vector that was compared, *r* the similarity criterion, *N* the number of COP data points, and $C^{m}(r)$ the correlation sum. For this study, we used the "default" parameter values m = 2 and r = 0.2. Higher values of entropy represent greater complexity (i.e., less regularity).

All of the variables were subjected to a four-way Multivariate Analysis of Variance (MANOVA): 2 (age group: young adults, older adults) x 2 (reinvestment group: high, low) x 2 (verbalization condition: verbalization, non-verbalization) x 2 (time: pre-test, post-test). Significant effects were first followed up with three-way and two-way MANOVAs and then with Bonferroni corrected follow-up tests. Effect sizes were calculated using partial eta squared (ηp^2). Statistical significance was set at $p = .05$ for all tests.

The content of the verbal reports was analyzed by two independent raters. Statements indicating conscious verbal involvement in balancing were considered to be task-relevant (i.e., "my knees should not be completely straight"). Statements unrelated to conscious verbal processing of balancing were considered to be task-irrelevant (i.e., "I tried to really concentrate"). Task-irrelevant statements were excluded from analysis. Pearson's product-moment correlation coefficient indicated high inter-rater reliability for task-relevant statements ($r = .791$, $p < .001$). The sum of these statements was subjected to a 2 (age group: young adults, older adults) x 2 (reinvestment group: high, low) ANOVA.

3. Results

3.1. Performance

The balancing data were first visually screened for skewness and ‘extreme values’ (i.e., values more than 3 times the interquartile range). Twelve participants (young adults = 3, older adults = 9) were excluded from further analysis because they displayed ‘extreme values’ for one or more postural stability measures.

Descriptive statistics of scores for all five COP measures for young and older adults with a high or a low propensity for reinvestment in verbalization and non-verbalization condition are presented in Table 1.

Table 1. Pre- and post-test scores for five COP measures (Area, SD-ML, SD-AP, SampEn-ML, SampEn-AP) for young and older adults with a high or a low propensity for reinvestment separately for verbalization and non-verbalization conditions.

	Verbalization condition				Non-verbalization condition			
	High reinvestors		Low reinvestors		High reinvestors		Low reinvestors	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
Young adults	N = 12		N = 11		N = 11		N = 11	
Area (mm2)	131.33 (82.38)	103.36 (54.93)	90.88 (50.77)	127.23 (79.67)	89.71 (57.65)	103.03 (50.03)	94.47 (35.92)	90.52 (34.27)
SD-ML (mm)	2.63 (0.77)	2.27 (0.89)	1.93 (0.80)	2.49 (0.97)	2.23 (0.96)	2.43 (0.74)	1.96 (0.53)	2.24 (0.74)
SD-AP (mm)	4.29 (2.05)	4.05 (1.28)	4.00 (0.91)	4.72 (1.94)	3.53 (0.86)	3.70 (1.04)	4.38 (1.52)	3.82 (1.03)
SampEn-ML	0.12 (0.04)	0.16 (0.08)	0.22 (0.12)	0.17 (0.09)	0.17 (0.09)	0.15 (0.08)	0.19 (0.05)	0.18 (0.08)
SampEn-AP	0.08 (0.03)	0.07 (0.01)	0.08 (0.03)	0.07 (0.03)	0.09 (0.02)	0.08 (0.03)	0.08 (0.03)	0.08 (0.02)
Older adults	N = 17		N = 14		N = 16		N = 18	
Area (mm2)	149.49 (95.48)	142.52 (70.63)	128.15 (67.97)	131.77 (76.85)	112.76 (55.15)	125.31 (56.70)	163.56 (123.76)	156.36 (75.75)
SD-ML (mm)	2.83 (1.13)	2.95 (1.16)	2.68 (0.99)	2.61 (1.07)	2.12 (0.55)	2.55 (1.02)	2.75 (1.27)	2.85 (0.87)
SD-AP (mm)	4.34 (1.10)	4.44 (1.49)	4.22 (1.35)	4.33 (1.33)	4.76 (2.33)	4.74 (1.79)	4.56 (1.67)	4.63 (1.78)
SampEn-ML	0.15 (0.05)	0.15 (0.07)	0.14 (0.04)	0.14 (0.05)	0.18 (0.07)	0.16 (0.06)	0.16 (0.05)	0.14 (0.05)
SampEn-AP	0.11 (0.03)	0.11 (0.04)	0.09 (0.03)	0.09 (0.03)	0.10 (0.05)	0.09 (0.03)	0.10 (0.03)	0.10 (0.04)

3.1.1. The effect of verbalization

Repeated measures MANOVA revealed a significant 4-way interaction between age group, reinvestment group, verbalization condition and time ($F(5,98) = 3.09$, $p = .012$, $\eta p^2 = .14$). No other significant main or interaction effects were evident (all *p*'s > .05).

The significant four-way interaction was further investigated with three-way MANOVAs, examining the verbalization conditions separately. For the non-verbalization condition, no significant main effects or interactions were evident (all *p*'s > .05). For the verbalization condition, a significant 2-way interaction between reinvestment group and time was observed ($F(5,48) = 2.59$, $p = .038$, $\eta p^2 = .21$); however, it was superseded by a 3-way interaction between age group, reinvestment group and time ($F(5,48) = 3.01$, $p = .019$, $\eta p^2 = .24$). Separate 2-way MANOVAs were conducted for young and older adults. For older adults, no significant main effects or interactions were evident (all *p*'s > .05). For young adults, however, a significant interaction between reinvestment group and time was evident ($F(5,17) = 3.08$, $p = .037$, $\eta p^2 = .48$). For young adults with a high propensity for reinvestment, the follow-up tests revealed a significant difference between pre- and post-test SE-ML ($p = .028$). For young adults with a low propensity for reinvestment, the results revealed a significant difference between pre- and post-test Area ($p = .05$) and SD-ML ($p = .028$). As illustrated in Figure 1A, SampEn-ML increased from pre- to post-test for young adults with a high propensity for reinvestment, indicating that they adopted more complex (i.e., less regular) postural control strategies following verbalization. For young adults with a low propensity for reinvestment, an increase in Area and SD-ML was evident from pre- to post-test, indicating increased area of sway and medial-lateral sway variability following verbalization (Figure 1B and 1C).

Figure 1 near here

Figure 1. Pre-and post-test differences in SampEn-ML (A) for young adults with a high propensity for reinvestment and in Area (B) and SD-ML (C) for young adults with a low propensity for reinvestment in verbalization condition

3.2. Verbal protocols

An ANOVA of verbal protocols revealed a significant main effect of age group ($F(1,54) = 4.32$, $p = .043$, $\eta p^2 = .07$), with young adults reporting significantly more task-related statements (M = 2.43, SD = 1.41) compared to older adults (M = 1.63, SD = 1.50). There were no other significant main effects or interactions (all *p*'s > .05).

4. Discussion

An effect of verbalization was not found for balance performance in older adults, regardless of their propensity for reinvestment; however, an effect was evident for young adults. A significant increase in area of sway and sway variability in the medial-lateral direction was found in low reinvestors after engaging in verbalization. Furthermore, a significant increase in medial-lateral entropy was found in high reinvestors after engaging in verbalization.

Greater amplitude and variability of COP is generally thought to reflect higher instability of the body, suggesting that younger adults with a low propensity for reinvestment displayed worse postural control following verbalization. Sample entropy quantifies the regularity of the signal (Richman & Moorman, 2000), with higher entropy indicating that the COP time series is more complex (i.e., less regular). It has been argued that healthy systems demonstrate greater complexity and are therefore better able to adapt to the external environment and cope with physiological stress (Lipsitz, 2002). Additionally, it has been argued that greater complexity in body sway reflects a more automatic and less constrained mode of balance control (Borg & Laxåback, 2010; Donker, Roerdink, Greven, & Beek, 2007). Reduced complexity, on the other hand, reflects a less automatic form of balancing. Consequently, we speculate that increased entropy following verbalization by high reinvestors in our study was a consequence of adopting a more natural sway pattern (high reinvestors tend to rely on verbal processing operations) and perhaps, therefore, less attention demanding balance control.

The findings in young adults are comparable to those of Flegal and Anderson (2008) and Lewis and Dawkins (2015). For example, Flegal and Anderson (2008) argued that engaging in declarative processing for five minutes prior to golf-putting disrupted the operations of the procedural memory system and diminished performance of high skilled golfers, for whom non-verbal procedural processing of golf-putting was the norm. Similarly, our study shows that verbalization disrupted performance by young adults with a low propensity for reinvestment, for whom motor performance is controlled by procedural memory system.

Alternatively, it is possible that verbalization induced self-focused attention (e.g., Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992) and disrupted performance of low reinvestors who were less accustomed to verbal processing of skilled movements. Similar results were reported by Jackson, Ashford, and Norsworthy (2006), who showed that adverse effects of adopting skill-focused attention[4] were more prominent in low reinvestors (Experiment 2). Jackson et al. (2006) argued that low reinvestors are less used to focusing on processes underlying motor performance and if specifically asked to do so they are more likely to choke. They also emphasized that degraded performance by low reinvestors was only evident when they were specifically asked to engage in movement processing; it does not mean that they would voluntarily choose this tactic. If left to their own devices, low reinvestors are unlikely to choose conscious verbal processing of their movements.

Regardless of their propensity for reinvestment, older adults showed no change in balance performance following verbalization intervention. At this stage, we can only speculate about why that was the case. One of the assumptions of the Theory of Reinvestment as well as verbal overshadowing is that the 'performer' must have access to verbal knowledge of the task at hand (Masters, 1992; Masters & Maxwell, 2008; Schooler & Engstler-Schooler, 1990). Although we purposefully employed verbalization intervention to promote verbal

[4] Participants were asked to attend to the side of the foot that made contact with the ball during a soccer-dribbling task.

information processing, it is possible that older adults no longer have access to verbal knowledge underlying balance performance, given that balance is a phylogenetic motor skill, which is acquired early in childhood (see Uiga et al., 2018, for a similar argument). On the other hand, young adults, specifically undergraduate sport science students who learn about human body and its functions, may find it easier to access that knowledge. This assumption is supported by the verbal reports data which shows that young adults reported an average of 2.43 statements, whereas older adults only 1.63 statements. It is likely that 1.63 statements were not enough to trigger conscious verbal processing.

From a different point of view, researchers examining dual-task performance by older adults have interpreted age-related dual-task costs to be a consequence of attention involvement in postural control (e.g., Boisgontier et al., 2013; Shumway-Cook et al., 1997; see for a review Woollacott & Shumway-Cook, 2002). It is, therefore, possible that the process of reinvestment operates at different levels of consciousness and does not capture controlled processes that take place outside awareness (i.e., the controlled processes that cannot be verbalised). Indeed, Shiffrin and Schneider (1977) argued that "...not all control processes are available to conscious perception, and not all control processes can be manipulated through verbal instruction" (p. 159). They distinguished between accessible control processes, which are slow and easily perceived, and veiled control processes, which are fast and difficult to perceive through introspection. Likewise, Block (1995) distinguished between phenomenal and access consciousness, with phenomenal consciousness dealing with experiential properties (e.g., sensations, feelings and perceptions) and access consciousness dealing with reasoning, planning, and verbal report. These theories and theories alike suggest that one form of consciousness is related to language based reasoning, whereas the other is not. It is possible, therefore, that even though older adults do not have access to balance-related verbal knowledge, cognitive processes still play a role in their balance.

This study was not without limitations. Our sample had relatively high variability in all postural control measures. The high variability, especially in older adults, might have masked potential influences of the verbalization intervention. Indeed, despite force platform COP measures being considered as gold standard, it has been suggested recently that COP measures are better able to rank order individuals rather than reproduce reliable outcomes for a given individual (Hébert-Losier & Murray, 2020). In addition, we did not conduct a manipulation check to confirm that participants indeed engaged in conscious movement processing during balancing, making interpretations of the findings somewhat speculative.

Regardless, the results from the present study inform our understanding of the interaction between movement specific reinvestment, verbalization and ageing. Future research should more specifically investigate the conscious processing of movements by older adults. This could be done by employing more objective measures of conscious motor processing, such as electroencephalography (EEG), to examine brain activity during balancing prior to and following a verbalization intervention.

Conflict of interest

The authors confirm that there are no conflicts of interest regarding the current manuscript.

Funding

The work was supported in part by a grant from the Research Grants Council of the Hong Kong Special Administrative region (Project No. HKU 750311H).

Acknowledgment

We thank A. Tse, T. Wong and K. Cheng for assistance with data collection and J-H. Ko for data processing.

References

Abernethy, B. (1988). Dual-task methodology and motor skills research: some applications and methodological constraints. *Journal of Human Movement Studies, 14,* 101-132.

Andersson, G., Hagman, J., Talianzadeh, R., Svedberg, A., & Larsen, H.C. (2002). Effect of cognitive load on postural control. *Brain Research Bulletin, 58,* 135-139.

Baumeister, R.F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology, 46,* 610-620. doi:10.1037/0022-3514.46.3.610

Beilock, S.L., & Carr, T.H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*, 701-725. doi: 10.10.1037//0096-3445.130.4.7011

Bergamin, M., Gobbo, S., Sieverdes, J.C., Alberton, C.L., Zaccaria, M., & Ermolao, A. (2014). Influence of age on postural sway during different dual-task conditions. *Frontiers in Aging Neuroscience, 6,* 271.

Block, N. (1995). On a confusion about a function of consciousness. *Behavioral and Brain Sciences, 18,* 227-287. doi:10.1017/s0140525x00038188

Boisgontier, M.P., Beets, I.A.M., Duysens, J., Nieuwboer, A., Krampe, R.T., & Swinnen, S.P. (2013). Age-related differences in attentional cost associated with postural dual tasks: Increased recruitment of generic cognitive resources in older adults. *Neuroscience and Biobehavioral Reviews, 37,* 1824-1837. doi: 10.1016/j.neubiorev.2013.07.014.

Borg, F.G., & Laxåback, G. (2010). Entropy of balance – some recent results. *Journal of NeuroEngineering and Rehabilitation, 7,* 38. doi:10.1186/1743-0003-7-38

Chell, B.J., Graydon, J.K., Crowley, P.L., & Child, M. (2003). Manipulated stress and dispositional reinvestment in a wall-volley task: An investigation into controlled processing. *Perceptual and Motor Skills, 97*, 435-448.

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. *Journal of Hong Kong College of Psychiatrists, 4,* 25-28.

Chiviacowsky, S., Wulf, G., & Wally, R. (2010). An external focus of attention enhances balance learning in older adults. *Gait & Posture, 32,* 572-575.

Chow, V.W.K., Ellmers, T.J., Young, W.R., Mak, T.C.T., & Wong, T.W.L. (2019). Revisiting the relationship between internal focus and balance control in young and older adults. *Frontiers in Neurology, 0:1131.* doi:10.3389/fneur.2018.01131

Chu, C.K.H., & Wong, T.W.L. (2019). Conscious postural control during standing on compliant surface by older adults. *Journal of Motor Behavior, 51,* 342-350. doi:10.1080/00222895.2018.1481820

Donker, S.F., Roerdink, M., Greven, A.J., & Beek, P.J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research, 181,* 1-11. doi:10.1007/s00221-007-0905-4

Flegal, K. E., & Anderson, M. C. (2008). Overthinking skilled motor performance: Or why those who teach can't do. *Psychonomic Bulletin & Review, 15*, 927-932. doi:10.3758/pbr.15.5.927

Folstein, M., Folstein, S.E., & McHugh, P.R. (1975). "Mini-Mental State" a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198. doi:10.1016/0022-3956(75)90026-6

Hébert-Losier, K., & Murray, L. (2020). Reliability of centre of pressure, plantar pressure, and plantar-flexion isometric strength measures: A systematic review. *Gait & Posture, 75,* 46-62. doi:10.1016/j.gaitpost.2019.09.027

Huffman, J.L., Horslen, B.C., Carpenter, M.G., & Adkin, A.L. (2009). Does increased postural threat lead to more conscious control of posture? *Gait & Posture, 30*, 528-532. doi: 10.1016/j.gaitpost.2009.08.001

Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport & Exercise Psychology, 28*, 49-68. doi: 10.1123/jsep.28.1.49

Ko, J-H., & Newell, K.M. (2016). Aging and the complexity of center of pressure in static and dynamic postural tasks. *Neuroscience Letters, 610,* 104-109. doi:10.1016/j.neulet.2015.10.069

Laborde, S., Musculus, L., Kalicinski, M., Klämpfl, M.K., Kinrade, N.P., & Lobinger, B.H. (2015). Reinvestment: Examining convergent, discriminant, and criterion validity using psychometric and behavioral measures. *Personality and Individual Differences, 78,* 77-87. doi: 10.1016/j.paid.2015.01.020

Lacour, M., Bernard-Dermanze, L., & Dumitrescu, M. (2008). Posture control, aging, and attention resources: models and postural-analysis methods. *Clinical Neurophysiology, 38,* 411-421. doi: 10.1016/j.neucli.2008.09.005

Lewis, M.B., & Dawkins, G. (2015). Local Navon letter processing affects skilled behavior: A golf-putting experiment. *Psychonomic Bulletin & Review, 22,* 420-428. doi: 10.3758/s13423-014-0702-6

Lipsitz, L.A. (2002). Dynamics of stability: the physiologic basis of functional health and frailty. *Journal of Gerontology: Biological Sciences, 57A,* B115-B125. doi:10.1093/gerona/57.3.b115

Lu, L., & Bigler, E.D. (2000). Performance on original and a Chinese version of Trail Making Test Part B: a normative bilingual sample. *Applied Neuropsychology, 7,* 243-246. doi: 10.1207/S15324826AN0704_6

Malhotra, N., Poolton, J.M., Wilson, M.R., Ngo, K., & Masters, R.S.W. (2012). Conscious monitoring and control (reinvestment) in surgical performance under pressure. *Surgical Endoscopy, 26,* 2423-2429. doi:10.1007/s00464-012-2193-8

Masters, R.S.W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83,* 343-358. doi:10.1111/j.2044-8295.1992.tb02446.x

Masters, R.S.W., Eves, F.F., & Maxwell, J.P. (2005). *Development of a movement specific Reinvestment Scale*. In: Morris T, Terry P, Gordon S, Hanrahan S, Ievleva L, Kolt G, et al., editors. Proceedings of the ISSP 11th World Congress of Sport Psychology. Sydney, Australia.

Masters, R.S.W., & Maxwell, J.P. (2004). 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). London: Routledge.

Masters, R.S.W., & Maxwell, J.P. (2008). The theory of reinvestment. *International Review of Sport Exercise Psychology, 1,* 160-183. doi:10.1080/17509840802287218

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,* 655-666. doi:10.1016/0191-8869(93)90113-h

Maxwell, J.P., Masters, R.S.W., & Eves, F.F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. *Journal of Sports Sciences, 18*, 111-120.

Meier, B., Morger, V., & Graf, P. (2003). Competition between automatic and controlled processes. *Consciousness and Cognition, 12*, 309-319. doi: 10.1016/S1053-8100(02)00069-7

Melcher, J.M., & Schooler, J.W. (1996). The misremembrance of wines past: Verbal and perceptual expertise differentially mediate verbal overshadowing of taste memory. *Journal of Memory and Language, 35,* 231-245. doi:10.1006/jmla.1996.0013

Murman, D.L. (2015). The impact of age on cognition. *Seminars in Hearing, 36,* 111-121. doi: 10.1055/s-0035-1555115

Partington, J.E., & Leiter, R.G. (1949). Partington's Pathway Test. *Psychological Service Center Journal, 1,* 11-20.

Posner, M.I., & Keele, S.W. (1969). Attentional demands of movement. In, *Proceedings of the 16th International Congress of Applied Psychology*. Amsterdam: Swets & Zeitlinger.

Qiu, H., & Xiong, S. (2015). Center-of-pressure based postural sway measures: Reliability and ability to distinguish between age, fear of falling and hall history. *International Journal of Industrial Ergonomics, 47,* 37-44.

Ramsay, M.C., & Reynolds, C.R. (1995). Separate digits tests: A brief history, a literature review, and a reexamination of the factor structure of the test of memory and learning (TOMAL). *Neuropsychology Review, 5,* 151-171.

Richman, J.S., & Moorman, J.R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *The American Journal of Physiology. Heart and Circulatory Physiology, 278, H2039-H2049.*

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*, 1-66.

Schooler, J. W. (2002). Verbalization produces a transfer inappropriate processing shift. *Applied Cognitive Psychology, 16*, 989-997. doi:10.1002/acp.930

Schooler, J.W., & Engstler-Schooler, T.Y. (1990). Verbal overshadowing of visual memories: Some things are better left unsaid. *Cognitive Psychology, 22*, 36-71. doi:10.1016/0010-0285(90)90003-m

Schooler, J. W., Fiore, S. M., & Brandimonte, M. A. (1997). At a loss from words: Verbal overshadowing of perceptual memories. In L. M. Douglas (Ed.), *Psychology of Learning and Motivation* (Vol. 37, pp. 291-340). San Diego, CA: Academic Press.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127-190.

Shumway-Cook, A., Woollacott, M., Kerns, K., & Baldwin, M. (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *Journal of Gerontology: Medical Sciences, 52A,* M232-M240.

Tombaugh, T.N., & McIntyre, N.J. (1992). The Mini-Mental State Examination: A comprehensive review. *Journal of the American Geriatrics Society, 40,* 922-935. doi:10.1111/j.1532-5415.1992.tb01992.x

Uiga, L., Capio, C.M., Ryu, D., Wilson, M.R., & Masters, R.S.W. (2018). The role of conscious control in maintaining stable posture. *Human Movement Science, 57,* 442-450. doi.org/10.1016/j.humov.2017.10.008

West, S.K., Munoz, B., Rubin, G.S., Schein, O.D., Bandeen-Roche, K., Zeger, S., German, S., & Fried, L.P. (1997). Function and visual impairment in a population-based study of older adults. The SEE project. Salisbury Eye Evaluation. *Investigative Ophthalmology & Visual Science, 38,* 72-82.

Wong, W.L., Masters, R.S.W., Maxwell, J.P., & Abernethy. B. (2008). Reinvestment and falls in community-dwelling older adults. *Neurorehabilitation & Neural Repair, 22,* 410-414. doi: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 American Geriatrics Society, 57,* 920-922. doi:10.1111/j.1532-5415.2009.02228.x

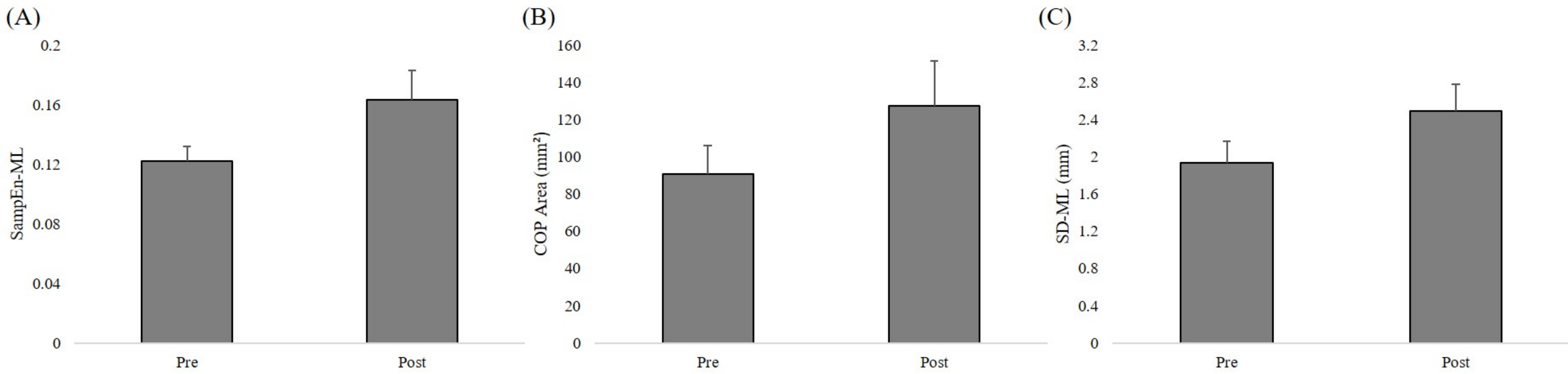
Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait & Posture, 16,* 1-14.

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. A, Human Experimental Psychology, 54*, 1143-1154.

Wulf, G., Mercer, J., McNevin, N., & Guadagnoli, M.A. (2004). Reciprocal influences of attentional focus on postural and suprapostural task performance. *Journal of Motor Behavior, 36,* 189-199.

Zaback, M., Cleworth, T.W., Carpenter, M.G., & Adkin, A.L. (2015). Personality traits and individual differences predict threat-induced changes in postural control. *Human Movement Science, 40,* 393-409. doi:10.1016/j.humov.2015.01.015

Zhu, F.F., Poolton, J.M., Wilson, M.R., Maxwell, J.P., & Masters, R.S.W. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*, 66-73. doi:10.1016/j.biopsycho.2011.02.004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