Postural control entropy is increased when adopting an external focus of attention

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Abstract:

Falls in older adults are a public health challenge due to their influence on well-being and health-care costs. One way to address this challenge is to discover new methods to enhance postural control in older adults so they are better prepared to maintain an upright stance. Older and younger adults ($N = 32$) performed a static balance task on a force plate with no instructions, internal focus instructions, or external focus instructions. Center of pressure displacement time series were analyzed using sample entropy and standard deviation. Only the external focus condition significantly increased postural control entropy, which was observed across both age groups. This study showed that an external focus of attention can be used to increase postural control entropy within a single session of testing.

Keywords: balance | older adults | posture

Article:

Postural control is a complex task that becomes more difficult with age (Costa et al., 2007; Maki & McIlroy, 1996; Shaffer & Harrison, 2007), which can lead to increased fall risk (Ambrose, Paul, & Hausdorff, 2013; Melzer, Benjuya, & Kaplanski, 2004; Rubenstein, 2006). Since the cause of falls is typically multifactorial (Delbaere et al., 2010; Tinetti et al., 1994), the development of effective fall prevention programs can be challenging. Some programs have been shown to reduce fall prevalence (Clemson et al., 2004; Mikolaizak et al., 2018; Palvanen et al., 2014), whereas others have shown little or no effectiveness in reducing older adult falls (Chang et al., 2004; Hendriks et al., 2008; Lord et al., 2005; Schwendimann, Bühler, De Geest, & Milisen, 2006; Vlaeyen et al., 2015). In an effort to enhance the effectiveness of fall prevention programs, evidence from a related body of literature showing the role of attentional focus on postural control could be adopted (Chiviacowsky, Wulf, & Wally, 2010; Kee, Chatzisarantis, Kong, Chow, & Chen, 2012; Landers, Hatlevig, Davis, Richards, & Rosenlof, 2016; Landers, Wulf, Wallmann, & Guadagnoli, 2005; McNevin, Wulf, & Carlson, 2000; Wulf, 2013).

Wulf, Höß, and Prinz (1998) defined attentional focus as either internal or external. An internal focus of attention is directed at the performer’s own body or own movements, whereas an external focus is directed at the effects a particular movement has on the environment. For example, when training participants to enhance their balance using a wobble board, the trainer could ask them to focus on keeping their trunk vertical (i.e., an internal focus) or on keeping the wobble board level (i.e., an external focus). Research over the past 15 years has repeatedly shown that an external focus of attention leads to greater motor performance and learning than an internal focus of attention (see Wulf, 2013 and Wulf and Lewthwaite, 2016, for reviews). This finding is robust across a variety of different motor skills, including in the context of postural control in healthy older adults (Chiviacowsky et al., 2010) and patients with Parkinson's disease who have a history of falls (Landers et al., 2005).

Complementing the work on attentional focus as a way to better understand how posture is controlled, there is a growing area of study using nonlinear dynamics as a means to quantify how postural control unfolds over time. Research in this area suggests that entropy—a metric of repeated patterns—in postural sway provides additional information about the current state of a person's postural control in conjunction with traditional balance metrics (Hansen et al., 2017). The concept of entropy has long been used to understand how systems work, with a specific focus on the time-evolving patterns within the system (Williams, 1997). Traditional motor control research focused on summary statistics to obtain an average of the movement characteristic of interest. To obtain a more finite understanding of motor control at the moment-to-moment level, entropy analyses were adopted in the field (Newell & Vaillancourt, 2001; Slifkin & Newell, 1998). Research over the past two decades has linked entropy in motor control to the adaptive capacity (and potentially the health) of the motor control system (Manor et al., 2010; Rhea & Kiefer, 2014; Stergiou & Decker, 2011; van Emmerik, Ducharme, Amado, & Hamill, 2016). Specific to postural control, entropy has been shown to decrease (i.e., more repeating patterns) when neurological deficits are present, such as vision or somatosensory impairment (Manor et al., 2010), after a concussion (Cavanaugh et al., 2006; Sosnoff, Broglio, Shin, & Ferrara, 2011), and in those with multiple sclerosis (Busa, Jones, Hamill, & van Emmerik, 2016). Postural control entropy has also been show to increase (i.e., fewer repeating patterns) when a secondary cognitive task is introduced (Cavanaugh, Mercer, & Stergiou, 2007), highlighting the continuum on which the entropy of a system can be described, with values that are on either end of the continuum representing dysfunctional behavior (Stergiou, Harbourne, & Cavanaugh, 2006; Vaillancourt & Newell, 2002). Furthermore, it has been suggested that there are different ways to interpret what a decrease or increase in entropy may mean relative to postural control (Borg & Laxåback, 2010). Therefore, it is important to first understand which direction entropy has moved (and why) before an appropriate intervention can be developed to either increase or decrease entropy.

Relative to aging and postural control, some research has shown that postural control entropy is increased in older adults relative to younger adults (Borg & Laxåback, 2010; Duarte & Sternad, 2008). However, recent review papers by Gow, Peng, Wayne, and Ahn (2015) and Busa and van Emmerik (2016), along with several research studies (Costa et al., 2007; Jiang, Yang, Shieh, Fan, & Peng, 2013; Kang et al., 2009; Lamoth & van Heuvelen, 2012; Yeh, Lo, Chang, & Hsu, 2014), highlight the observation that the majority of research examining postural control entropy in older adults suggests that it declines with aging and frailty. A potential reason for these dichotomist observations could be methodological differences between the studies, as suggested by Gow et al. (2015). Since a decline in postural control entropy has recently been associated with fall risk in a longitudinal and large-sample-size study (Zhou, Habtemariam, Iloputaife, Lipsitz, & Manor, 2017), we take the position that a decline in postural control entropy is expected with aging, and it reflects a change in postural control that characterizes the difficulty in responding to perturbations. It is postulated that the mechanism for the association between postural control entropy and fall risk is that aging leads to fewer inputs into the sensory integration process, which causes the behavior to exhibit a more regular and repeating characteristic and leads to a more frail system that is less poised to respond to perturbations (Lipsitz, 2002). However, this change in postural control entropy is not a one-way path, as previous work has shown that postural control entropy is modifiable with stochastic stimulation (Costa et al., 2007; Glass, Ross, Arnold, & Rhea, 2014) and Tai Chi practice (Manor, Lipsitz, Wayne, Peng, & Li, 2013; Wayne et al., 2014). It has been suggested that discovering ways to increase entropy in a behavior would reflect the system's transition back toward a more adaptive state that is better prepared to respond to perturbations (Manor & Lipsitz, 2013). Although stochastic stimulation and Tai Chi practice are two viable options, their implementation may be restricted by equipment or expertise limitations. Thus, there is a need to discover alternative ways to alter postural control entropy that are easier to implement in a clinic setting.

One early approach to modify postural control entropy through attentional focus strategies was adopted by Kee et al. (2012). They used approximate entropy to examine postural sway patterns in young healthy adults while performing a static posture task when attention was focused internally or externally. The authors discovered that approximate entropy increased when attention was focused externally, supporting the notion that an external focus can modify postural control entropy. However, it is unclear if older adults similarly benefit from external focus instructions.

This study uses methods adopted in previous work to examine whether focusing internally or externally altered postural control entropy during a static balance task in older adults, in addition to an attempt to replicate previous findings in younger adults. The rationale to examine potential age differences in this context is due to sensory integration differences previously observed between younger and older adults (Redfern, Jennings, Martin, & Furman, 2001)—indicating that observations for one age group may (or may not) generalize to another age group. Our primary hypothesis was that an external focus would lead both age groups to exhibit higher postural control entropy relative to the internal focus or no focus of attention instruction, and no differences would be observed when comparing the internal focus and no focus of attention instructions. In recognition that nonlinear dynamics provide complimentary information about postural control relative to traditional metrics, we also included standard deviation (*SD*) in our analysis so that we could report both the magnitude (*SD*) and structure (sample entropy, SampEn) of postural control variability when attentional focus is manipulated. A decrease in *SD* is typically interpreted as more stable postural control. Thus, our secondary hypothesis was that *SD* would significantly decrease in the external focus condition, relative to the internal focus and baseline conditions.

Method

Participants

Healthy men and women with no disabilities that would prevent them from performing the experimental task (i.e., standing balance) were recruited. Inclusion criteria included the stipulations that participants be naïve to the purposes of the study and have no prior experience with the attentional focus task. Participants were enrolled if they were within our targeted age range for younger adults (18–30 years) or for older adults (50–80 years). A total of 32 adults (younger: *n* = 19 [13 females and 6 males], mean [*SD*] age = 23.1 [3.8] years; older: *n* = 13 [9 females and 4 males], 60.6 [10.4] years) participated in this study. Written informed consent was provided by all participants, and all procedures were approved by The University of North Carolina at Greensboro's Institutional Review Board.

Procedures

Participants stood with their feet shoulder width apart on a force plate (AMTI, Watertown, MA) for 30 s in each of three conditions: baseline (no instructions) and two experimental conditions (internal focus or external focus instructions). The baseline was always collected first, followed by three trials of each experimental condition, of which the order was randomized. Only one trial of the baseline condition was collected due to the stable performance within this condition (i.e., no learning effect), and thus there was no need to average the performance over three trials as was required in the experimental conditions. During the internal focus conditions, participants were instructed to focus on keeping their feet level. During the external focus condition, participants were instructed to focus on keeping the floor level.

Data Collection and Processing

Center of pressure displacement time series data were collected at 100 Hz (leading to 3,000 data points per trial) and filtered with a fifth-order low-pass Butterworth filter using a 5-Hz cutoff, congruent with previous research (Kuznetsov, Bonnette, Gao, & Riley, 2013; Rhea, Kiefer, Wright, Raisbeck, & Haran, 2015; Ruhe, Fejer, & Walker, 2010) and clinical stabilometry guidelines (Scoppa, Capra, Gallamini, & Shiffer, 2013). This paper focuses only on medial-lateral (ML) data because ML postural control has been previously associated with fall risk in older adults (Maki, Holliday, & Topper, 1994). The variability in the center of pressure ML displacement time series was then analyzed with respect to the magnitude (*SD*) and structure (SampEn) of the variability. For SampEn, we used a previously published method to determine that m and r should be set to 2 and $.11 \times SD$ (Lake, Richman, Griffin, & Moorman, 2002).

Statistical Analysis

Separate two age (older vs. younger) × three condition (baseline vs. internal focus vs. external focus) mixed analysis of variance tests with repeated measures on condition were used for *SD* and SampEn. Alpha was set at .05 for the analysis of variance tests. Follow-up pairwise comparisons using the Bonferroni post hoc test to adjust for multiple comparisons were used when appropriate. All statistical tests were completed in IBM SPSS Statistics for Windows (version 21; IBM Corp., Armonk, NY).

Results

For SampEn, the Age × Condition interaction was not significant, $F(2, 60) = 0.13$, $p = .880$, $\eta^2_p=.004$, nor was the age main effect significant, $F(1, 30) = 1.51$, $p = .23$, $\eta^2_p = .05$. However, the main effect of condition was significant, $F(2, 60) = 6.75$, $p = .002$, $\eta^2_p = .18$. Post hoc analyses showed no difference in SampEn between baseline and internal focus, $p = .247$, nor between internal focus or external focus, $p = .067$. However, a significant increase in SampEn from baseline to external focus was observed, $p = .008$. The two age groups were collapsed within each condition due to the lack of an interaction or main effect for age and are presented in Figure 1a.

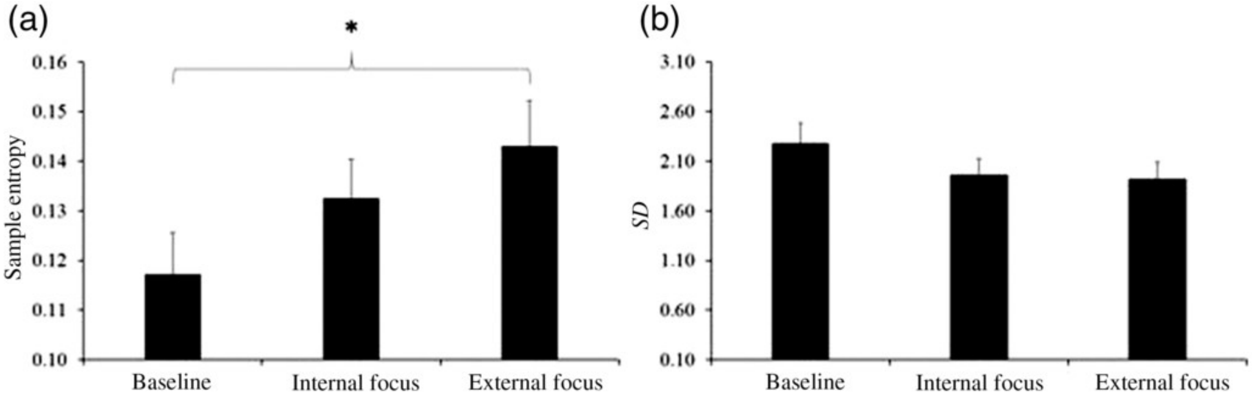

Figure 1. Age groups were collapsed within each condition due to a lack of an age effect. (a) Sample entropy significantly increased between the baseline and the external focus condition (*$p = .008$). No differences were observed in *SD* (b).

For *SD*, the Age × Condition interaction, age main effect, and condition main effect were all not significant ($p > .05$ for all). To be consistent with the SampEn data presentation, the two age groups were collapsed within each condition and are presented in Figure 1b.

Discussion

This study showed that both older and younger adults increase postural control entropy when adopting an external focus of attention, supporting our primary hypothesis as well as previous findings that showed that an external focus of attention can enhance balance (Chiviacowsky et al., 2010; Kee et al., 2012; Landers et al., 2005). More specifically, our data extend work from Kee et al. (2012) by showing that both older adults and younger adults increase entropy of postural control when focusing externally. This observation supports the notion that an external focus of attention during a motor task allows the body to organize in a manner that is more conducive to efficient and effective motor control relative to an internal focus of attention (Wulf, 2013).

It is interesting to note that we did not observe a main effect of age. This is likely due to the simplicity of the static balance task that was used. We selected a static balance task due to its long history of serving as a task to probe neuromotor control (Abrahamova & Hlavacka, 2008; Manor et al., 2010; Peterka, 2002; van Emmerik & van Wegen, 2002; Winter, Prince, Frank, Powell, & Zabjek, 1996) and fall risk (Fernie, Gryfe, Holliday, & Llewellyn, 1982; Lajoie & Gallagher, 2004). However, the ecological validity of this task has been questioned, with researchers rightfully arguing that humans rarely stand for the sake of standing (Haddad, Rietdyk, Claxton, & Huber, 2013). Rather, a human stance is typically integrated as part of a larger task, such as standing while reaching for an object or as part of gait. Nevertheless, we took the position that an upright quiet stance is an appropriate place to start when testing hypotheses such as the ones presented in this paper. If attentional focus is shown to influence this rather easy task, then the next logical step would be to scale-up the complexity of the motor task to determine if similar attentional focus effects are observed. Using our findings as rationale for the adoption of more complex tasks, future studies should adopt a range of balance tasks (both static and dynamic) with varying difficulties, which may lead to a better understanding of the role attentional focus has on a spectrum of posture behaviors and fall risk. This approach is particularly important to understand age-related differences, as more difficult balance tasks have been shown to magnify the differences in postural control between younger and older adults (Baloh et al., 1994).

This study shows that postural control entropy is modifiable in older (and younger) adults within a single session, opening the potential for using cognitively based interventions to enhance balance training programs aimed at reducing fall risk. Specifically, augmenting current moderately successful fall prevention programs with an attentional focus framework may afford the ability to explore different postural control strategies so that the participant can discover the most stable and adaptive behavior relative to their individual constraints. Thus, removing focus from the body may allow for the emergence of self-organized postural control in a manner that leads to decreased fall risk.

The notion of self-organization in motor control is commonly examined by quantifying variability in movement profiles, which provides an indication of how changes in movement occurred over time (Hausdorff, 2007; Manor et al., 2010; Rhea & Kiefer, 2014; Stergiou & Decker, 2011; van Emmerik et al., 2016). Movement variability can be expressed in terms of magnitude (i.e., how much the movement changed over time) and/or structure (i.e., temporal organization of the changes in movement during the task). Magnitude of variability is commonly measured using *SD*, with a large *SD* potentially indicating less controlled behavior. Alternatively, a large *SD* could also indicate more exploratory behavior as the participant tests the boundary of their capabilities within a given task. In this study, it is plausible that the external focus condition afforded the participants the ability to explore their balance in a way that allowed the most stable posture to emerge. Such an exploratory behavior could have been expressed by an increase in *SD* and SampEn, representing a change at the magnitude and temporal structure levels of postural control. However, contrary to our secondary hypothesis, we observed no change in *SD*, but an increase in SampEn, suggesting that an external focus of attention can alter motor organization at the temporal structure level without parallel changes at the magnitude of variability level.

It is important to note that while there is significant literature showing motor performance is enhanced and retained when adopting an external focus of attention (Wulf, 2013), this finding is not universally supported. Specifically, recent work applying the attentional focus paradigm to gait did not show support for enhanced performance when an external focus was adopted (de Melker Worms, Stins, van Wegen, Loram, & Beek, 2017; de Melker Worms, Stins, van Wegen, Verschueren, et al., 2017). The reason for these differences may be due to the manner in which constraints are imposed between studies. Behavior emerges from the interaction between the person, task, and environment—each of which may have constraints that affect the behavior (Newell, 1986). At that task level, it is plausible that the structure of some tasks may not allow the dichotomy of internal or external focus to be applied. That is, the task may be structured in a way that does not allow the participant to solely focus on either their body (internal focus) or the result of their movement (external focus). An illustration of this point is provided by de Melker Worms, Stins, van Wegen, Verschueren, et al. (2017), who had participants focus on either their legs (internal focus) or the movement of the treadmill (external focus) during a gait task. No differences were observed between the internal and external focus conditions. In a separate study, de Melker Worms, Stins, van Wegen, Loram, et al. (2017) observed no differences in gait kinematics between fallers (defined as one or more self-reported falls in the past 12 months) and nonfallers when they adopted an internal versus external focus of attention during treadmill walking. In both studies, de Melker Worms and colleagues suggested that the lack of a distinct effect on the environment during treadmill walking tasks may have made it difficult for the participants to fully adopt an external focus, highlighting how task constraints may influence the utility of an attentional focus framework. Similarly, constraints at the individual level may limit the adoption (and potential benefits) of an external focus of attention. For example, Gokeler et al. (2015) had patients with an anterior cruciate ligament reconstruction perform a single-leg hop for a distance task 5–7 months postsurgery, with half of the group placed in an external focus group and half in an internal focus group. No differences in hop distance between the groups were observed, but there was a significant difference in lower extremity kinematics during the hop between the groups, suggesting that the focus of attention instructions altered the biomechanics but not the overall performance. It is possible that any residual structural deficits or pain may have altered the way in which the participants adopted the attentional focus instructions. Thus, while the utility of adopting an external focus has been extensively shown, care should be taken into how it is applied, especially in clinical populations.

As research in this area moves forward, there is a need to balance controlled laboratory-based tasks (such as an upright quiet stance) with more real-world tasks in order to systematically understand the role attentional focus cues have on human motor control. As described by Haddad et al. (2013), task-dependent postural control has stronger ecological validity than a simple upright quiet stance. Moreover, although promising results are reported in this paper and in previous literature that tested the influence of attentional focus on rather simple balance tasks (Chiviacowsky et al., 2010; Kee et al., 2012; Landers et al., 2005; Wulf, 2013), recent work showed that scaling these results to more complex tasks is not a trivial task (de Melker Worms, Stins, van Wegen, Loram, et al., 2017; de Melker Worms, Stins, van Wegen, Verschueren, et al., 2017). Lastly, this paper reports on only one aspect of postural control (the magnitude and structure of center of pressure displacement in the ML direction), so future work should expand the variables/characteristics studied in this context to more holistically quantify changes in the ability to maintain an upright stance. Thus, there is a need for systematic implementation of the attentional focus paradigm as it transitions from basic to applied science to ensure best practices are developed with evidence-based research.

In sum, this study showed that an external focus of attention can be used to increase postural control entropy within a single testing session. Future studies should measure the dose-response effect of multisession balance training with an external focus, as well as the magnitude of change necessary to significantly reduce fall risk by defining the minimal detectable change or clinically significant difference in postural control entropy.

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