ARTICLE IN PRESS

Human Movement Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

The role of conscious control in maintaining stable posture

Liis Uiga[a,b,*], Catherine M. Capio[a,b], Donghyun Ryu[c], Mark R. Wilson[d], Rich S.W. Masters[a,b]

[a] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong
[b] Te Huataki Waiora Faculty of Health, Sport and Human Performance, University of Waikato, New Zealand
[c] School of Sport, Health and Exercise Sciences, Bangor University, UK
[d] College of Life and Environmental Sciences, University of Exeter, UK

ARTICLE INFO

Keywords:
Postural control
Movement specific reinvestment
Older adults

ABSTRACT

This study aimed to examine the relationship between conscious control of movements, as defined by the Theory of Reinvestment (Masters & Maxwell, 2008; Masters, Polman, & Hammond, 1993), and both traditional and complexity-based COP measures. Fifty-three young adults (mean age = 20.93 ± 2.53 years), 39 older adults with a history of falling (mean age = 69.23 ± 3.84 years) and 39 older adults without a history of falling (mean age = 69.00 ± 3.72 years) were asked to perform quiet standing balance in single- and dual-task conditions. The results showed that higher scores on the Movement Specific Reinvestment Scale (MSRS; Masters, Eves, & Maxwell, 2005; Masters & Maxwell, 2008), a psychometric measure of the propensity for conscious involvement in movement, were associated with larger sway amplitude and a more constrained (less complex) mode of balancing in the medial–lateral direction for young adults only. Scores on MSRS explained approximately 10% of total variation in the medial–lateral sway measures. This association was not apparent under dual-task conditions, during which a secondary task was used to limit the amount of cognitive resources available for conscious processing. No relationship between postural control and score on the MSRS was found for either older adult fallers or non-fallers. Possible explanations for these results are discussed.

1. Introduction

Postural control is enabled by the sensory system, the central nervous system and the musculo-skeletal system (Winter, Patla, & Frank, 1990). The complex interaction between these systems supports upright stance and adaptation to the ever-changing environment (Manor et al., 2010). Postural control has long been considered to be automatic, requiring minimal conscious information processing; however, research during the past two decades, using dual-task methodology (Dault, Frank, & Allard, 2001; Melzer, Benjuya, & Kaplanski, 2004; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Swanenburg, de Bruin, Favero, Uebelhart, & Mulder, 2008), manipulations of attentional focus (e.g., Rotem-Lehrer & Laufer, 2007; Wulf, Landers, Lewthwaite, & Töllner, 2009; Wulf, Töllner, & Shea, 2007) and examination of personality characteristics (e.g., Huffman, Horslen, Carpenter, & Adkin, 2009; Zaback, Cleworth, Carpenter, & Adkin, 2015), has challenged that idea.

Traditionally, postural control has been described by center-of-pressure (COP) displacements during an attempt to stand as still as possible. Greater amplitude and variability of COP is generally thought to reflect higher instability of the body. For example, research

* Corresponding author at: Te Huataki Waiora Faculty of Health, Sport and Human Performance, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand.

E-mail address: liisu@waikato.ac.nz (L. Uiga).

http://dx.doi.org/10.1016/j.humov.2017.10.008
Received 2 May 2017; Received in revised form 16 October 2017; Accepted 16 October 2017
0167-9457/

has shown that in comparison to young adults, older adults (especially those who have fallen previously) show increased area of sway, higher sway velocity, and more sway variability in medial-lateral and anterior-posterior directions (Bergamin et al., 2014; Hageman, Leibowitz, & Blanke, 1995; Qiu & Xiong, 2015). Reductions in postural stability have been reported in older adults when an additional secondary task that consumes available attention resources has been added (e.g., Marsh & Geel, 2000; Shumway-Cook & Woollacott, 2000). In some cases (e.g., Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Riley, Baker, Schmit, & Weaver, 2005), but not in others (e.g., Andersson et al., 2002; Riley et al., 2005), the same effect has been detected in young adults. Differences in balance performance under dual-task conditions suggest that postural control relies on cognitive processing and is therefore not fully automated.

Further evidence of cognitive involvement in balance comes from studies that have manipulated conscious processing of movement during maintenance of stable posture. Wulf and colleagues (Wulf et al., 2009; Wulf, McNevin, & Shea, 2001; Wulf, Mercer, McNevin, & Guadagnoli, 2004), for example, showed that adopting an internal rather than an external focus of attention caused increased postural sway. They argued that adopting an internal focus of attention encourages conscious control of movements, which is likely to interfere with automatic motor control processes. Similarly, people with a higher predisposition to consciously control their movements, as defined by the Theory of Reinvestment (Masters, 1992; Masters & Maxwell, 2008), have been shown to lean further away from a platform edge and sway at larger amplitudes when attempting to maintain stable posture during postural threat conditions (i.e., on an elevated surface; Huffman et al., 2009; Zaback et al., 2015). Huffman et al. (2009) were the first to use a balancing task to show what Masters, Polman, and Hammond (1993) have argued earlier '…the automatic processing system in some individuals can be more easily disrupted than in the others…' (p. 656). These findings suggest that in some conditions, or in certain people, maintaining a stable posture utilizes cognitive resources.

Over the past two decades, however, it has become apparent that '…changes in postural sway may reflect things other than changes in stability…' (Fraizer & Mitra, 2008, p. 276), as variability of COP displacement is not always a consequence of uncorrelated random errors (Cavanaugh, Guskiewicz, & Stergiou, 2005; Costa et al., 2007). Consequently, traditional COP-based measures, which disregard the complex dynamics of COP movement, may be inadequate. For example, rather than reflecting instability, higher average sway velocity may be a function of searching for a stable solution (Palmieri, Ingersoll, Stone, & Krause, 2002). Consequently, researchers have employed methods of nonlinear dynamics and fractal analysis from complexity theory to explain and quantify the characteristics of postural sway dynamics. Entropy-based measures (e.g., sample entropy, SampEn) and detrended fluctuation analysis (DFA) are examples of such methods.

SampEn is the negative natural logarithm of the conditional probability that two sequences that are similar for a certain number of data points remain similar at the next data point if self-matches are not included in computing the probability (Richman & Moorman, 2000). SampEn indicates how much each data point depends on the value of previous data points. Lower values of SampEn, therefore, reflect higher self-similarity, or higher regularity, in the time series. DFA quantifies the fractal-like long-range correlation properties in the COP time series (Duarte & Zatsiorsky, 2001; Peng et al., 1994). DFA values close to 1.0 are considered to indicate high complexity, whereas values close to 0.5 or 1.5 indicate low complexity (Duarte & Sternad, 2008; Lipsitz, 2002). In simple terms, both of the measures describe the complex dynamics of COP.

Researchers have argued that complexity is associated with a system's health and reflects the ability to adapt to changes in the environment; higher complexity has been linked to better performance and superior ability to adapt, whereas, lower complexity has been linked to reduced ability to do so (Goldberger, Peng, & Lipsitz, 2002; Lipsitz & Goldberger, 1992; Manor & Lipsitz, 2013). For example, a growing body of evidence shows that loss of complexity is associated with biological aging and/or disease (e.g., Costa et al., 2007; Kang et al., 2009; Manor et al., 2010). It has, therefore, been argued that older adults, especially those who have fallen, display a more constrained mode of postural control compared to young healthy adults. Indeed, some authors have suggested that higher levels of complexity in the COP time series reflect greater 'automaticity' of postural control, but lower levels of complexity reflect greater cognitive involvement (Donker, Roerdink, Greven, & Beek, 2007; Roerdink, Hlavackova, & Vuillerme, 2011; Stins, Michielsen, Roerdink, & Beek, 2009). To date, there is only limited evidence to support this proposition (e.g., Cavanaugh, Mercer, & Stergiou, 2007; Donker et al., 2007), and not all investigators fully agree with such an interpretation (e.g., Borg & Laxåback, 2010; Duarte & Sternad, 2008).

The present study was conducted in order to examine the relationship between conscious control of movement and traditional and complexity-based COP measures, with an intention to better understand the role of conscious control in maintaining stable posture. We first examined static balance performance of young adults, older adult non-fallers and older adult fallers under single- and dual-task conditions. We then examined the relationship between individual predisposition for conscious control of movement, as defined by the Theory of Reinvestment (Masters, 1992; Masters & Maxwell, 2008), and COP-based traditional and complexity-based measures. We aimed to investigate whether traditional and complexity-based COP measures were associated with conscious movement processing when maintaining stable posture. We anticipated that higher propensity for conscious control of movement would be associated with increased sway velocity, amplitude and area, and with lower complexity (i.e., greater regularity) in the COP time series. We expected to observe such associations during single-task balance but not during dual-task balance, when cognitive resources normally available for conscious control of movement were occupied by a secondary task.

2. Methods

2.1. Participants

Participants consisted of 78 community dwelling older adults and 53 young adults. Young adults (YA; age range 18–35 years, mean = 20.93 ± 2.53 years) were undergraduate students who participated for course credits. Older adults were recruited via local