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New insights into neck-pain-related postural control using measures of signal frequency and complexity in older adults

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ABSTRACT

There is evidence to implicate the role of the cervical spine in influencing postural control, however the underlying mechanisms are unknown. The aim of this study was to explore standing postural control mechanisms in older adults with neck pain (NP) using measures of signal frequency (wavelet analysis) and complexity (entropy).

This cross-sectional study compared balance performance of twenty older adults with (age = 70.3 ± 4.0 years) and without (age = 71.4 ± 5.1 years) NP when standing on a force platform with eyes open and closed. Anterior–posterior centre-of-pressure data were processed using wavelet analysis and sample entropy. Performance-based balance was assessed using the Timed Up-and-Go (TUG) and Dynamic Gait Index (DGI).

The NP group demonstrated poorer functional performance (TUG and DGI, $p < 0.01$) than the healthy controls. Wavelet analysis revealed that standing postural sway in the NP group was positively skewed towards the lower frequency movement (very-low [0.10–0.39 Hz] frequency content, $p < 0.01$) and negatively skewed towards moderate frequency movement (moderate [1.56–6.25 Hz] frequency content, $p = 0.012$). Sample entropy showed no significant differences between groups ($p > 0.05$).

Our results demonstrate that older adults with NP have poorer balance than controls. Furthermore, wavelet analysis may reveal unique insights into postural control mechanisms. Given that centre-of-pressure signal movements in the very-low and moderate frequencies are postulated to be associated with vestibular and muscular proprioceptive input respectively, we speculated that, because NP demonstrate a diminished ability to recruit the muscular proprioceptive system compared to controls, they rely more on the vestibular system for postural stability.

1. Introduction

There is growing evidence to implicate the role of the cervical spine in influencing postural control, with most studies demonstrating greater postural sway in people with neck-pain (NP) when compared with healthy controls [1]. Given that the neck has extensive connections with the vestibular, visual and central nervous systems, balance impairments associated with cervical spine dysfunction are thought to be due to aberrant cervical afferent input causing a mismatch between this abnormal input and normal information from the vestibular and visual systems [2]. Despite these postulations, the mechanisms underlying NP-related balance impairments remain unclear. Considering that the prevalence of NP is high in the elderly population – approximately 33% and 40% in men and women, respectively [3], and older adults are at high risk of falls [4], an in-depth understanding of the mechanisms underlying the effects of NP on postural stability is warranted.

One issue that limits clear understanding of these underlying balance mechanisms in NP may be the complexity in interpreting information obtained from standard balance measures. Previous studies investigating the effects of NP on postural control have mostly employed traditional measures such as centre-of-pressure (CoP) displacement, velocity and area [1]. This assumes that CoP displacement is a good proxy for postural performance and that conventionally, lower CoP sway parameters indicate greater postural stability [1]. However, this assumption can be challenged, with the argument that a decrease in sway parameters may also result from an increased-body stiffness that may be associated with a fear of falling [5]. As such, traditional balance measures have been criticised for their limitations in detecting context-dependent

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postural performance changes because they fail to capture the richness of postural data [6]. Consequently, this demonstrates a need for additional measures to better describe postural performance [7]. Based on these reasons, studies have employed analytical approaches such as "rambling and trembling" decomposition of a stabilogram [8,9], wavelet analysis and sample entropy in order to better depict changes in postural stability in NP [10–12]. "Rambling and trembling" represent dynamic components of CoP. An increase in the slow component in patients with chronic neck pain is argued to reflect increased sensory input and processing [13]. An increase in the fast component is thought to reflect normal centre-of-mass control in healthy individuals but the mechanisms underlying whiplash remains unknown [9].

Wavelet transform is an analytical technique which decomposes the postural sway data into multiple independent frequency bands [6], where each frequency band is postulated to represent involvement of a physiological domain. Specifically, CoP signals in four distinct bandwidths ranging from moderate to ultralow frequency have been identified [10] based on the hypothetical physiological significance of postural movements associated with muscular proprioception [7,14], the cerebellar [14], vestibular [15] and visual systems [6]. For instance, a high proportion of activity in the ultralow (<0.10 Hz) and moderate (1.56–6.25 Hz) frequency bandwidths have been associated with increased use of vision [6] and increased muscular activity in response to proprioceptive input [14] respectively.

We have performed two recent, neck-related experimental studies using wavelet analysis. One assessed the effects of neck muscle fatigue on postural control in healthy subjects, and demonstrated that fatigue significantly increases the energy in the ultralow and moderate frequency bandwidths of the signal [10]. The second study compared postural control between people with NP, with and without asymmetry of cervical spine range of motion, with the asymmetry group demonstrating standing postural sway skewed towards ultralow frequencies (<0.10 Hz) [11]. In the context of this study, the difference in postural control strategy adopted by the asymmetrical group was potentially due to altered proprioceptive input and processing arising from cervical spine dysfunction. Consequently, based on the association between ultralow frequency and visual input, and given that both groups had similar levels of function, we speculated that the postural strategy adopted by the asymmetrical group was adaptive and that this group may be relying on the visual system to achieve these compensations. Despite these novel findings, and because this study lacked a concurrent control group, clear conclusions could not be drawn concerning these postural control mechanisms. Our current study extends prior research by (i) using additional analytical techniques of wavelet analysis and sample entropy, and (ii) incorporating a control group, to further investigate postural mechanisms in this population.

Sample entropy uses non-linear time-dependent analysis that can quantify the complexity or regularity of the CoP signal [16], with higher entropy suggested to reflect increased complexity and greater efficiency in postural control [16]. Sample entropy has been investigated in a small number (n = 11) of whiplash patients [12], with a trend towards decreased complexity of CoP motion during eyes closed standing balance when compared to control participants, however there remains a paucity of evidence in populations with NP.

Against this background, we aimed to explore possible mechanisms underpinning reduced standing balance in older adults with NP using wavelet analysis and sample entropy. We hypothesised that older adults with NP will demonstrate reduced postural stability compared to healthy controls, wavelet analysis will reveal an increased proportion of ultralow frequency postural movement, indicating increased visual system dependence for postural stability, an increased proportion of moderate frequency postural movement, indicating changes to muscular proprioceptive input, and finally, sample entropy will demonstrate decreased signal complexity.

2. Methods

2.1. Participants

This cross-sectional study involved 40 older women with (n = 20, age = 70.3 ± 4.0 years) and without (n = 20, age = 71.4 ± 5.1 years) NP. Participants >65 years reporting chronic NP for ≥3 months, and with a neck disability index (NDI) of >9%, were recruited from the Brisbane metropolitan area using convenience sampling. Subjects were excluded if they had a history of falls, recent orthopaedic surgery, diabetes, neurological or vestibular pathology, arthritis that required active management, acute musculoskeletal injuries, or were taking more than four medications. All participants provided informed consent as outlined by the Medical Ethics Committee of the University of Queensland and all procedures were conducted according to the Declaration of Helsinki.

2.2. Questionnaires

Age, medication intake, co-morbidities and other demographic details were obtained. The Neck Disability Index (NDI) [17], was used to assess the degree of self-reported NP and disability [17].

2.3. Standing balance

Standing balance was assessed using a force platform (400 mm × 600 mm Kistler 9286A, Switzerland). Participants were instructed to stand as still as possible while looking straight ahead, in a standardised position 1.5 m away from a wall with arms by their side. Foot position for comfortable stance was repositioned exactly using a paper trace as described by McIlroy and Maki [18]. One trial of 30-s was performed with eyes open then closed in standing. This test duration is sufficient to monitor sway and prevent exacerbation of pain from prolonged standing [19]. Force platform signals were analogue-to-digital converted at a sampling rate of 100 Hz and recorded using a LabVIEW (National Instruments, USA) programme and a USB-6008 (National Instruments, USA) data acquisition system.

2.4. CoP measures

The CoP measures consisted of:

(a) Discrete wavelet transform, a signal processing method that separates the CoP data into multiple independent signals based on frequency content. Specifically, the signal is spilt into four bands: (1) moderate (1.56–6.25 Hz), (2) low (0.39–1.56 Hz), (3) very-low (0.10–0.39 Hz), and (4) ultralow (<0.10 Hz) frequency. These frequency ranges are believed to capture postural movements associated with the muscular proprioception (moderate) [14], cerebellar (low) [14], vestibular (very-low) [15], and visual systems (ultralow) [6] respectively. Signal bandwidths were separated using a 9-level Symlet-8 wavelet, with multiresolution analysis used to combine detail levels where necessary. In order to better represent the spectral content of the data, we took into account inter-individual variability by expressing the CoP velocity of each frequency band as a percentage of the overall CoP velocity.
(b) Sample entropy, a measure of the complexity of the CoP signal. Specifically, higher sample entropy values are indicative of