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Low Back Pain Development Differentially Influences Centre of Pressure Regularity Following Prolonged Standing

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Highlights

- Changes in neuromuscular control of upright standing did occur
- Changes were as a result of an increase in centre of pressure regularity
- Low back pain developers had a larger change in centre of pressure regularity
- Findings support the theory that increased COP regularity occurs with pain/pathology

1. Introduction:

An interesting subgroup of individuals without pre-existing low back pain (LBP) consists of individuals who develop a transient acute episode of LBP during 2 continuous hours of standing [1–4]. These individuals identified as pain developers (PDs) have a reported 3x the likelihood to seek clinical care for LBP in the future [5]. Since balance control has been shown to be affected in those who have clinical LBP [6–9] it is possible that this subgroup may also demonstrate differences during a constrained balance task. As a result, determining if changes in standing dynamic balance control occur following a 2-hour bout of upright standing may provide additional insight to the acute development of LBP during standing, subsequent development of clinical LBP, and potential intervention strategies.

Individuals identified as PDs have been shown to adopt a pattern of coactivitation between the right and left gluteus medius muscles while standing [1,2,4]. Bilateral coactivity of the gluteus medius muscles may be a predisposing factor for the development of transient acute LBP in PDs during prolonged standing [10]. The strategy of muscular co-activation is theoretically adopted to increase joint stiffness and enhance robustness [11]; however, co-activation has been associated with an increased average velocity for the center of pressure (i.e. diminished performance) during an unstable seated balance task [11]. This suggests that the gluteal co-activation strategy adopted by PDs may diminish performance during balance assessment.

Traditional measures of balance control derived from the COP time-series use the principle of centrality to describe the magnitudes of movement and variability [12,13] Under the principle of centrality the mean is the desired outcome, and deviation away from the mean is considered undesirable noise or error. Nonlinear analysis techniques

attempt to characterize the structure of variability in the COP time-series, which is not necessarily correlated with the magnitude of variability [13,14]. Several recent investigations have employed nonlinear analysis techniques to the COP time-series to assess differences between those with varying degrees of LBP [7,9,15–17]. These investigations have primarily focused on quantifying regularity/complexity in the COP time-series by using various techniques to estimate signal entropy [18,19]. Findings from these investigations present conflicting evidence that individuals with increased LBP intensity exhibited either increased [7,16] or decreased [9,17] regularity with varying sensory and support surface conditions. Nonetheless, a consistent finding across these studies was that regularity of the COP time-series was differentially influenced by the presence of LBP. Employing similar analysis techniques to standing balance data obtained before and after a 2-hour standing protocol may provide additional insight to differences in postural control between PDs and non-PDs.

The purpose of this study was to determine if regularity, quantified using sample entropy, derived from the COP time-series during standing was altered after 2-hours of standing. Furthermore, it was our goal to determine if PDs and non-PDs were differentially influenced by the 2-hours of standing. In addition, linear measures of postural sway were also computed to provide a reference for comparison with COP regularity. It was hypothesized that regularity would be affected by the prolonged standing protocol, and that PDs would be influenced to a greater extent than non-PDs.

2. Methods:

2.1 Participants:

Thirty-one volunteer participants (18 male, 14 female) were recruited from a university population. Exclusion criteria included any previous history of low back pain that was significant enough to seek medical intervention or that resulted in greater than three days off work or school, previous lumbar or hip surgery, employment in a task that required prolonged static standing during the past 12 months, and the inability to stand for at least two hours. Ethics approval for research involving Human Subjects was obtained from the Office for Research Ethics at the University of Waterloo.

2.2 Instrumentation

Analog data from two force platforms (AMTI, Watertown, MA, USA), sampled at 2048 Hz, simultaneously measured the ground reaction forces and moments (Fx, Fy, Fz, Mx, My, and Mz), one under each foot of the participants.

2.3 Data Collection

Each participant completed a baseline measure of current LBP symptoms on a 100 mm visual analog scale (VAS) with end point anchors of “no pain” and “worst pain imaginable”. Participants completed two (one with their eyes open, one with eyes closed) 2-minute constrained standing tasks before and after 120 minutes of level standing. Positions of each foot were constrained for each 2-minute trial by outlining a box using masking tape with the dimensions equal to the participant’s foot length (while wearing shoes). The participant stood within the box with the lateral border of the small toe positioned at the side of the box [20,21]. The participant was instructed to look straight ahead, stand as still as possible with your arms by your side and weight evenly distributed

between your feet [22]. Once the first set of 2-minute constrained standing trials were completed participants entered into the prolonged standing task. A standing work-table was positioned in front of the participant where they performed light assembly and sorting tasks. Participants were instructed to stand 'in their usual manor as if they were standing for an extended period' throughout the 120 minute standing protocol. Participants were not constrained to stand within the box during the prolonged standing trial. The only stipulations on feet placement were that they could not rest either foot on the standing table frame or cross their legs onto the other force platform. After the 120 minutes of prolonged standing was completed, participants completed another two, 2-minute constrained standing trials, one with eyes open, one with eyes closed. During the post-standing trials participants stood within the constraints of the same box marked using masking tape during pre-standing for each participant, this was completed to ensure step-width remained consistent during the pre and post standing trials. The trial with eyes open was always collected first to ensure that the participant could safely stand in the constrained standing posture [21].

2.4 Data Analysis

Categorization of participants as either a PD or NON-PD was done based on VAS scores. A participant was considered a PD if they reported any change in VAS score greater than 10 mm from baseline during the 120 minute standing protocol [1,10]. In line with prior work, this is a conservative estimate based on the minimum clinically important difference for patients to feel their low back pain symptoms worsening [23].

Force plate data collected for each of the 2-minute constrained standing trials

were used to quantify time-series data of net anterior-posterior (AP) and medial-lateral (ML) COP using the following equation [24]:

$$netCOP(t) = COP_L(t)\frac{VL(t)}{VL(t) + VR(t)} + COP_R(t)\frac{VR(t)}{VL(t) + VR(t)}$$

where t=frame number, $COP_{L,R}$= Center of Pressure from the left and right plate, VL,R = Vertical component of the right and left vertical ground reaction forces.

Each of the AP and ML time-series were down-sampled to 128 Hz, and then digitally treated with a dual pass second order Butterworth filter with a cutoff frequency of 10 Hz [25]. This filtering approach is in line with Schmid and colleagues, whom proposed a standard filter cut-off frequency of 10 Hz to enhance comparisons between laboratories [25]. The first and last 7.5 seconds of data were removed to account for potential adaptations in postural control due to commencement or anticipation of trial termination. Next, the means of the AP and ML time-series over the remaining 105 seconds were subtracted prior to determining the time-varying resultant distance (RD) for the COP [26]. Based on previous recommendations for quantifying sample entropy from COP data, an incremental representation of the resultant distance was obtained by taking the difference between successive points in the time [18,25,26]. The incremental time-series was then normalized to unit variance. This process is illustrated in Figure 1.

Regularity of the incremental RD time-series was quantified using sample entropy [27]. Sample entropy required the definition of a tolerance (r), and a length (m) for the number of repeating samples. Optimal values for these parameters (m = 3, r = 0.1) were determined using the maximum relative error and previously established methods

[25,28]. All estimates of sample entropy and maximum relative error were determined using software implemented in Matlab (The Mathworks Inc., Natick, MA, USA) that was obtained online from the PhysioToolkit [29]. Change in sample entropy was then determined for each participant by subtracting the values obtained after the 2-hour standing protocol from those obtained prior to the 2-hour standing protocol.

In addition, median power frequency (MDF) and RMS amplitude (equivalent to the standard deviation of the COP position when the mean of the signal is removed) of the filtered AP and ML COP data were calculated. Pre-Post change in MDF and RMS was then determined for each participant by subtracting the values obtained after the 2-hour standing protocol from those obtained prior to the 2-hour standing protocol.

2.5 Statistical Analysis

All statistical analyses were conducted using SPSS (SPSS Inc., Chicago, IL, USA). A two way mixed model analysis of variance with one between (Pain Group) and one within (Vision) subjects factors was used to determine if there were main or interaction effects on the pre-post change in sample entropy, MDF and RMS. Post hoc analyses to compare group means for significant main and interaction effects were performed by paired and independent samples t-tests. The level of statistical significance was set to $p < 0.05$ for all analyses.

3. Results:

3.1 Participants

Of the 31 participants 42% were identified as reporting LBP during the 2-hour standing

protocol. Baseline characteristics of the participants within each PD and non-PD group were statistically similar. There were no significant differences between pain groups for age, body mass index, and baseline visual analogue scale score.

3.2 Post 2-Hour Change in Sample Entropy

Statistical results from the 2-way ANOVA did not reveal a significant interaction between vision and pain group ($p = 0.105$; $F(1,29) = 6.249$) (Table 1), or main effect of vision ($p = 0.520$; $F(1,29) = 0.424$) (Table 1) for the change in sample entropy of the RD COP time-series. However, a main effect of pain group was found ($p = 0.018$; $F(1,29) = 2.807$) (Table 1). Sample entropy of the RD COP time-series decreased after the 2-hours for both PDs and NPDs, but the decrease for NPDs was only 21% of the PDs' decrease (Figure 2).

3.3 Post 2-Hour Change in Linear Measures

There was a significant interaction of pain group and vision for AP MDF ($p = 0.011$; $F(3,29) = 7.36$). During the eyes open condition both non-PDs and PDs had an increase in AP MDF, however, non-PDs had a greater increase (PDs = -0.0220 $\pm$ 0.0862; non-PDs = -0.0773 $\pm$ 0.0831). During the eyes closed condition non-PDs displayed no change in AP MDF, while PDs displayed an increase in MDF following prolonged standing (PDs = -0.418 $\pm$ 0.0564; non-PDs = 0.000530 $\pm$ 0.0701). There was a main effect of Vision ($p = 0.01$; $F(1,29) = 7.66$) and Pain ($p = 0.046$; $F(1,29) = 4.35$) for ML MDF. For the eyes open condition, there was a greater pre-post change in ML MDF when compared to eyes closed (EO = -0.0814 $\pm$ 0.0903; EC = -0.0372 $\pm$ 0.0778). Regardless of vision, non-PDs had a greater pre-post change in ML MPF when compared to PDs (PDs = -0.0810 $\pm$

0.0817; non-PDs = -0.0293 ± 0.0829). No significant effects were observed for pre-post change in ML or AP COP RMS (Table 2).

4. Discussion

The current investigation used a nonlinear dynamics analysis of the COP time-series to quantify changes in neuromuscular control of upright standing following a 2-hour standing protocol in people either identified as PDs or non-PDs. Consistent with the hypothesis, regularity of the COP increased (i.e. decreased sample entropy) after 2-hours of standing for both PDs and non-PDs; and, PDs had a larger decrease in sample entropy after 2-hours of standing.

Increased regularity in the COP has been attributed to a decrease in automaticity of postural control during upright standing [30]. The decreased automaticity of postural control observed after the 2-hours of standing may be a sign that participants paid more attention to postural control during the upright stance trials post 2- hours of standing [31]. The larger pre-post change in COP regularity within PDs may indicate that these individuals paid greater attention to postural control, relative to their baseline value, than non-PDs after the 2-hours of standing. Increased COP regularity in PDs after 2-hours of standing is consistent with previous comparisons between individuals with and without LBP, and those with LBP of increasing intensity [7,17]. A significant increase in COP regularity has also been reported for other populations following injuries/health events such as anterior cruciate ligament rupture, concussion, and stroke [15,29,31]. Increasing regularity of the COP is indicative of an overly constrained postural control system that may be less able to produce a physiological response to a particular task or environmental

demand [32]. The results from the current study suggest that individuals invest more attention to postural control after 2-hours of standing, and that the effect may be larger in PDs.

However, while changes in regularity have been previously explained through voluntary control, the co-contraction responses typically observed in PDs could also be potentially linked to increased regularity. Previous work has shown that one of the first differences in neuromuscular control of the standing posture between PDs and non-PDs was that PDs adopted a pattern of coactivity between the left and right gluteus medius muscles [2]. Subsequent work has suggested that coactivity between the gluteus medius muscles is a neuromuscular strategy to increase system stiffness that may predispose individuals to LBP during prolonged standing [10]. Cavanaugh and colleagues [32] have also suggested that co-activation is a strategy adopted by individuals following concussion that could be related to an increase in COP regularity; however, no study to our knowledge has directly investigated the effects of co-activation on COP regularity. Nonetheless, it is possible that co-activation of the gluteus medius muscles was present in this group of PDs, and may have contributed to their observed larger change in regularity pre and post 2-hours of standing.

Our data also demonstrated that the post 2-hour change in COP regularity was not significantly influenced by visual occlusion. Previous work has shown that COP regularity during upright standing is increased when vision is removed as a sensory input in young healthy adults [28]. Other work has suggested that a loss in complexity of physiological systems results when the number of sensory inputs is reduced and/or the coupling that exists between the inputs is altered, such as the removal of visual sensory

information [33]. It is possible that visual occlusion may cause an overweighting of proprioceptive information, resulting in a more static posture for PDs associated with the previously illustrated reduced COP movement and elevated gluteus medius co-contraction in PDs (add some refs here). The finding in the current investigation meant that any differential influence of visual occlusion on COP excursion in PDs and NPDs was not reflected in the pre-post change in sample entropy.

In contrast to sample entropy, the linear measures demonstrated that post 2-hour changes in MDF was significantly influenced by visual occlusion. Post 2-hours of standing resulted in an increase in AP MDF with eyes open, for both PDs and non-PDs. During the eyes closed condition, only PDs displayed an increase in AP MDF. Similarly, for ML MDF, post 2-hours of standing resulted in significant increases in MDF for eyes open. Both PDs and non-PDs displayed increases in ML MDF however, non-PDs displayed a greater change.

The COP MDF measures also did not follow the same trend as the sample entropy values. Intuitively one would expect that entropy would be correlated with frequency content (i.e. higher entropy with higher MDF). However, in this investigation our data revealed that changes in MDF were significantly influenced by visual occlusion, while entropy displayed no effects of vision. One possible explanation is that the frequency spectral analyses were performed individually on AP and ML components of the COP data, and the entropy analysis was performed on the RD COP (computed from combined AP and ML components). Determining the RD may have in fact changed the frequency content of the signals and this may explain why different trends in MDF were observed. In addition, the changes observed pre-post in the linear measures were very small (under

0.1 Hz for AP and ML MDF and no significant changes in RMS). Thus, linear measures may not be the most appropriate measure to elicit changes in COP, pre-post prolonged standing.

This study was limited in a few respects. First the sample size was relatively small and reflected a university-aged population. Nonetheless, previous work using a similar population has demonstrated that those identified as PDs had a greater likelihood of seeking future clinical treatment for low back pain [5]. As well, epidemiological studies have shown that it is a younger population who suffer from prolonged standing induced back pain [34]. A second limitation was that stance width was not controlled for across participants. Previous work has demonstrated that changing the dimensions of the base of support can affect dependent measurements derived from nonlinear analyses of the COP time-series [7,17,32]. A third limitation was that gluteus medius co-contraction was not quantified and therefore this difference between PDs and non-PDs is based solely on previous work.

5. Conclusion

Changes in neuromuscular control of upright standing pre and post 2-hours of standing did occur based on an increase in COP regularity after 2-hours of standing for both PDs and non-PDs. PDs had a larger change in COP regularity and this finding supports the theory that increased COP regularity occurs with pain/pathology. Using the proposed approach, sample entropy could be a good dynamic analysis technique to characterize and differentiate the postural effects of standing induced LBP and form the basis for early identification of PDs before clinical LBP development. Future studies

should look at how co-activity between the left and right gluteus medius muscles influences COP regularity and if a relationship exists between increased COP regularity in PDs and increased co-activity.

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Conflict of Interest Statement:

The authors have no conflicts of interests to disclose.

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Figure Captions

Figure 1: Illustration of the process for determining the increment time-series of the resultant distance, normalized to unit variance, from the anterior-posterior and medial-lateral time-series.

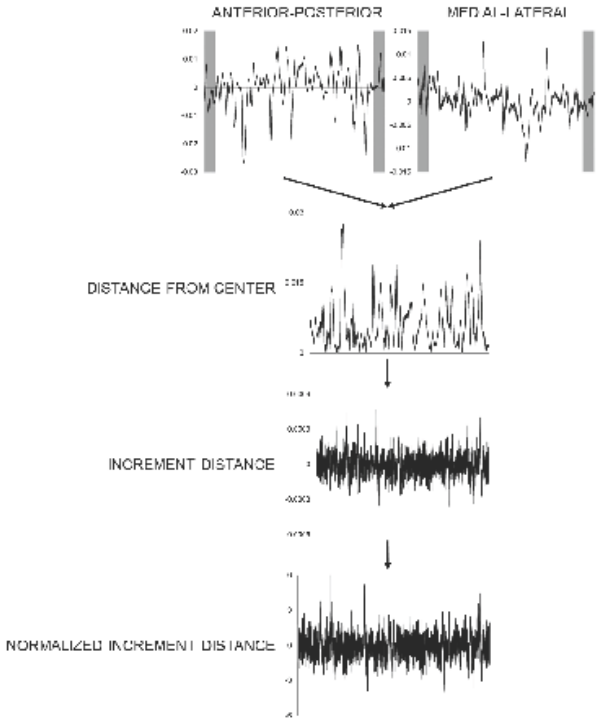

Figure 1

Figure 2: Post 2-hour change in sample entropy for upright standing trials performed by both pain developers and non-pain developers with their eyes open and eyes closed. Sample entropy was derived from the resultant distance center of pressure time-series. The asterisk denotes a statistically significant difference between pain developers and non-pain developers. Error bars represent the standard error of the mean.

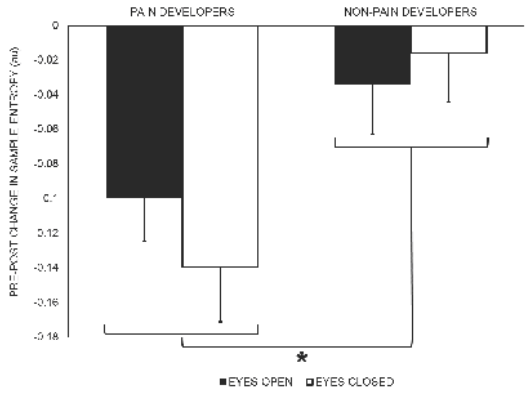

Figure 2

Table 1: Anterior-Posterior and Medial-Lateral Pre-Post Change in COP RMS for PDs and non-PDs during Eyes Open and Eyes Closed constrained standing trials.

		ANTERIOR-POSTERIOR COP		**MEDIAL-LATERAL COP**	
		Mean RMS Pre-Post Change (cm)	Standard Deviation	Mean RMS Pre-Post Change (cm)	Standard Deviation
EYES OPEN	PD	-0.031	0.46	-0.017	0.13
	non-PD	-0.19	0.30	-0.0025	0.093
EYES CLOSED	PD	-0.13	0.17	-0.047	0.097
	non-PD	-0.13	0.31	-0.074	0.21