Postural recovery following voluntary arm movement is impaired in people with chronic low back pain

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ABSTRACT

Study design: Recovery of postural equilibrium following bilateral voluntary arm movement was evaluated using a case-control study, with 13 subjects with chronic LBP and 13 age- and gendermatched control subjects.

Objectives: To evaluate control of the centre-of-pressure (COP), as a marker of the quality of control of postural equilibrium associated with voluntary arm movements, in people with and without LBP.

Summary of background data. When healthy individuals perform rapid voluntary arm movements, small preparatory spinal movements associated with postural adjustments [3,4]. For instance, it is known that lumbo pelvic movement is critical to maintain upright stance when standing on a short base [5] and subjects with LBP frequently lose balance when standing quietly on a short base with no visual input [3]. In trials when they were asked to stand on a short base, the LBP group had reduced antero-posterior (AP) shear force which suggests reduced use of AP lumbo pelvic movement during quiet stance.

Results: Subjects performed bilateral voluntary rapid arm flexion while standing on support surface of different dimensions with eyes opened or closed.

Methods: Subjects performed bilateral voluntary rapid arm flexion while standing on support surface of different dimensions with eyes opened or closed.

Results indicated that people with LBP consistently took longer to recover postural equilibrium and made more postural adjustments in different stance conditions. However, there was no increase in the excursion of the COP during the recovery period in the LBP group.

Conclusion: These data suggest that while COP is tightly controlled during postural recovery, the finetuning of the control of postural equilibrium is compromised in people with LBP. Postural control dysfunctions should be considered in the management of chronic low back pain.

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1. Introduction

People with low back pain (LBP) commonly have impaired postural control [1,2]. In particular, LBP subjects have difficulty controlling lumbo pelvic movements associated with postural adjustments [3,4]. For instance, it is known that lumbo pelvic movement is critical to maintain upright stance when standing on a short base [5] and subjects with LBP frequently lose balance when standing quietly on a short base with no visual input [3]. In trials when they were asked to stand on a short base, the LBP group had reduced antero-posterior (AP) shear force which suggests reduced use of AP lumbo pelvic movement during quiet stance.

An important element of postural control is appropriate anticipatory control in association with voluntary movement. When healthy individuals perform rapid bilateral arm flexion, the lumbar spine flexes as a result of reactive forces, altered body configuration, and anterior shift of the body's centre-of-mass (CoM). This flexion motion has been termed resultant motion of the lumbar spine as it is the result of the reactive forces from arm movement [6]. In healthy individuals, this resultant motion is preceded by a small preparatory trunk extension, which is in the opposite direction to the resultant motion [4,6]. Although preparatory motion appears to provide an ideal mechanism to limit the perturbation to the trunk, this strategy is used relatively infrequently by people with LBP. Notably, trials with no preparatory spinal movement are associated with increased spinal displacement following arm movement in people with LBP [4]. This compromise in the quality of spinal control may contribute to balance impairment in this population.

Reduced spinal motion prior to the onset of arm movement was thought to be a biomechanical consequence of altered muscle control in people with LBP [4,7]. Increased co-activation of the trunk muscles has been reported in people with LBP during various motor tasks [8,9], and in association with arm movements when

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LBP is induced experimentally [10]. Co-activation has been argued to be an adaptation to limit spinal movement and therefore increase spinal stability. This may be a strategy used by the nervous system to protect the spine from further pain and injury or to compensate for impaired proprioception [8]. However, this strategy to reduce spinal movement in people with LBP may adversely affect postural control as multi-segmental movement is a critical component of balance.

It has been acknowledged by many authors that movement of the spine is essential to overcome balance disturbance as ankle moment alone is insufficient to maintain equilibrium [11]. With fast support surface translations, movement of the hip/trunk is necessary to adjust the CoM over the new base of support [5]. Even in quiet stance, movement of the spine is ongoing to overcome the challenge to balance imposed by the rhythmic cardiac and respiratory events [12]. Furthermore during arm movements, it is argued that trunk movements contribute not only to the control of perturbation of the trunk but also to assist in the maintenance of the position of the CoM [6,13]. We hypothesised that chronic LBP may be associated with impaired control of centre-of-pressure (CoP) displacement and whole body equilibrium. The aim of the present study was to test this hypothesis by investigation of the quality of postural recovery following arm movement in people with and without LBP. In the present study, the quality of postural recovery was examined by two characteristics: the time taken to regain postural recovery and the number of postural adjustments during the period of postural recovery following rapid bilateral upper limb movement.

2. Method

2.1. Subjects

Twenty-six subjects participated in the study; 13 in the LBP group with a mean (SD) age of 28.8 (5.3) years and 13 age- (±3 years) and gender-matched control subjects, aged 27.7 (4.2) years. All subjects were on full work duty at the time of testing. Prior to testing, participants completed a Habitual Physical Activity Questionnaire (HPA) [14] and anthropometric measures (height, weight and foot length). 

2.2. Demographic data

Prior to testing, participants completed a Habitual Physical Activity Questionnaire (HPA) [14] and anthropometric measures (height, weight and foot length) were recorded. Subjects in the LBP group completed an additional questionnaire related to their LBP history. Severity of LBP was measured using a 10 cm visual analog scale (VAS) and the Roland Morris disability questionnaire (RMS) [15]. The characteristics of subjects are listed in Table 1. t-Tests for independent samples showed no difference between groups.

Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low Back Pain Subjects (n = 13) [mean (SD)]</th>
<th>Matched Controls (n = 13) [mean (SD)]</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>28.8 (5.3)</td>
<td>27.7 (4.2)</td>
<td>0.57</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 (0.12)</td>
<td>1.75 (0.06)</td>
<td>0.82</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75.1 (14.7)</td>
<td>70.4 (12.0)</td>
<td>0.34</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>24.7 (3.5)</td>
<td>22.9 (3.2)</td>
<td>0.20</td>
</tr>
<tr>
<td>Habitual physical activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work (scale 1–5)</td>
<td>2.5 (0.5)</td>
<td>2.4 (0.3)</td>
<td>0.60</td>
</tr>
<tr>
<td>Sports (scale 1–5)</td>
<td>2.7 (1.1)</td>
<td>2.8 (0.6)</td>
<td>0.65</td>
</tr>
<tr>
<td>Leisure (scale 1–5)</td>
<td>2.8 (0.7)</td>
<td>3.0 (0.3)</td>
<td>0.18</td>
</tr>
<tr>
<td>Duration of back pain (yr)</td>
<td>5.0 (5.3)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>VAS score (scale 0–10)</td>
<td>1.9 (1.8)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Roland Morris score (scale 0–24)</td>
<td>2.5 (1.6)</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

P values indicate results of independent t-test. NA indicates not applicable.
in the ordinal data of the number of postural adjustments were analysed using Wilcoxon’s rank sum test. Between-group characteristics including shoulder movement were compared using independent t-tests. SPSS v11.0 was used for all analyses and a P-value of 0.05 was set for significance.

3. Results

3.1. Shoulder movement

When subjects moved the arms forward rapidly, there was no difference in the range ($F_{1,23} = 0.12, P = 0.74$) or peak acceleration ($F_{1,23} = 0.96, P = 0.34$) of shoulder movement between groups (Table 2).

3.2. Baseline COPVap

There was no difference in baseline COPVap between the two groups ($F_{1,23} = 0.67, P = 0.42$) (Table 2). However, there was a significant main effect for base ($P < 0.01$), visual condition ($P = 0.02$) and an interaction between base and visual condition ($P = 0.01$). Antero-posterior COP velocity trajectory was increased with reduced base length and when visual input was removed and this was identical for both groups.

3.3. Time to stabilization

Comparison of the mean time to stabilization of COPVap following arm movement between the control and the LBP groups indicated that there was a significant main effect for group ($F_{1,23} = 29.8, P < 0.001$). Following voluntary bilateral arm flexion, the average time for COPVap to return to pre-movement level was significantly longer in the LBP group (679 ± 45 ms) compared with the controls (513 ± 26 ms). As shown in Fig. 2, there was no significant interaction between group and visual or base condition (all: $P > 0.47$). This indicates that the LBP group consistently took longer for postural recovery after voluntary arm movement.

3.4. Number of postural adjustments

The number of postural adjustments during the period between onset of shoulder movement and postural recovery was significantly greater ($F_{1,23} = 13.3, P = 0.01$) in the LBP group (5.4 ± 0.7) compared with the controls (3.8 ± 0.2) (Fig. 3). Again, no interaction was found between group and either visual or base condition (all: $P = 0.06$). This indicates that people in the LBP group consistently made a greater number of postural adjustments in the period of postural recovery.

3.5. Excursion of COP

There was a significant main effect for base ($P = 0.01$), visual condition ($P = 0.02$) and an interaction between base and visual condition ($P = 0.02$). Antero-posterior excursion of COP trajectory was increased with reduced base length and absence of visual input.

Table 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>FS/EO</th>
<th>SB/EO</th>
<th>FS/EC</th>
<th>SB/EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder flexion range (°)</td>
<td>60.0 (16.9)</td>
<td>61.2 (13.7)</td>
<td>62.0 (17.8)</td>
<td>60.7 (13.5)</td>
</tr>
<tr>
<td>LBP</td>
<td>62.9 (18.3)</td>
<td>55.3 (13.8)</td>
<td>63.2 (15.0)</td>
<td>59.0 (12.7)</td>
</tr>
<tr>
<td>Shoulder acceleration (°/s²)</td>
<td>555.0 (125.4)</td>
<td>551.7 (225.9)</td>
<td>488.8 (162.0)</td>
<td>543.9 (208.5)</td>
</tr>
<tr>
<td>LBP</td>
<td>501.8 (275.7)</td>
<td>551.4 (270.9)</td>
<td>694.0 (364.8)</td>
<td>668.8 (360.6)</td>
</tr>
<tr>
<td>COP Velocity in Antero-posterior direction (mm/s)</td>
<td>2.34 (0.73)</td>
<td>3.23 (2.36)</td>
<td>3.88 (2.17)</td>
<td>4.19 (3.12)</td>
</tr>
<tr>
<td>LBP</td>
<td>2.27 (1.98)</td>
<td>3.23 (2.86)</td>
<td>2.78 (2.36)</td>
<td>4.19 (3.12)</td>
</tr>
</tbody>
</table>

FS = flat surface; SB = short base; EO = eyes open; EC = eyes closed. Values are mean (SD).

Fig. 2. Group data for the length of time for postural stabilization in the control and LBP group in all tasks (mean ± SD). The number of time to restore postural equilibrium was greater for the LBP group across all tasks ($P < 0.001$). FS = flat surface; SB = short base.
input for both groups. However, there was no difference in the range of COPpap during the period of postural recovery between the two groups ($F_{1,23} = 0.53, P = 0.47$) (Fig. 4, Table 2).

4. Discussion

This is the first study that reveals people with LBP have impaired ability to recover postural stability after internal perturbations induced by arm movement. When compared with their age- and gender-matched pain-free controls, LBP participants took a longer time to regain postural stability and required a greater number of postural adjustments during recovery. It is unlikely that the impaired postural recovery in the LBP group is due to deconditioning as all subjects were performing full job duties, there was no between-group difference in physical activity level, and the reported pain level in the LBP group was low at the time of testing.

4.1. Inferior quality of postural recovery in people with LBP

In the present study, balance performance was examined using COP velocity, and the quality of postural recovery was quantified using two parameters; the time taken for the COPVap to return to the pre-perturbation level and the number of postural adjustments during the period of postural recovery. COPV reflects the speed of movement of the COP, and its timing to resume steadiness has been used as a measure of quality of postural recovery [16,17]. It has been suggested that increased time taken for postural stabilization is associated with poor postural control [16,18]. For instance, time to regain postural equilibrium is increased in elderly individuals compared with a younger population [18], and elderly with known reduced balance performance (versus elderly with better balance performance) [16]. The number of postural adjustments represents major direction changes of the COP around its neutral position which reflects the fine tuning of postural control during the recovery period, and was used to quantify the quality of postural recovery after external postural perturbation [17]. Previous work has shown that this measure of quality of postural recovery is sensitive to changes in postural ability as a result of changed mechanical demands in healthy individuals [17]. It has been shown that postural recovery does not correlate with postural steadiness during quiet stance and should be considered independently when assessing balance performance [18,19]. The present study extends existing findings of balance deficits in LBP (static balance [1–3] and following unexpected external perturbations [2,7,20]). As the perturbation was performed by the individual and therefore predictable, the postural recovery is initiated in a pre-planned manner before the movement is started. The reduced quality of recovery implies that pre-planned strategies and later refinement of these strategies (once feedback becomes available) are not ideal in people with chronic LBP.

There are reports of several neuromuscular impairments in people with chronic LBP which might contribute to this finding. First, spinal proprioception is compromised in this population. As proprioception constitutes one of the sensory inputs for regulation of postural stability, defective input may affect the accuracy of postural control. Previous studies reported that LBP subjects are less sensitive to detect rotary motion in both directions [21], make errors with reproduction of a previously presented lumbo-pelvic angle [22], and consistently tend to undershoot target angles during active repositioning of sacral tilt [23]. If the quality of proprioceptive feedback from the lumbar spine is poor, control of the CoM position might become ineffective when the lumbo-pelvic movement is involved in postural control (i.e. hip strategy). A hip strategy is more complex and requires calculation of CoM position from interpretation of angle changes at the angle, hip and spine [24]. If spine position is uncertain, this task could be near-impossible. This may explain the reduced tendency for people with LBP to use the hip strategy for balance control.

As ankle torque is generally sufficient to maintain balance in association with minor disturbances, it could be argued that this strategy may be sufficient to control equilibrium in a simple task such as voluntary arm movement when standing on a flat surface. However, lumbo-pelvic movement has been shown to be an essential component during this task [6]. Notably, lumbo-pelvic motion is less frequently used by people with LBP: people with LBP use preparatory lumbar movement less frequently and this is associated with increased spinal displacement following voluntary arm movement [4]. Furthermore, the reduced tendency to use shear forces at the ground (suggesting reduced hip strategy) and the corresponding dominance of ankle torque for postural control in people with LBP accounts for the increased frequency of balance loss when standing on a short base [3]. Thus, in order to maintain balance and precise control of spinal movement is needed. The tendency of people with LBP to undershoot a previously set position [23] and the reduced sensitivity for spinal motion might compromise the effectiveness of resumption of the pre-perturbation position.
Second, people with LBP have been found to have altered muscle control. Superficial trunk muscle activity is increased in people with LBP during various voluntary tasks [8–10]. Trunk muscle co-contraction has been shown in vivo and in modeling studies to increase spinal stiffness [25,26], and has been argued to be an attempt to compensate for insufficiency in the osseoligamentous system, or to prevent further pain and/or injury [8]. However, the resultant increase in trunk stiffness would reduce spinal movement, which has been reported in people with chronic or experimental LBP [27,28]. Similar increases in co-contraction have been observed in less-skilled performers and older adults [29] as an attempt to reduce variability of movement [18]. Regardless of the mechanism, the potential advantages of this strategy (prevention of pain and (re)injury, decreased variability) may be offset by the loss of flexibility to use spinal movement for postural control in people with LBP. It is well accepted that control of postural equilibrium is dependent on movement of the hips and spine, particularly when stability is challenged dynamically. Eng et al. [11] and Friedli et al. [13] argued that spinal movement is a crucial element in the control of postural stability if the multi-segmental nature of the human body is taken into consideration. Although adjustment of antero-posterior instability would still be possible via movement of the lower limbs, especially the hip and ankle [5], previous data from our laboratory showed evidence of increased compensation by hip during similar tasks [4] and respiration [30] in people with LBP. However, healthy individuals appear to have the capacity to adapt to use other joints when conditions are changed [31]. This suggests that people with LBP have an impaired ability to adapt with a changed postural set.

4.2. No change in COP excursion

The results showed no difference in the COPap excursion between LBP and the control subjects during postural recovery following voluntary arm movement. This suggests postural steadiness is tightly constrained during the recovery period after voluntary arm movement in people with LBP in order to prevent falling.

4.3. Methodological considerations

Several methodological limitations require consideration. First, the case-control methodology is not able to establish a temporal sequence of postural dysfunction and development of chronic LBP. Second, although the sample size was sufficient to identify group differences, additional studies are required to establish the generalisability of the results, due to the small sample size. Third, the time taken for the COPV to return to a pre-perturbation level as a measure of the quality of postural recovery may be influenced by a difference in the baseline variability of COPV between groups. However, no between group difference was found in this study and this can be excluded as an explanation for our results. Fourth, participants in this study were involved in an earlier experiment with a similar protocol. As such, the observed recovery strategy may vary slightly from a naïve cohort, but we do not anticipate that this would compromise the main conclusions of the study as this would be similar for both groups.

5. Conclusion

During voluntary arm movements, postural instability is self-imposed and predictable to the nervous system. Thus, the current data imply compromised organisation of pre-planned mechanisms of postural control. The inability to achieve timely postural recovery associated with the minor internal perturbation in this task may place the individuals with LBP at risk of overbalancing or falling during situations where rapid recovery is critical. Clinical assessment and treatment of balance are not commonly addressed in the management of LBP. Clinicians should consider the postural stability of patients with LBP during the course of rehabilitation.

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Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, “Balance recovery following arm movement is impaired in people with chronic low back pain”.

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