Effects of proprioceptive disruption on lumbar spine repositioning error in a trunk forward bending task

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Abstract.

BACKGROUND: Various inputs of proprioception have been identified and shown to influence low back proprioception sense.

OBJECTIVE: To investigate the effect of disrupting proprioception on lumbar spine repositioning error during forward bending.

METHOD: Healthy-subjects (n = 28) and patients with non-specific chronic low-back pain (n = 10) aged between 20–50 years. Subjects performed 5 repetitions of a lumbar repositioning task targeting 30° of trunk-forward-bending from a seated-position with different proprioceptive disturbances administered to the low back. Video analysis of skin reflective markers measured lumbar spine range-of-motion. A control-task was performed without any proprioceptive disturbance, while the remaining 4 tasks were electro-stimulation, vibration, taping and sitting on an unstable surface.

RESULTS: The healthy group showed significantly altered repositioning error when compared with the control task (p = 0.004): control-task vs. taping-task, vibration-task and unstable-sitting. In the NS-CLBP group, one motor-task showed significant difference in control-task vs. taping-task (p = 0.004). Comparison between the NS-CLBP and matched-healthy groups revealed that the NS-CLBP subjects had larger repositioning-error (p = 0.009) for control, taping and vibration tasks.

CONCLUSIONS: Proprioceptive disturbances had the most significant effect in increasing repositioning-error among healthy subjects. The between-group analysis confirmed evidence consistent with the literature of greater repositioning-error in people with NS-CLBP than healthy subjects.

Keywords: Kinematics, low back pain, proprioception, repositioning error, spine
The non-specific chronic low back pain (NS-CLBP) group was composed of 10 patients aged 34 ± 8.9 years with BMI of 22.34% ± 3.09 (5 male and 5 female).

To compare both groups, a matched-health group of 10 subjects was composed from the healthy subjects. Anthropometric data are reported in Table 1.

Healthy subjects were recruited on a voluntary basis and had no history of NS-LBP in the 12 months prior to the experiment.

The NS-CLBP group included patients recruited from Saint-Luc University Hospital (Brussels, Belgium) with chronic (≥ 6 months) NS-LBP without pain radiating into the leg. The Visual Analogue Scale (VAS) score of the chronic NS-CLBP group represents the pain on the day prior to the experiment and was 3.4 ± 0.9. The mean duration of pain was 11.4 ± 4.7 months.

Exclusion criteria for both groups were vestibular diseases, pregnancy, diabetes, neurologic disorders, specific low-back pain and having no history of musculoskeletal system surgery in the low-back area.

The Ethics Committee of the “Université Catholique de Louvain” approved the study protocol and informed consent was obtained from subjects prior to testing.

2.2. Protocol and material

2.2.1. Placement of markers and kinematic spine model

The following standardised marker locations were used: two markers were placed on the spinous processes of S2 and T12. The segment between S2-T12 was considered as rigid and homogenous, delimited by proximal (S2) and distal markers (T12) as illustrated in Fig. 1. The selected variable is the range of motion (ROM) and corresponded to the range of the angular displacement of the spinal segment during each trial. At each frame, the average of 10 sequential frames was calculated to minimize oscillations and true range was calculated as the difference between the minimum and maximum angles.

2. Methodology

2.1. Subjects

The cohort was composed of 28 healthy subjects aged 26 ± 9.84 years (mean ± SD) with a body mass index (BMI) of 23.18% ± 2.64 (14 male and 14 female).

Baseline characteristics of healthy subjects and those with chronic non-specific low back pain

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>M/F</th>
<th>Age (years)</th>
<th>BMI (kg/m²)</th>
<th>VAS</th>
<th>Pain duration (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>28</td>
<td>14/14</td>
<td>27.7 (9.7)</td>
<td>23.1 (2.4)</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>NS-CLBP</td>
<td>10</td>
<td>5/5</td>
<td>33.8 (7.5)</td>
<td>22.4 (2.9)</td>
<td>3.4 (0.9)</td>
<td>11.4 (4.7)</td>
</tr>
<tr>
<td>Matched healthy</td>
<td>10</td>
<td>5/5</td>
<td>30.0 (11.7)NS</td>
<td>22.9 (2.2)NS</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

Data are shown as the mean (standard deviation). NS-CLBP, non-specific chronic low back pain; M, male; F, female; BMI, body mass index; VAS, 10-point visual analogue scale pain score (present pain); NS, non-significant difference between NS-CLBP and Matched Healthy (Student t-test, p > 0.05).

...movement of body in space... Since proprioception is essential for motor control of the trunk it should be quantitatively evaluated. Therefore, the developments of accurate tools providing a quantifiable measure of spinal proprioception are required [6,7].

Several studies have investigated motor control and lumbar proprioception [6]. For example, one study focused on the detection of trunk motion during passive movements induced by an electromechanical device [13], while a further study used a force-platform to evaluating postural-balance with external stimulations [10,12]. Another common assessment of proprioception is the measurement of active and/or passive repositioning error (RE, i.e. the difference between a target position and the reached position of the patient) using kinematic-tools [6,9,13–20]. These studies [13–20] showed conflicting evidence about a higher RE in chronic NS-LBP patients. This discrepancy could also be due to different protocols used to measure RE. However, the main tendency supports the hypothesis that reposition sense is altered in patients with chronic NS-LBP when compared to healthy subjects [13,17–20], while a minority revealed no differences [9].

The aims of this study were to investigate the effects of various proprioceptive disturbances (i.e. electrostimulations, vibrations, tapping on the low-back area or sitting on unstable support) on RE in healthy and chronic NS-LBP subjects and to compare RE accuracy between both groups. To our knowledge, the introduction of various proprioceptive disturbances on both these populations while simultaneously performing RE motor tasks have never been undertaken in the same study.
Fig. 1. Illustration of the repositioning error in control and TENS tasks conditions. (A): starting position of control task, (B): spine model, (C): target position at 30° of control task, (D): spine model, (E): illustration of electrodes placement for TENS task. The acquisitions and calculation of torso-angle were made only on two markers of the spine model on S2 (proximal) and T12 (distal) spinous process. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/BMR-130396)

Similarly to Wilson et al. [23], only the low-back segments (S2-T12) from the spine model [7] were used to calculate the torso angle in the sagittal plane given the trunk position in flexion [23].

Placements of markers on bony landmarks, the spine model (Fig. 1) and method of angles calculation are well described in details elsewhere in Hidalgo et al. [7].

The testing protocol included five trunk repositioning error tasks and was performed at a non-imposed speed (spontaneous speed).

All trunk repositioning error tasks were executed from a seated position on a stool; the height of the stool was adjusted for each subject to create a 130° angle between the thigh and trunk, allowing the maintenance of normal physiological curvature by anterior pelvic tilt in the starting position (corrected position) (Fig. 1(A)). From this position, subjects successively performed the five tasks described below.

2.2.2. Tasks and instructions

To minimize proprioceptive feedback from the lower limbs and pelvis [9,24], the subjects were sitting in a standardized position described here above. Both feet were placed on marks to keep the knees and feet apart in standardized positions and both upper limbs were crossed in front of the chest with the hands on the contralateral shoulder.

Subjects were asked to follow the following five rules during each task: (1) begin each movement in a seated position with corrected spine posture (2) maintain this curvature while moving (3) move at their own pace (4) aim for the target position of 30° and (5) keep the eyes closed except for the initial warm-up trial.

Fig. 2. The repositioning error in control and vibration tasks, illustration of one healthy subject. TP: target position at 30 degrees of trunk flexion. T1–10: 10 trials (reached positions).

The repositioning error task (RE): As shown in Wilson et al. [23], subjects were instructed and trained to bend forward while trying to hold the spine physiological position to the target position of 30° ROM indicated by an audio-signal. The subjects paused for 3 seconds, to memorize the target position. The subjects were instructed to move to the target position and return to the starting position 10 times as precisely as possible (Figs 1 and 2).

2.2.3. The RE and proprioception disturbance tasks

Five RE tasks were carried out. The first task was the control task (CT) with the eyes closed/blindfolded and 4 other tasks with eyes closed/blindfolded and standardized proprioceptive perturbation inputs. To limit
Within group comparison with one-way repeated measures ANOVA

<table>
<thead>
<tr>
<th>Motor tasks</th>
<th>Healthy (n = 28)</th>
<th>NS-CLBP (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td></td>
<td>in degrees</td>
<td>in degrees</td>
</tr>
<tr>
<td>Control task</td>
<td>2.84 (2.04)</td>
<td>4.32 (2.60)</td>
</tr>
<tr>
<td>Taping task</td>
<td>4.42 (2.40)**</td>
<td>7.89 (5.02)**</td>
</tr>
<tr>
<td>Vibration task</td>
<td>4.20 (2.76)*</td>
<td>5.09 (2.84)</td>
</tr>
<tr>
<td>TENS task</td>
<td>3.34 (2.08)</td>
<td>5.50 (4.30)</td>
</tr>
<tr>
<td>Unstable sitting task</td>
<td>4.60 (3.50)**</td>
<td>5.80 (2.55)</td>
</tr>
<tr>
<td>Between tasks</td>
<td>p = 0.004; P = 0.8</td>
<td>p &lt; 0.05; P = 0.5</td>
</tr>
</tbody>
</table>

Table 2

Between groups’ comparisons with two-way repeated measures ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Difference of means in degrees</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control task</td>
<td>2.54</td>
<td>0.03*</td>
</tr>
<tr>
<td>Taping task</td>
<td>3.20</td>
<td>0.006*</td>
</tr>
<tr>
<td>Vibration task</td>
<td>2.34</td>
<td>0.003*</td>
</tr>
<tr>
<td>TENS task</td>
<td>1.73</td>
<td>0.14</td>
</tr>
<tr>
<td>Unstable sitting task</td>
<td>1.90</td>
<td>0.08</td>
</tr>
<tr>
<td>Between groups</td>
<td>2.4</td>
<td>0.009*</td>
</tr>
<tr>
<td></td>
<td>P = 0.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

Within group comparison with one-way repeated measures ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Difference of means in degrees</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.006*</td>
</tr>
<tr>
<td>Vibration task</td>
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</tr>
<tr>
<td>TENS task</td>
<td>3.34</td>
<td>0.14</td>
</tr>
<tr>
<td>Unstable sitting task</td>
<td>4.60</td>
<td>0.08</td>
</tr>
<tr>
<td>Between groups</td>
<td>2.4</td>
<td>0.009*</td>
</tr>
<tr>
<td></td>
<td>P = 0.8</td>
<td></td>
</tr>
</tbody>
</table>

2.2.4. Data and kinematic recording analysis

The Elite 3D track-system (BTS, Italy) was used to record the positions of the reflective markers by eight infrared cameras recording at a frequency of 200 Hz. Based on the positions of the markers (proximal = S2 and distal = T12), a customized program established the displacement of the lower-back segment (between S2 and T12 spinous process) as a function of time [7].

Repositioning error for each trial was evaluated from lower-back displacements according to the equation [15,23]:

\[
RE = RP_i - TP
\]

Where \(i\) represents the number of trials (\(n = 10\)), “RP” the reached position, “TP” the target position at 30° ROM and finally “RE” is the repositioning error (Fig. 2). Mean value of absolute algebraic RE, representing the mean of deviation between reached and target-positions, was calculated for every task as well as standard deviation (SD), representing the variability of reached positions.

2.2.5. Statistical analysis

To assess the reliability of the repositioning error task (CT) at target position of 30° ROM, 15 subjects from our cohort executed the repositioning error tasks without perturbation and with eyes closed. The tasks were performed three times with an interval of 5 minutes between sessions.

Intraclass correlation coefficient (ICC) was used to measure reproducibility of intra- and inter-subject variability [7] during tasks (SPSS software).

To assess the effect of disturbance on RE, within-group comparisons were made between the 4 proprioceptive disturbances and the CT and were calculated with one-way repeated measures ANOVA (Table 2).

Between-groups comparisons (matched-healthy and NS-CLBP groups) on RE motor tasks were estimated with two-way repeated measures ANOVA (Table 3). To compare both groups, the subjects of the NS-CLBP group \((n = 10)\) were matched with 10 subjects from the healthy group according to gender, BMI and age (Table 1).

3. Results

3.1. Reliability

The reliability of the measurement of RE was excellent (ICC = 0.94) during the control task.
3.2. Within-group difference in motor tasks

The healthy group showed significantly altered RE measurement between motor tasks (p-value = 0.004, statistical-power = 0.8): Multiple Comparisons versus Control-Group (Holm-Sidak method) determined differences for: CT vs. taping-task (p-value = 0.003; standardized mean of difference [SMD] = 0.8), CT vs. vibrations-task (p-value = 0.01; SMD = 0.6), CT vs.

3.3. Between-groups differences in motor tasks

Between-groups comparison showed that NS-CLBP subjects had larger RE in the tasks from those of the matched healthy group (p-value = 0.009, statistical-power = 0.5), the 4 proprioceptive disturbances had almost no significant effects except that post-hoc analysis with Multiple Comparisons versus Control Group (Holm-Sidak method) determined a significant difference for CT vs. taping-task (p-value = 0.004, SMD = 0.5).

4. Discussion

The major goal of this study was to measure the effect of various forms of perturbations on the lower back “proprioceptive system” during RE tasks. The design of this study concerning proprioceptive inputs during RE tasks was carried out in a fashion consistent with Stillman, who described five inputs of proprioception: from cutaneous tissues, articulations, muscle, tendon and visual inferences [25]. Mann et al., studied the effect of visual privation on postural stability. Their results showed that NS-CLBP patients are better able to compensate proprioceptive deficiency using vision to perform postural stability [26]. Therefore, each test was performed with the eyes closed to exclude bias related to vision. Newcomer et al. [15] and McNair et al. [27] evaluated the effect of a lumbar support (an elastic lumbar brace) on repositioning error in a standing position. They observed that CLBP subjects who wore a brace had decreased RE. Theoretically the brace stiffens the lumbar spine and decreases all movements from this portion of the spine. Moreover, no high quality evidence has tested the effect of taping on proprioception and stabilization [28]. In our study, tape showed that it had a significant influence on RE in both populations.

It was hypothetically assumed that there would be greater perturbation on RE tasks with electro-stimulation, but no significant effect on either population were established. As described by Paillard et al. [29], Golgi-tendinous-organ’ activity could be modified and neuromuscular activity increased, with the aim of disturbing the length/tension relationship of paravertebral muscles and therefore the real position of the spine. Grunnesjö et al. [30] and many other experts [8–31] agree that CLBP can be caused by a deficit of proprioception. The deficit of proprioception could be affected by an increase in muscle spindle sensitivity, producing an erroneous signal of spinal position [30]. Despite any significant effects of electro-stimulation on RE, our results supports the hypothetical mechanism described above and reflect that the low level of change demonstrated in the present study are probably due to lower intensity levels of the electro-stimulation used in this studies protocol.

Li et al., studied whole-body vibration at 5 Hz applied to a healthy population for 20 minutes prior to measurement of RE in trunk flexion executed from a sitting position with a target position of 30° ROM. Their results were in concordance with our study showing a significantly larger mean RE after vibration application in a healthy population [32]. Differences between both studies arose from the application of vibrations on lumbar paravertebral-muscles only, with a frequency of 50 Hz for 3 minutes. Moreover, we also studied the effect of vibration perturbation on NS-CLBP patients and no significant effect on RE was found. Brumagne et al., demonstrated that vibration applied to paravertebral muscle led to an increase of RE in healthy subjects and therefore provided evidence that muscle spindles are major elements of lumbar proprioceptive ability [33]. On the other hand, Brumagne et al., found that muscle vibration in LBP subjects decreased the RE. Previous and present evidence suggested that LBP and healthy subjects are different in the way they process spindle information [33]. For Hill et al., the effects of vibration on the spine is a very complex issue depending on the axis, frequency, amplitude, duration, and soft-tissue health that could influence the spine’s response to vibration [34]. There is a long history of investigation to determine the effect...
of vibration on the spine. Nevertheless, clinical data shows mixed effects and conflicting evidence [34].

To our knowledge, no study has directly examined active RE while sitting on an unstable surface, such as the Swissball. Some authors have, however, examined trunk muscular [35] or re-equilibration [14] in healthy-subjects during an equilibration task on a rocker-board. The first study [35], described above, showed that trunk muscle activation was more important during unstable sitting position. The second study [14] described an effect of gender and age on equilibration, but in the present study we did not find any effect for gender. The unstable sitting task on the Swissball showed a significantly larger mean RE when compared to the CT in healthy subjects. Moreover, we could again observed that for the NS-CLBP group; unstable sitting did not increase RE.

Proprioceptive disturbances clearly raise doubt about the accuracy of RE tasks in healthy subjects, and to a much lesser extent in the NS-CLBP group. This can perhaps be explained by the fact that proprioception is already disturbed in the LBP patients and it is not possible to add further disruptive effects artificially.

In accordance with the literature [15–22], there was significant difference for active RE tasks between both populations, the NS-CLBP group showed larger RE than healthy subjects. Literature reports that pain-free subjects have a RE of around 1–2 degrees, while LBP patients have an error about twice as great, probably due to altered proprioceptive input from the lumbar spine [21]. Impaired proprioception may contribute to the worse RE accuracy in patients with LBP [33]. Moreover, previous work on peripheral joints has revealed that proprioception is affected by muscular or joint injuries or degeneration [17].

Conversely, two other studies [9,13] also using active RE, have found no differences between both populations. This conflicting evidence between studies is probably due to protocol and design variations. As an illustration, Assel et al., studied active RE in healthy and CLBP subjects using a longer segment between S2 and T7 [9], thus including the low-thoracic spine for evaluation from a sitting position but in a physiological curvature repositioning task. Lee et al., used a similar active RE but from a side-lying position [13]. Results showed no difference between groups. These studies assessed spinal proprioception with major differences between patient positions and task from our protocol.

The small sample in NS-CLBP group, in comparison to healthy subjects, could, within NS-CLBP group, slightly bias outcome measures, but between-group comparisons showed good statistical power.

5. Conclusion

Artificial proprioceptive perturbations had effects on the RE sense of the lumbar spine in healthy subjects, increasing RE during trunk forward bending. In contrast, subjects with NS-CLBP seemed to be unaffected by almost all perturbations on RE tasks, probably because proprioceptive alterations resulting from LBP cannot be further influenced by external perturbations or could be dependent on stimulation intensities. Between-group comparisons showed larger RE for the NS-CLBP group in 3 of the proprioceptive disturbance RE tasks. The present study confirms evidence that patients with CLBP have larger active RE than healthy subjects. Further studies are necessary to evaluate the impact of different intensities of proprioceptive disturbance on RE; to investigate RE in different sub-groups of NS-CLBP such as motor control impairment or instability. Indirectly, these results may also have clinical implications and confirm the importance of RE in people with LBP.

References


