Low Back Pain and Postural control, effects of task difficulty on Centre of pressure and spinal kinematics

Abstract:

Association of Low Back pain and standing postural control (PC) deficits are reported inconsistently. Demands on PC adaptation strategies are increased by restraining the input of visual or somatosensory senses. The objectives of the current study are, to investigate whether PC adaptations of the spine, hip and the Centre of pressure (COP) differ between patients reporting Non-Specific Low Back Pain (NSLBP) and asymptomatic controls.

The PC adaption strategies of the thoracic and lumbar spine, the hip and the COP were measured in fifty-seven NSLBP patients and 22 asymptomatic controls. We tested three "feet together" conditions with increasing demands on PC strategies, using inertial measurement units (IMUs) on the spine and a Wii Balance Board for Centre of pressure (COP) parameters.

The differences between NSLBP patients and controls were most apparent when the participants were blindfolded, but remaining on a firm surface. While NSLBP patients had larger thoracic and lumbar spine mean absolute deviations of position (MADpos) in the frontal plane, the same parameters decreased in control subjects (Relative change (RC): 0.23, 95% Confidence interval: 0.03 to 0.45 and 0.03 to 0.48). The Mean absolute deviation of velocity (MADvel) of the thoracic spine in the frontal plane showed a similar and significant effect (RC: 0.12 95%CI: 0.01-0.25). Gender, age and pain during the measurements affected some parameters significantly.

PC adaptions differ between NSLBP patients and asymptomatic controls. The differences are most apparent for the thoracic and lumbar parameters of MADpos, in the frontal plane and while the visual condition was removed.

Keywords:
Non-Specific Low Back pain, Postural Control, frontal plane, sagittal plane, spinal kinematics

Introduction

Postural control (PC) of the trunk when standing is regarded as essential to keep or regain one's body position for stability and orientation, within challenging environments [1]. Postural control strategies are described as a feedback mechanism derived by the interaction of sensory input and adapted motor output [1]. Postural control strategies on firm ground with open eyes predominantly use peripheral or ankle strategies for the sagittal plane [2, 3]. In contrast the frontal plane control-mechanisms are described as proximal or hip loading/unloading strategies [3]. In a recent review changes in postural control sway excursions in patients with Non-specific Low Back Pain (NSLBP) compared to asymptomatic controls were inconsistently reported in previous studies [4]. Some studies showed impaired postural control in the presence of LBP with increased body sway, sway velocity and loss of balance [5, 6] others didn't find any differences in body sway or sway velocity [7, 8]. Possible reasons for these contradictory reports are the differences in tasks and conditions used in those studies [7, 9, 10].

Most studies evaluate centre of pressure (COP) movements using force plate technology [5, 8, 11]. However, range and velocity of segmental adaptations in thoracic, lumbar and hip segments cannot be described by COP variables, as only kinematic models can adequately account for segmental and directional strategies. [6, 9, 10, 12-15]. One recent study used additional kinematic measurements to evaluate hip and trunk control strategies in the sagittal plane while standing [5, 8]. Two electrogoniometers were placed over the first thoracic vertebra and the second sacral vertebra. They assessed sagittal plane kinematics and the mean position of the trunk. The sway of the segments trunk and pelvis was not evaluated. They found, that patients with LBP have larger forward trunk inclination during the PC tasks. Further kinematic measurements of body segments might even better discern differences in PC strategies of LBP patients and asymptomatic controls.

To date, no research evaluated movement of the thoracic and lumbar spine and the hip in the frontal and sagittal plane parallel with COP measurements during standing PC tasks. Therefore the aim of this study was to examine the sway of the thoracic and lumbar spine, the hip and COP during three standing tasks conditions with increasing PC requirements in patients with NSLBP and asymptomatic controls. The research questions were a) does the presence of LBP affects sway and sway velocity and are PC strategies different in asymptomatic controls and those with NSLBP, b) how does changing the task difficulty in terms of visual and surface condition influences sway and sway velocity of the thoracic and lumbar spine, the hip and COP.

Method

Subjects

Participants between 18-65 years were recruited at physiotherapy-practices, the university campus and by newspaper advertisements. Included were patients with NSLBP for longer than 4 weeks with at least moderate disability, defined as an Oswestry-disability-index (ODI) >8% and a low level of having biopsychosocial risk factors defined with less than 4 points in the STarT Back Screening tool [16, 17]. Excluded were subjects with specific LBP, vertigo or disturbance of the equilibrium, systemic diseases (diabetes, tumours), pain in other areas of the body (neck, head, thoracic spine, or arms), complaints, injury, or surgery of the legs (hips to feet) within the last six months, medication affecting postural control (e.g. anti-depressants) and pregnancy. The exclusion criteria for healthy controls were the same as for the LBP-group, and additional no current, and no LBP during the preceding 3 months. The study was approved by the Ethics Committee of the Canton Zurich. All participants signed informed consent prior to the study.

Measurement Systems

Movements of the spine and hip were measured using four inertial measurement units (IMUs), ValedoSensors, Hocoma, Volketswil, Switzerland) at a sampling frequency of 200Hz. The system's validity has been shown before [18]. Sensors were placed on the right tight (RTH), the sacrum (S2), the lower back (L1) and the upper back (T1). The RTH sensor was placed on the line connecting the lateral epicondyle of the femur and the trochanter major. Sensors on the back were placed following the method described by Ernst and colleagues [19].

The COP was measured with a Wii-balance board (WBB, Nintendo Incorporation, Kyoto, Japan) sampling with 200Hz. The WBB is valid for COP measurements [20].

Procedure

Descriptive data and covariates were recorded before assessing the postural control tasks. All participants had to fill in a questionnaire about their physical activity, their bodily and mental stress at work and their education level [21]. LBP patients additionally filled in the Oswestry disability index (ODI) [16].

Subjects were asked to stand stable, arms crossed in front of the chest, in three different conditions in a fixed order of increasing requirements on PC adaptation:

1. feet together on firm surface, eyes open = (Open-Firm)
2. feet together on firm surface, blindfolded = (Blind-Firm)
3. feet together on foam, blindfolded = (Blind-Foam)

Standing tasks lasted for one minute and were repeated three times, for each condition. Pain intensity was recorded after each condition using a numeric rating scale from 0 (no pain) to 10 (maximal pain).

Data processing and analysis:

The IMU sensors consist of an accelerometer, a gyroscope and a magnetometer. Data acquisition was undertaken with the Valedo Research Software (Hocoma, Volketswil, Switzerland). Further calculation and analysis were done using MATLAB (The MathWorks, Inc, Natick, MA, US, Version R2012a). The scaled data from the sensors were converted into quaternions according to Madgwick et al. [22]. Data were then filtered using a fourth-order zero-phase low-pass Butterworth filter with a cut-off frequency of 1Hz. The filtered data were transformed into rotation matrices and then into Tilt-Twist angles, according to Crawford et al. [23]. The hip angle was defined as the differential signal between RTH and S2 (Hip), the lower back angle as the differential signal between S2 and L1 (lumbar spine) and the thorax angle as the differential signal between L1 and T1 (thoracic spine).

The following quantities were calculated: The *mean absolute deviation (MAD)* of the sway position, MADpos, and the *mean absolute deviation* of sway velocity, MADvel, the MAD was computed by

$$MAD = \frac{1}{T}\sum_{i=1}^{T}|x_i - \bar{x}|,$$

with x_i representing the *i*-th sampled signal, $\bar{x}$ the mean signal and T the number of samples. It was decided to take the MAD instead of a root mean square (RMS), as big evasion movement have less influence on the variable.

The variables were calculated for the angular movement of each segment and for the COP excursion in the sagittal and frontal plane. The mean value of the three repetitions was taken for the statistical analysis.

Statistical analysis:

For each MAD, a linear mixed model was fitted to the data with *condition* (Open-Firm, Blind-Firm, and Blind-Foam), *group* (LBP or asymptomatic control) and the interaction (*condition x group)* as fixed effects. Reference levels were "Female" for gender, "Open-Firm" for condition and "Control" for group. "Subject" was included as a random intercept. It was adjusted for gender, BMI, age, pain during the tests, physical and mental stress at work. A stepwise model selection procedure with optimisation of the AIC-criterion was used to eliminate covariates. Random intercept models are equivalent to repeated measures ANOVA and take into account the correlation between repeated measurements. Residual analysis was performed to check the model assumptions. Based on residual analysis, the logs of the outcomes were modelled. The model for observation Y_{ijk},(outcome for condition i, group j, subject$k$ nested in group$j$) was (without other between-group variables)

$$\log Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + U_{kj} + \epsilon_{ijk}, i = 1,2,3; j = 1,2; k = 1,\ldots,n_j,$$

with α_i as the i-th condition effect,β_j as the j-th group effect,$\alpha\beta_{ij}$ as the ij-th group-condition interaction,U_{kj}as the random intercept of subject k in group j (with between-subject variance σ_S^2) and ϵ_{ijk}as within-subject error (with within-subject variance σ_W^2). From the estimated parameters, relative changes with 95%-confidence intervals were calculated, exp (β value of predictor) - 1. The alpha-level of statistical significance was set at 0.05.

The intrasession reliability was assessed calculating the Intraclass Correlation Coefficient (ICC) over the three repetitions.

For statistical computing, R was used (R Development Core Team (2010), R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/).

Results

Fifty-seven patients with NSLBP and 22 asymptomatic controls from Winterthur area (Switzerland) were included (Table 1).

Subjects completed all tests with the exception of condition 3 (Blind-Foam). Three asymptomatic controls and four patients with NSLBP could not remain in the required position for 60s.

Due to technical problems with the sensors there were two missing values in the variables of the hip and lumbar spine, respectively (1 patient, 1 control). Technical problems with the balance board led to missing COP data in six subjects (3 patients, 3 controls).

The ICCs of the three repetitions were between 0.38 to 0.86 for asymptomatic controls and 0.43 to 0.83 for NSLBP patients, with higher values for MADvel.

MADpos showed larger **between-group** differences than MADvel. Patients with NSLBP had generally greater MADpos and higher MADvel than asymptomatic controls (Table 2 and 3). These differences reached statistical significance for MADpos in the lumbar spine in the frontal plane (Relative change -0.19, Table 2).

There were three **interaction** effects (condition x group), all for the frontal plane (Figure 1, Table 2 and 3). Asymptomatic controls and NSLBP patients showed significantly different strategies, when they changed from condition 1(Open-Firm) to condition 2 (Blind-Firm) for the MADpos of the thoracic (Relative change: -0.23) and lumbar spine (Relative change: -0.23) (Table 2, Figure 1). MADvel of the thoracic spine was significantly lower in asymptomatic controls then in subjects with NSLBP (Relative change: -0.12). There were no significant interaction effects in MADpos and MADvel in the sagittal plane for the spinal, hip and COP parameters. There was a tendency for the MADpos parameter for the COP in the sagittal plane (Relative change: -0.14) (Figure 2, Table 2).

In both groups the MADpos and MADvel values of COP, hip, thoracic and lumbar spine parameters increased with the demands of the task condition, and were significantly larger during **condition** “Blind-Foam” than for the two other conditions (Table 2 and 3).

Gender significantly affected trunk and hip movements in the sagittal plane, with women showing greater MADpos (Relative change: 0.17 to 0.39) and higher MADvel (Relative change: 0.13 to 0.21) (Table 2 and 3).

Pain intensity significantly increased MADpos in the frontal plane with 0.03 to 0.07 more sway, $p < 0.05$, for every unit pain on the NRS (Table 2 and 3). Pain also increased MADpos in the sagittal plane but effects were not significant.

Age had a statistically significant effect on MADpos values of the lumbar spine in both planes, and on the hip values in the frontal plane and for MADvel of the lumbar spine and the COP in the sagittal plane. With every year the MADpos and MADvel reduced about 1% ($p < 0.05$).

BMI and bodily or mental stress at work had no significant effect on any MADpos or MADvel variables.

Discussion

Different adaptation strategies in postural control between NSLBP patients and asymptomatic controls were found for frontal plane variables of the trunk when the visual condition changed from open eyes to blindfold. This indicates that NSLBP patients need adaptive PC strategies using trunk movements, while in control subjects hip loading/unloading strategies, with a more stable trunk, suffices. Significant gender and age effects were demonstrated, with less MADpos and slower MADvel in men in six out of eight sagittal plane variables and four out of eight frontal plane variables, indicating that in men spinal adaptations were more uniform than in women. Less MADpos and MADvel with increasing age may reflect an increase in spinal stiffness. The effect of pain intensity during the tests showed Relative Change (RC) of 0.03 to 0.07 for every unit on a Numeric rating scale ranging from 0 to 10, which was significant for some frontal plane variables (p-values only in Table 2 and 3). BMI, physical or mental stress at work did not affect PC.

These significantly different postural control strategies, when changing from Open-firm to Blind-firm condition, were detected only due to the additional use of inertial measurement units attached to the spine and thigh, which measured proximal adaptation strategies of thoracic, lumbar and hip segments.

No group or interaction effects (*group* times *condition*) were found for the COP parameters. Only one parameter in the sagittal plane (MADpos) was found close to significance (RC 0.14, 95% CI: -0.01 to 0.31), but frontal plane COP parameters were far from significance or meaningfulness. This is in line with results by a recent systematic review concerning COP parameters in case-control studies with NSLBP patients and asymptomatic controls [4]. The authors report inconsistent results with a majority of studies demonstrated enlarged sway values in LBP patients whereas other included studies found reduced sway [4].

In one recent study, Brumagne et al. examined additional to COP parameters, spinal parameters at the sacrum and thoracic spine [8]. NSLBP subjects showed more forward inclination of the trunk while standing on a firm surface and expecting muscle vibration at the calf and/or active arm movement tasks.[8]. Frontal plane variables were not reported [8]. Contrary to our findings the differences in postural control strategies between NSLBP patients and controls were most dominant while changing the surface condition [8]. This discrepancy might be due to the fact that we did not test a condition "Open-foam", as we expected a sway increase in NSLBP when the visual condition changed, according to the review by Mazaheri et al. [4]. In the current study all three test conditions were conducted in the "feet together" position, as larger condition effects in frontal plane parameters were expected[24]. Decreasing the base of support by keeping the feet together might affect the frontal plane adaptation strategies, whereas standing on a beam affects sagittal plane adaption strategies [9, 24]. Mazaheri et al. mention only two studies, which examined COP sagittal and frontal plane sway in a feet together position. In both studies the sagittal plane COP parameters differed between NSLBP and controls [25, 26]. This goes in line with results by the current study, in which for the COP parameters in the sagittal plane and for the Blind-Firm condition, a similar tendency has been shown, (RC: 0.14, 95%CI: -0.01 to 0.31, Table 2, Figure 2).

Within the current study, subjects in both groups had the largest condition effect when changing form hard to foam surface, while remaining blindfolded. However no significant between group differences were observed. Changing the somatosensory condition (like the surface condition) has larger effects on COP variables than changing the visual condition alone [2], which is in line with the results of the current study. Changing to Blind-Foam condition affected the velocity in the sagittal COP parameters stronger than the frontal COP parameters, but spinal and hip parameters were more affected within the frontal plane parameters (Table 3). These results suggest that spinal control strategies are generally more needed, when the feet are close together, in the frontal plane [24]. These strategies cannot be observed by COP measurements alone. Frontal plane movements in distal joints are either insufficient (Ankle) or impossible (Knee) which leads to compensational movements of the spine [27]. In the sagittal plane, peripheral control strategies, using combined hip-knee-ankle adaptations while keeping the spine as a functional unit, may be sufficient, [24]. Studies which failed to find significant differences between LBP and controls in standing postural control positions, might have failed as they either did not examine corrective trunk movements, or as the stance width was too wide to provoke these movements. A possible explanation why patients with NSLBP need spinal adaptations within the frontal plane may be an insufficiency in the control mechanism for hip abduction in the frontal plane, as has been shown by Nelson-Wong et al [28]. Another explanation is the reported inability of LBP patients to control a neutral lower back position while performing active movements of the trunk or the lower limbs, which may also be relevant for postural control tasks [29]. Further research exploring these relationships is needed.

The current sample of NSLBP patients showed only minimal disability (ODI-Score: Mean 18%, SD: 6%, Table 1), which may limit the validity of the results [16]. Within the review by Mazaheri et al. the disability level of subjects in included studies ranged from 12.6 to 38.4 %, with a mean value of 23.9%, on the ODI [4]. It might be assumed that larger disability in NSLBP subjects have led to larger differences in PC strategies between groups.

In contrast to many other case-control studies, we included more cases than control subjects, as we expected subgroups within LBP patients with either increased or decreased postural sway in COP parameters according to Mazaheri et al.[4]. However we could not confirm the existence of these subgroups. In our LBP sample the postural sway in COP parameters were almost always larger than for the control group, although the absolute values are small and may not be detectable by naked eye. Absolute values of 0.28-1.04° for MADpos and 0.47-2.49°/s for MADvel in this study were comparable with findings by Gage et al.[30]. We found mean deviation of position more sensitive to discriminate between patients and controls, but mean deviation of velocity showed similar tendency, had higher reliability values, and has been reported as valid and reliable in other studies too [31].

Conclusion

The current study states that increasing standing tasks difficulties affect COP, hip and spine control strategies in both sagittal and frontal planes. The frontal plane postural control mechanism measured directly on the spine using inertial movement sensor technology, differ between NSLBP patients and asymptomatic controls, when visual condition changes. These differences couldn't be detected by COP measurements alone and are valid, if the stance width is small, i.e. feet together. Mean positional sway shows higher discriminatory validity than mean velocity. As frontal plane mechanism are supposed to be dominantly proximal in normal conditions by the hip load-unload strategy, further PC adaptions are only possible even more proximal within the spine, when visual and somatosensory conditions are deprived. Age, gender and pain effects should be considered when comparisons are made between NSLBP patients and asymptomatic controls.

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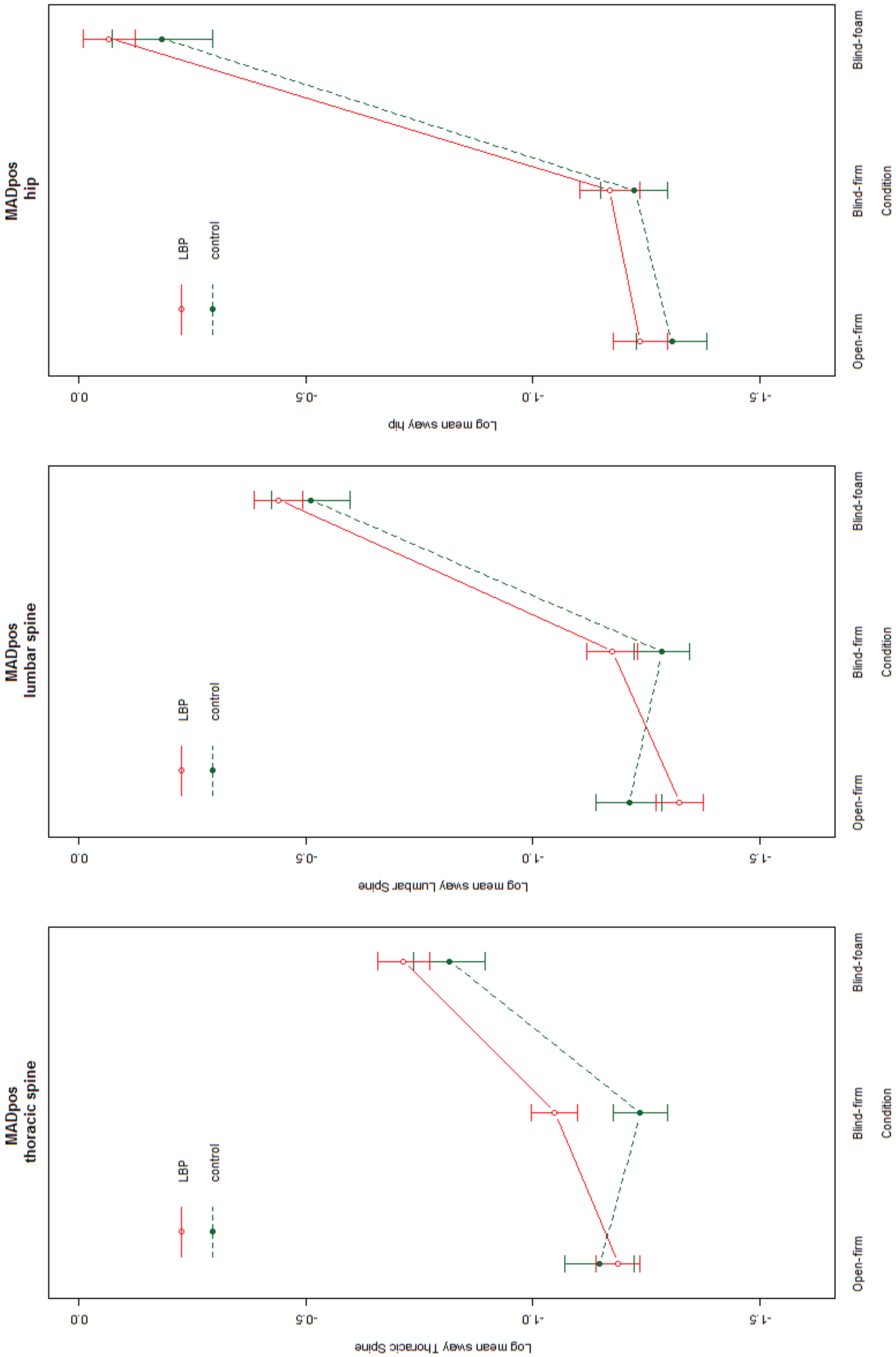
Figure 1: Mean absolute deviation of position (MADpos) in the frontal plane
Values are means and standard error of the mean

Figure 2: Mean absolute deviation of COP position (MADpos) for both sagittal and frontal plane
Values are means and standard error of the mean


MADpos
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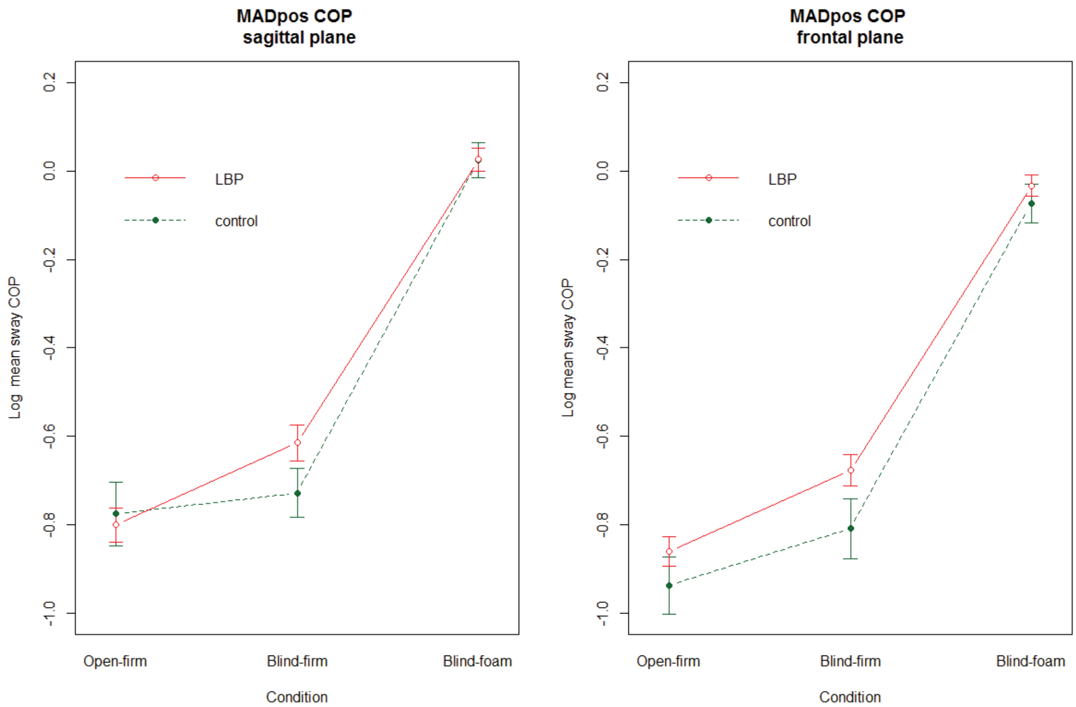
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MADpos COP
frontal plane
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control
Log mean sway COP
Open-firm
Blind-firm
Blind-foam
Condition

Conflict of interest

All contributing authors confirm, that no conflicts of interest exists that may have affected the outcome of the study.

*Research Highligts

Research Highlights

- Reporting about Postural Control strategies in patients with low back pain vary
- We examine spinal kinematics and Centre of pressure in 3 standing tasks
- Patients with low back pain differ in Postural Control strategies from controls
- Frontal plane kinematics of the spine are best distinctive.
- Centre of pressure parameters alone are not sufficient