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Lumbar and thoracic kinematics during step-up: comparison of three-dimensional angles between patients with chronic low back pain and asymptomatic individuals

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Abstract:

While alterations in spinal kinematics have been repeatedly observed in chronic low back pain (CLBP) patients, their exact nature is still unknown. Specifically, there is a need for comprehensive assessments of multi-segment spinal angles during daily-life activities. The purpose of this exploratory study was to characterize three-dimensional angles at the lower lumbar, upper lumbar, lower thoracic and upper thoracic joints in CLBP patients and asymptomatic controls during stepping up with three different step heights. Spinal angles of 10 patients with non-specific CLBP (6 males; 38.7±7.2 years old; 22.3±1.6 kg/m^2) and 11 asymptomatic individuals (6 males; 36.7±5.4 years old; 22.9±3.8 kg/m^2) were measured in a laboratory using a camera-based motion capture system. Seven out of the 12 angle curves had characteristic patterns, leading to the identification of 20 characteristic peaks. Comparing peak amplitudes between groups revealed statistically significantly smaller sagittal- and frontal-plane angles in the patient group at the upper lumbar joint with the two higher steps and at the lower lumbar joint with the higher step. Significantly reduced angles were also observed in sagittal-plane at the upper thoracic joint with the two smaller steps. Moreover, a higher number of significant differences between groups was detected with the two higher steps than with the smallest step. In conclusion, this study showed the value of a comprehensive description of spinal angles during step-up tasks and provided insights into the alterations with CLBP. These preliminary results support prior research suggesting that CLBP rehabilitation should facilitate larger amplitudes of motion during functional activities.

Keywords: amplitude of motion, multi-segment model, functional activity, stairs, pattern

Introduction

The understanding and therapeutic management of chronic low back pain (CLBP), one of the most frequent causes for pain-related disability, remain limited [1,2]. While there is evidence that CLBP patients move with reduced ranges of motion [3,4], improving the characterization of spinal angle alterations is necessary to better understand the role of movement dysfunctions in CLBP and hopefully enhance rehabilitation [5,6].

Asking patients to move their spine as much as possible and assessing lumbar range of motion during these maximum movements is common in clinical practice. However, studies showed that these measures are not sufficient to discriminate patients with CLBP from controls [7,8]. This agrees with recent literature suggesting that spinal movement dysfunction should be characterized during functional activities, to provide more representative measures of motor behaviour alterations [9–13]. Analyzing step-up tasks seems particularly relevant in this regards because steps are performed frequently in daily-life, notably with stairs climbing. Stepping up is also a relevant activity to study because it allows testing standardised movements and increasing the task difficulty by changing the step height. The possibility to increase the complexity of the task has been shown to be particularly valuable in previous CLBP studies testing analytical movements [14,15].

A few studies already analyzed step-up tasks and showed differences in sagittal-plane lumbar angles with CLBP [16,17]. However, none characterized the angles in the three planes of movement at multiple spinal joints. In fact, the three-dimensional angle patterns have still not been described during this functional activity using multi-segment biomechanical models. Additionally, analysing alterations in spinal angles using range of motion measures, as done previously, could mask important information. For example, a prior study on sit-to-stand showed that the peak (i.e., maximum amplitude during a specific period of the movement) flexion at the upper lumbar joint during the first phase of the postural transition and the peak extension at the lower lumbar joint at the end of the transition differ between CLBP patients and asymptomatic controls [10]. Analysing only the ranges of motion would not have allowed detecting alterations at these two joints. Furthermore, this prior sit-to-stand study and others suggested that alterations of spinal angles in CLBP are best appraised using multi-segment spinal models, including at least two lumbar and two thoracic segments [10,18–21].

Thus, the primary objectives of this study were to characterize the three-dimensional spinal angles at the lower lumbar, upper lumbar, lower thoracic and upper thoracic joints in CLBP patients and asymptomatic controls during stepping up on three different step heights. Second, to assess the relevance of testing step-up tasks within the framework of CLBP, the following hypotheses were tested: 1) CLBP patients have specific amplitude reductions at certain joints and in certain planes in comparison to controls, 2) increasing step height increase the number of measures differing between groups.

Methods

Participants

This case-control study (Level III) prospectively enrolled 11 patients with non-specific CLBP. Patients were recruited through a physiotherapy private practice or through rheumatologic consultations at the University Hospital. Inclusion criteria were a medical diagnosis of pain in the lower back for more than three months with or without leg pain, an age between 30 to 50 years old and body mass index (BMI) between 18 and 27 kg/m^2. Exclusion criteria for this group were the presence of infection, rheumatological or neurological diseases, spinal fractures, any known spinal deformities, history of back surgery, tumours or radicular symptoms. Eleven asymptomatic controls matched for age, sex and BMI without history of low back pain requiring medical attention during the last two years were included in a second time. Individuals were excluded from the study in cases of pain or injury in any other body parts that could compromise the evaluation of spinal motion and in case of pregnancy.

Motion data from one patient was corrupted, therefore statistical analyses were performed on 10 patients and 11 controls. There were no significant differences in age, weight, height and BMI between the patient and control groups ($p>0.4$) (Table 1). Based on their Oswestry Disability Index (ODI) score, half of the patients had minimal disability and the other half had moderate disability [22–24]. Furthermore, the patient group had a mean score on the Tampa Scale of Kinesiophobia (TSK) higher than 40, indicating kinesiophobia. The study population overlaps with prior works on sit-to-stand and gait [10,11]. The research was approved by the local Research Ethics Committee and all participants signed an informed consent form before enrolment in the study.

Experimental procedures

After verification of the inclusion and exclusion criteria, the experimental procedure started with the anthropometric assessment (Table 1). Patients' average and maximum pain during the 24 hours preceding the movements recording were also documented using the Numeric Pain Rating Scale (NPRS).

Spinal angles were then measured using an optoelectronic motion capture system with 14 cameras recording marker positions at 120Hz (VICON, Oxford Metrics, UK). Reflective markers were attached to the participants by the same experienced physiotherapist following a previously described protocol (Fig. 1a) [10,11,25]. Five markers were placed on the spinous processes of T1, T6, L1, L3 and L5. Two markers were next placed between each pair of successive spinous process markers, at a distance of 5 cm on the left and right sides of the spine. Markers were also placed bilaterally on the posterior superior iliac spine, the anterior superior iliac spine and the tip of the iliac crest. Two additional markers were attached to the lateral side of each heel. After markers placement, a reference standing posture was collected, where participants stood upright, looking forward with arms elevated at 90° of shoulder abduction. Spinal angles (described below in section 2.3) during the reference posture were not statistically significantly different between groups ($p>0.4$).

Participants were then asked, with standardized instructions, to step up on boxes of three different heights, every time with the same foot, at their normal self-selected speed. All participants except one placed the right foot first on the boxes. The height of the small step (Sstep) was 23cm, the medium step (Mstep) 36cm and the big step (Bstep) 47cm, and all participants did the experiment in this order. Steps heights were selected to correspond to 1.0, 1.5 and 2.0 times the usual stair height. The distance between the starting position and the step was marked on the floor to have the same starting position for each trial. For each step height, participants practiced the movement between one and three times and once they felt confident, three trials were recorded. At the end of the three trials, pain experienced during stepping up was measured with the NPRS for the patient group. Eighty percent of CLBP patients were pain-free during Sstep and Mstep and 70% were pain-free during Bstep. At the end of the measurement, the ODI and TSK were used to document disability and kinesiophobia (Table 1) [26,24,27,28].

Data processing

Spinal angles were quantified using a previously described five-segment biomechanical model, including the pelvis and the lower lumbar, upper lumbar, lower thoracic and upper thoracic spine (Fig. 1a) [10,25,29]. In brief, the orientation of the anatomical frame embedded in each segment was calculated using markers trajectories [30]. Three-dimensional angles at the lower lumbar (LLS), upper lumbar joint (ULS), lower thoracic (LTS), and upper thoracic (UTS) joints were calculated using the anatomical frame orientations and the joint coordinate system, with a sagittal, frontal and transverse angles sequence [31]. Angles were low-pass filtered at 15 Hz using a Butterworth filter. Sagittal-plane angles were expressed as flexion-extension, whereas frontal- and transverse-plane angles were reported relative to the stepping side (i.e., ipsilateral-contralateral bending and ipsilateral-contralateral rotation). The start and end of each trial were determined visually by a single investigator based on the lateral displacement of the iliac crests markers. These features were selected because they correspond to the beginning and end of the lateral weight shift that is characteristic of the entire step-up tasks. Additionally, to link the spinal angles to the lower-limbs motion, the periods of foot elevation were determined for each trial by the same operator using the vertical displacement of the heel markers (Fig 1b). The three-dimensional angle curves and the elevation periods were time-normalized to 0-100% between the start and end of each trial. Curve normalizations were achieved by linear interpolations (original curves had temporal resolution three times higher than normalized curves). As inter-individual variations in morphology could offset the spinal angles, the joint angle amplitudes during the reference standing posture were subtracted from the time-normalized angle curves. All calculations were performed with Matlab (R2013b, MathWorks, Inc, Natick, MA).

Statistical analysis

In order to identify the characteristic features of the spinal angles during stepping up, the consistency of the angle patterns was assessed in the control group separately for each step height, joint and plane using the coefficient of multiple correlation (CMC) as described in details in previous works [10,32,33]. Angles reporting a consistent pattern (CMC above 0.5) for the three step heights were considered as representative of spinal motion during stepping up and were screened to identify their characteristic minimum and maximum peaks. Once the characteristic peaks were listed, all trials from all participants were processed to record the amplitudes of the peaks as well as the ranges between peaks. Reliability of the amplitude measurements between trials was assessed using the intraclass correlation coefficient of variation (ICC 2,1) and the standard error of measurement (SEM). Next, the mean amplitudes and ranges were calculated over the three trials of each step height to have only one data point per participant, step height and variable of interest. These data were used to test the hypotheses of differences between groups and step heights. Assumption of normal distribution was assessed by the Shapiro-Wilk test and data were found to follow non-normal distributions [34]. Therefore, the mean amplitudes and ranges of the CLBP and control participants were compared using nonparametric Mann-Whitney U tests. Statistical analyses were performed with SPSS (Version 23, IBM, NY, USA), using a significance level set *a priori* at $\alpha < 0.05$. No correction for multiple comparisons was performed due to the exploratory nature of this study primarily aiming at characterizing the three-dimensional pattern of spinal angles during stepping up.

Results

On average, the step-up tasks lasted 2.9 sec (standard deviation: 0.5 sec). The elevation periods of the first and second feet were from 6.5 (4.4) to 38.4 (5.9) and from 41.9 (6.4) to 81.8 (6.5) percent of the trial duration, respectively (Fig. 1b).

From the control group data, seven out of the 12 angle curves had typical patterns during stepping up, with 20 characteristic peaks and 13 peak-to-peak ranges (Fig. 2). In the sagittal plane, all four joints reported CMC equal or above 0.55 with similar patterns across step heights. The lower lumbar (LLS), upper lumbar (ULS) and lower thoracic (LTS) joints typically demonstrated a first phase of flexion followed by a phase of extension. The upper thoracic joint pattern was characterized by two phases of flexion at the beginning and the end of stepping up, with a phase of extension in the middle. In the frontal plane, consistent angle patterns were found only at the upper lumbar (ULS) and lower thoracic (LTS) joints (CMC $\geq$ 0.60). Patterns were similar across step heights and, for both joints, consisted in ipsilateral bending (with the side of the first foot to step up) followed by contralateral bending. Finally, only the upper thoracic (UTS) joint showed a consistent pattern in the transverse plane (CMC $\geq$ 0.64). The transverse-plane UTS pattern were similar across step heights, with a succession of contralateral and ipsilateral rotations.

Using data from all participants, reliability analysis indicated median [interquartile range (IQR)] ICC of 0.85 [0.80 to 0.92] and median SEM of 1.19° [0.87 to 1.56] for the angle variables during Bstep. For Mstep, median ICC and SEM were 0.90 [0.84 to

0.96] and 1.02° [0.66 to 1.47], and for Sstep they were 0.92 [0.85 to 0.94] and 0.84° [0.61 to 1.30], respectively.

Statistically significant differences between groups were observed in sagittal-plane angles with the three step heights (Bstep, Mstep and Sstep) and in frontal-plane angles with Bstep and Mstep (Table 2). In the sagittal plane, the peak flexion at the upper lumbar joint (ULS_{min}) was smaller in the patient group compared to the control group during Bstep and Mstep, with a median difference of 10.8° (p=0.03) and 8.1° (p=0.05), respectively. Furthermore, the CLBP patients had smaller upper lumbar initial (ULS_{range_i}) and final (ULS_{range_f}) ranges, with median differences of 10.0° (p=0.001) and 6.4° (p=0.002) during Bstep and of 4.3° (p=0.01) and 6.1° (p=0.04) during Mstep. In addition, the second peak extension at the lower lumbar joint (LLS_{max_f}) was smaller in CLBP patients by 6.2° in median during Bstep (p=0.05). The sagittal-plane upper thoracic angles also differed between the groups. CLBP patients showed larger extension peaks (UTS_{max}) during Mstep (median differences of 2.0° (p=0.03)) and Sstep (2.0° (p=0.02)). Furthermore, CLBP patients demonstrated smaller final flexion peaks (UTS_{min_f}) during Mstep (median differences of 2.0° (p=0.02)) and Sstep (3.2°,p=0.01). Smaller initial flexion peak (UTS_{min_i}) was also observed during Sstep, by 1.9° in median (p=0.02).

In the frontal plane, CLBP patients stepped up with smaller upper lumbar initial range (ULS_{range_i}) during Bstep (median difference of 2.3° (p=0.04)) and Mstep (median difference of 2.1° (p=0.04)). Additionally, in the frontal plane, the final lower thoracic range (LTS_{range_f}) was smaller in patients than controls by 1.2° in median (p=0.05) during Bstep. Very small amplitudes of movement and no statistically significant differences between groups were noted in the transverse plane.

Discussion

This study described the characteristic patterns of multi-segment spinal angles during stepping up and confirmed the hypothesis that CLBP patients have specific amplitudes reduction at certain joints and in certain planes compared to asymptomatic controls. These results stressed the value of comprehensive analysis of spinal angles during step-up tasks within the framework of CLBP and brought new insight into the dysfunctions with CLBP in the lumbar and thoracic regions.

Regarding the lumbar spine, CLBP patients reported smaller flexion peak and smaller ranges of motion in the sagittal plane at the upper lumbar joint with the two higher steps. The differences between groups were large, with asymptomatic controls having twice as much amplitude than patients during Bstep. While previous research showed reduced sagittal-plane amplitudes in CLBP patients, this study suggested that the deficits are associated with a lack of lumbar peak flexion during the elevation of the second foot. Further studies will be necessary to understand why patients adopted this strategy. Plausible explanations might be an attempt to reduce symptoms with trunk flexion, fear of moving or reorganization of motor tasks planning [35]. CLBP patients also demonstrated a lack of peak extension at the end of stepping up (when both feet are on the step) at the lower lumbar joint during Bstep, which is consistent with previous research on sit-to-stand [10]. In these two functional activities, the lower lumbar joint is characterized by a succession of flexion and extension, suggesting that CLBP patients may have difficulties to move from a flexed position to an extended position at the lower lumbar spine during functional tasks.

Differences between groups in frontal-plane lumbar angles were also observed during Mstep and Bstep. Specifically, the initial upper lumbar range was smaller by a third in the CLBP group. This difference is interesting because it highlights the fact that patients perform functional activities with smaller angles, both in primary and secondary planes of movement. This is consistent with recent research on other daily-life activities, namely gait and step-down tasks, where reduced lower lumbar lateral bending was also reported [11,13]. Previous studies on stepping up did not report group differences in the frontal plane [16,17,36]. These discrepancies with our results might be explained by the more comprehensive analysis done in the present study that allowed comparing groups with more representative variables than the overall ranges used in prior works.

This study also stressed that angle alterations with CLBP are not only occurring in the lumbar spine. Indeed, the sagittal-plane upper thoracic angles were different between CLBP patients and controls, with patients demonstrating more extension and less flexion during Mstep and Sstep. This observation of a shift towards extension in patients could be related to the head position. Therefore, it could be useful to record the movement of the head in future studies on stepping up as it could influence upper thoracic angles. The group differences observed in thoracic angles corroborate with prior literature that showed alterations of upper or lower thoracic kinematics during other functional activities [10,11,20,37]. Therefore, they highlight the need to assess and manage spinal kinematics in CLBP patients with consideration for the entire spine.

According to our second hypothesis, a higher number of statistical differences was observed in Bstep and Mstep than in Sstep. However, upper thoracic differences were only found in Mstep and Sstep. Therefore, changing step height might affect the region (lumbar or thoracic) where angle alterations can be detected, and possibly increase or decrease the between groups differences. These results also suggested that more difficult or unusual functional activities might increase the alterations, as previously shown with analytical movements [14,15].

The very small amplitudes and lack of consistent patterns in the transverse plane suggested that stepping up does not involve much rotation. This does not mean that transverse-plane angles are irrelevant in the study and treatment of CLBP, but that other activities should be considered to evaluate and improve transverse-plane movements. For example, previous research reported angle differences between CLBP patients and controls in the transverse plane at the lower thoracic joint during gait [11,37]. Hence, different functional activities soliciting different spinal regions in different planes and with variation in the task demand may be necessary to have a comprehensive assessment and effectively rehabilitate spinal kinematics in CLBP.

The agreement between the present results and prior complementary research allows discussing some clinical implications. Firstly, as stepping up was not painful in most CLBP patients, it supports the idea that alterations in kinematics are not only due to painful stimuli [35,38]. Therefore, it is possible that motor behaviour is altered in many activities of daily living, and not only in painful ones. Secondly, and in association with previous research, the smaller angles at the lower and upper lumbar joints support the hypothesis of reduced spinal motion in CLBP patients during functional activities [3,10,11,16]. Interestingly, it seems that CLBP patients move with less amplitudes of motion during functional activities, even though these activities only require a portion of the total spinal range of motion [39]. This suggests that rehabilitation should facilitate larger spinal amplitudes of motion during functional activities, and not only during analytical movements. Nonetheless, it should be noted that little literature is available regarding the causes of the kinematic alterations. Future research should thus investigate which factors need to be targeted to improve motor performance in CLBP patients.

Several limitations to the current study need to be discussed. First, the small sample size could have prevented the identification of additional characteristic features or have resulted in mistaken feature identifications. Similarly, it could have masked additional group differences, and one cannot exclude that the statistical significance of some differences could have been overinterpreted due to the exploratory nature of this study. Consequently, now that the value of a comprehensive assessment of spinal angles during stepping up tasks has been shown, further research with larger sample size are warranted to better understand CLBP motor alterations. Second, the cross-sectional study design excludes determining any causal relationship, such as understanding if a change in symptoms and disability would affect spinal angles and vice-versa. Third, the mathematics of the spinal biomechanical model and soft tissue artefacts could have led to errors of measurement and misinterpretations. Nevertheless, the reliability presented in the current study demonstrated median SEM values of less than 1.2°, below all statistically significant group differences. Fourth, the start and end of the stepping up, as well as the periods of foot elevation, were determined by visual inspection of the marker trajectories. While partially subjective, this method was sufficient with respect to the present objectives and statistical analyses. Additional work is nonetheless required to automatize the detection of temporal events during step-up tasks as previously done for walking [40]. Finally, this study aimed to characterize spinal angles and compare CLBP patients and asymptomatic controls in terms of amplitudes of motion. Complementary understanding could be gained by analysing other descriptors of spinal kinematics in future studies, such as patterns of movement, coordination, variability and angular velocity or acceleration [7].

In conclusion, this study showed the value of a comprehensive description of spinal angles during step-up tasks and provided insights into the alterations with CLBP. Patients had less upper lumbar flexion and lateral bending during the first 60% of stepping up. Furthermore, reduced amplitudes of movement in the sagittal and frontal planes were observed at the lower and upper thoracic joints, suggesting that the lack of lumbar movement was not compensated in the thoracic spine. Additionally, varying step height might affect the region (lumbar or thoracic) where angle alterations can be detected, and possibly increase or decrease the between groups differences. Future works are encouraged to use the characteristic peaks identified in this study, rather than overall ranges of motion, to quantify spinal angles during stepping up.

Conflict of interest statement

The authors have no conflict of interest with this work.

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Table 1: Participant characteristics.

	CLBP patients	**Asymptomatic controls**	**P-value**
Sex (n)	6M, 4F	6M, 5F	0.85
Age (years)	38.7 ± 7.2	36.7 ± 5.4	0.43
Weight (kg)	67.8 ± 8.9	69.5 ± 9.8	0.70
Height (m)	1.74 ± 0.07	1.74 ± 0.05	0.95
BMI (kg/m^2)	22.3 ± 1.6	22.9 ± 3.8	0.63
Duration of LBP (months)	116 ± 86	-	
ODI	24.2 ± 9.8	-	
TSK	40.3 ± 8.9		

Average NPRS during the 24 hours preceding the test	3.7 ± 2.0	-
Maximum NPRS during the 24 hours preceding the test	5.2 ± 2.4	-

Data are presented either as numbers of male (M) and female (F), or as mean ± standard deviation. The p-values reported in the most right column correspond to the comparison of both groups (t-tests or Chi square test). BMI: Body Mass Index; ODI: Oswestry Disability Index; TSK: Tampa scale of kinesiophobia; NPRS: Numeric Pain Rating Scale.

Table 2: Amplitude of the characteristic angle peaks with significant differences between groups

Step	**Plan**	**Variable**	**CLBP patients**		**Asymptomatic controls**		**p-value**
			Median	**IQR**	**Median**	**IQR**	
Sstep	Sagittal	UTSmax	-0.8	[-1.2 - 0.5]	-2.8	[-4.6 - -1.0]	0.02
		UTSmin_i	-3.3	[-4.8 - -1.7]	-5.2	[-7.3 - -3.9]	0.02
		UTSmin_f	-2.2	[-3.9 - -1.2]	-5.4	[-7.5 - -3.7]	0.01
Mstep	Sagittal	ULSmin	-5.8	[-13.7 - -1.8]	-13.9	[-15.0 - -9.8]	0.05
		ULSrange_i	7.8	[4.1 - 10.8]	12.1	[10.6 - 18.5]	0.01
		ULSrange_f	5.3	[3.5 - 11.6]	11.4	[7.8 - 16.2]	0.04
		UTSmax	0.4	[-0.3 - 3.2]	-1.6	[-2.7 - 0.3]	0.03
		UTSmin_f	-2.9	[-4.1 - -1.0]	-5.0	[-7.5 - -3.9]	0.02
	Frontal	ULSrange_i	4.5	[3.6 - 6.6]	6.6	[4.8 - 8.1]	0.04
Bstep	Sagitta	LLSmax_f	-0.4	[-1.5 - 2.7]	5.8	[0.9 - 8.0]	0.05

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	ULSmin	-5.8	[	-16.7	-	-3.6	]	-16.6	[	-19.7	-	-11.8	]	0.03
	ULSrange_i	8.0	[	5.7	-	10.9	]	18.0	[	10.7	-	20.1	]	0.001
	ULSrange_f	6.2	[	4.2	-	11.4	]	12.6	[	11.4	-	18.2	]	0.002
Frontal	ULSrange_i	5.0	[	3.2	-	7.6	]	7.3	[	6.3	-	9.0	]	0.04
	LTSrange_f	5.3	[	3.7	-	5.8	]	6.5	[	5.2	-	8.2	]	0.05

The UTS, LTS, ULS and LLS abbreviations correspond to the upper thoracic, lower thoracic, upper lumbar and lower lumbar joints, respectively. For an illustration of the various characteristic peaks (“max” & “min”), please refer to Figure 2. “range_i” corresponds to initial range (difference between the first and second peak), and “range_f” to final range (difference between the second and the third peak). IQR: interquartile range. All data, except p-values, are in degrees.

Figure 1: a) Illustration of the five-segment spinal model. UTS: upper thoracic joint; LTS: lower thoracic joint; ULS: upper lumbar joint; LLS: lower lumbar joint b) Illustration of the periods of foot elevation for a stepping up movement normalized to 0-100% of its duration.

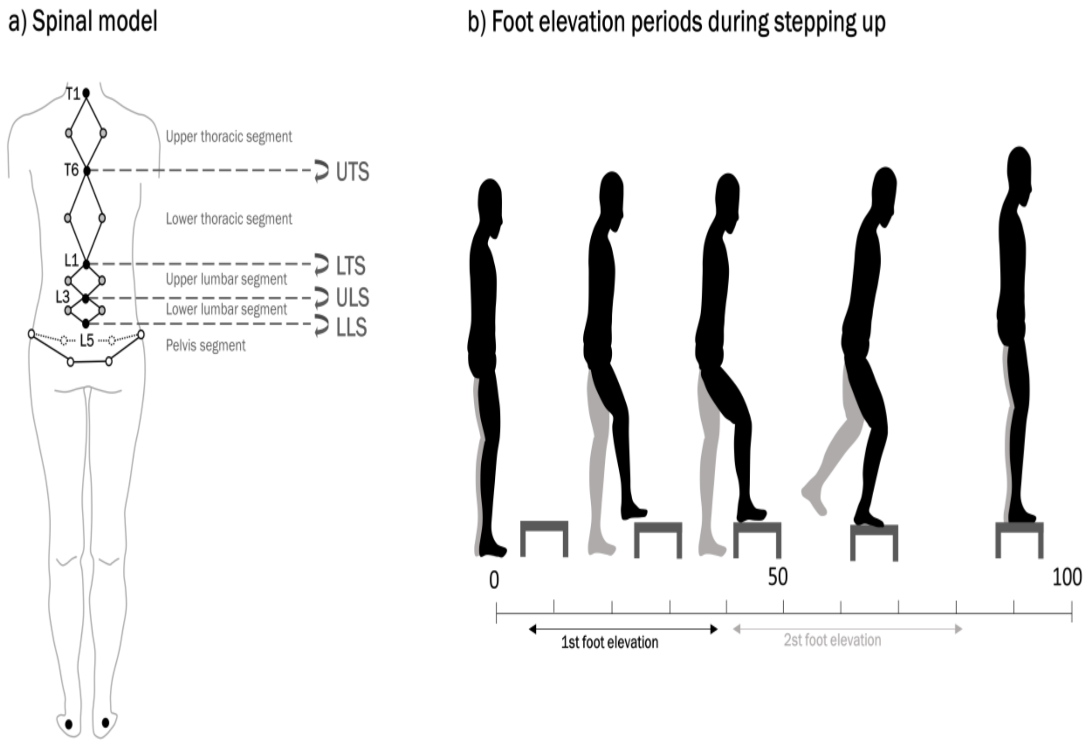
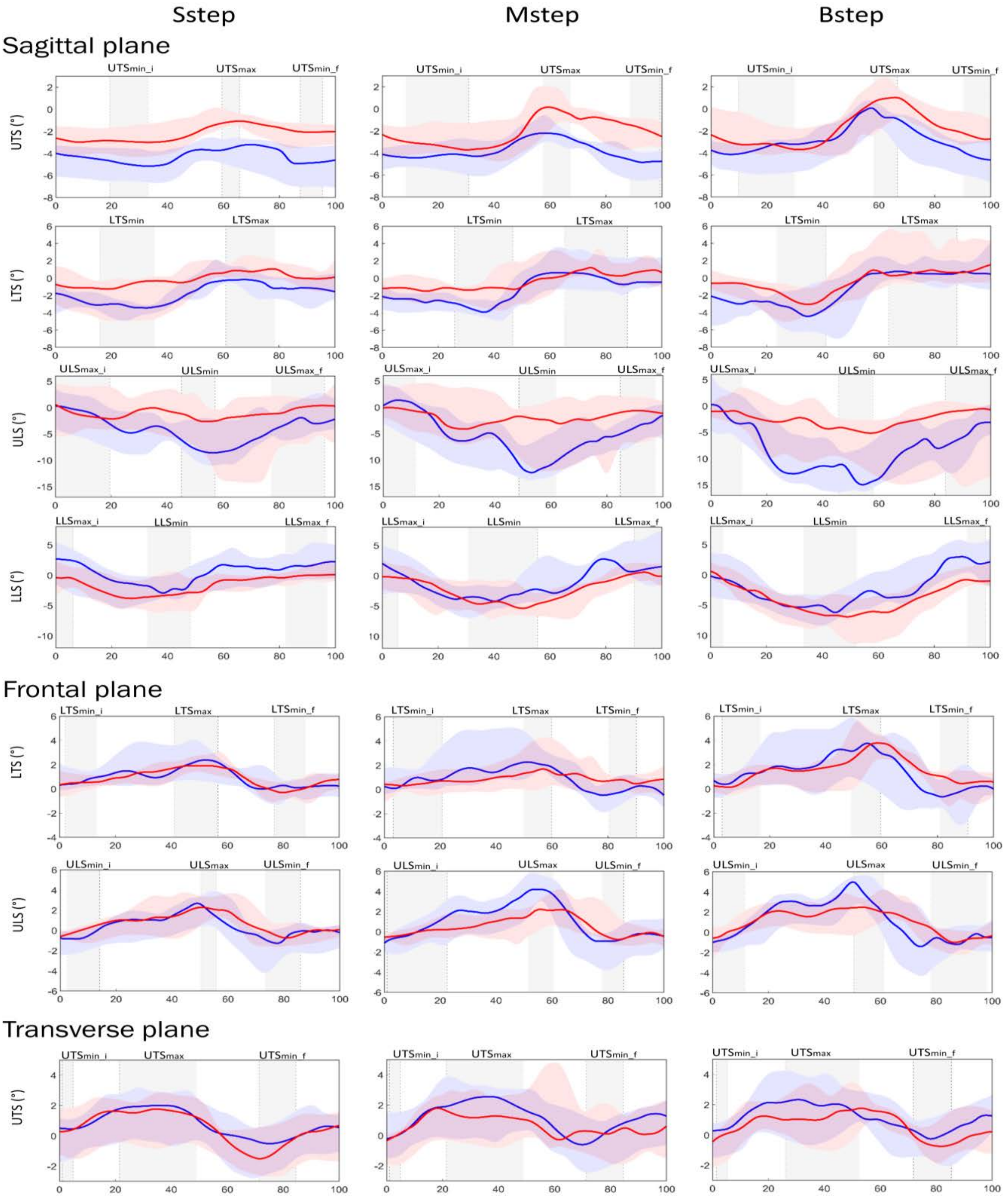


Figure 2: Median sagittal, frontal and transverse planes angle curves for the CLBP patient group (in red) and the asymptomatic control group (in blue). Positive values represent extension, ipsilateral bending and contralateral rotation. The light grey areas correspond to the time occurrence (interquartile range) of each of the characteristic peaks used to describe the angles. Vertical axes are in degrees (°) and horizontal axes in percentage of the movement duration. UTS: upper thoracic joint; LTS: lower thoracic joint; ULS: upper lumbar joint; LLS: lower lumbar joint.


Sstep
Mstep
Bstep
Sagittal plane
UTSmin_i
UTSmax
UTSmin_f
UTS (°)
LTSmin
LTSmax
LTS (°)
ULSmax_i
ULSmin
ULSmax_f
ULS (°)
LLSmax_i
LLSmin
LLSmax_f
LLS (°)
Frontal plane
LTSmin_i
LTSmax
LTSmin_f
LTS (°)
ULSmin_i
ULSmax
ULSmin_f
ULS (°)
Transverse plane
UTSmin_i
UTSmax
UTSmin_f
UTS (°)