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# Between/within-session reliability of spinal kinematic and lumbar muscle activity measures in patients with chronic low back pain and asymptomatic individuals

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ABSTRACT

*Background:* Longitudinal research is required to better understand the role of spinal movement alterations in chronic low back pain (CLBP). To this end, it is critical to assess the between-session reliability of spinal movement measures.
*Research question:* What is the within/between-session reliability of spinal movement measures in patients with CLBP and asymptomatic controls?
*Methods:* Spinal movement was recorded prospectively during two sessions, a week apart, for 20 patients with CLBP (60% male; 40.0 ± 12.3 years old) and 20 asymptomatic individuals (55% male; 38.2 ± 10.9 years old). Sagittal-plane angular amplitude and angular velocity at the lower lumbar, upper lumbar, lower thoracic and upper thoracic joints, as well as maximal erector spinae activity were measured during five daily-activity tasks. In addition, task-independent measures were obtained by averaging the measures across tasks. The Intraclass Correlation Coefficient (ICC 2,1) and the minimal detectable change (MDC) were calculated. Pearson correlation was used to compare task-independent and task-specific measures.
*Results:* Between-session ICCs in patients with CLBP were mostly moderate to good for maximal angular amplitude and erector spinae activity measures. Lower ICCs were observed for range of angular motion and angular velocity measures (42% of ICCs $< 0.5$). Median MDCs were 9.6°, 18.3°/s and 1.0% for angular amplitude, angular velocity and erector spinae activity measures, respectively. The reliability of task-independent and task-specific measures was strongly correlated ($r = 0.91$, $p < 0.001$).
*Significance:* Sagittal-plane maximal angular amplitude and erector spinae activity measures during various daily-activity tasks demonstrated mostly moderate to good between-session ICCs. However, relatively large MDCs suggested that important changes are needed to be detectable. Task-independent measures reported similarly acceptable ICCs than task-specific measures, supporting their use to describe spinal movement.

## 1. Introduction

The understanding of chronic low back pain (CLBP), a frequent causes of disability worldwide, remains limited [1]. While alterations in spinal movement have been suggested as one of the key physical factors in CLBP [2,3], with differences frequently reported between individuals with and without CLBP [4,5], the role of spinal movement in CLBP persistence and recovery remains poorly understood. Clarifying this relationship will notably require longitudinal research, which raises the question of the reliability of movement measures in repeated study designs. Indeed, a reliability assessment is critical beforehand to decide which measures to include in longitudinal evaluation as well as afterward to correctly interpret the results.

Prior research on spinal movement in CLBP highlighted two particularly relevant categories of measures for longitudinal studies. The first category corresponds to the measures of sagittal-plane lumbar angular amplitude and angular velocity, that have been consistently found to be reduced in patients with CLBP [4–6]. Recent research recommends to

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assess them during daily-activity tasks using multi-segment spinal models [7–11]. Despite a few studies reporting the between-session reliability of spinal kinematic measures, a comprehensive assessment remains strongly needed. In fact, so far, reliability studies for camera-based motion capture allowing three-dimensional multi-segment description included only asymptomatic participants [12–16], did not use multi-segment models [15–17] or ignored the angular velocity measures [12–15,17]. The second category of particularly relevant measures for longitudinal studies concerns the activity level of the erector spinae muscles during dynamic tasks [18–20]. Although the reliability of fatigue measures has been well quantified for these muscles [21], data are missing regarding the reliability of activity level measures during daily-activity tasks [5].

Recently, an individual movement signature was highlighted in CLBP patients, with consistent angular amplitude, angular velocity and muscle activity measures among various functional tasks [11]. Based on this finding, task-independent measures were proposed, consisting in an "average" of the measures obtained with multiple tasks. Task-independent measures could provide several advantages, including the fact of describing the general function of an individual (i.e., reveal his/her movement signature), facilitating the selection of the tasks to measure, as well as simplifying the statistical analysis and data interpretation. Yet, task-independent measures have been introduced lately and there is a need to assess their reliability.

The first objective of this study was to assess the between-session reliability of spinal movement measures during daily-activity tasks in patients with CLBP. This study also aimed to evaluate the within-session reliability and assess the reliability in asymptomatic individuals, as it may inform other study designs (i.e. case-control studies). A second objective was to compare the reliability of task-independent and task-specific measures. Sagittal-plane multi-segment lumbar and thoracic angular amplitude and velocity measures as well as level of erector spinae muscles activity measures were considered following recommendation in prior works [4,7,9–11].

## 2. Methods

### 2.1. Participants

Based on previous reliability assessments and guidelines for sample size [12,14,16,22], 20 patients with CLBP (60% male; 40.0 ± 12.3 years old; Body Mass Index (BMI) of 26.4 ± 2.7 kg/m$^2$) and 20 asymptomatic individuals (55% male; 38.2 ± 10.9 years old; BMI of 22.7 ± 2.8 kg/m$^2$) were included in this study. Patients were recruited at the local university hospital and physiotherapy practices and asymptomatic individuals were recruited from the local community through flyers and emails. Males and females with sufficient French level aged between 18 and 65 years old could participate to the study. General exclusion criteria included pregnancy, a BMI above 32 kg/m$^2$ and other concomitant pain or condition that could compromise the evaluation of spinal movement. To be included, patients with CLBP had to have a diagnosis of non-specific LBP with or without leg pain for more than three months. They were excluded in the presence of a diagnosis of specific LBP and/or previous back surgery limiting spinal mobility (i.e. spinal fusion). Inclusion criteria for asymptomatic individuals was no history of LBP requiring third-party attention during the last two years and no current or recent experience of LBP. The research was approved by the local Research Ethics Committee (CER-VD 2018–00188) and all participants signed an informed consent form before enrolment in the study.

### 2.2. Experimental procedures

Participants were invited to the movement analysis laboratory at the university hospital for two measurement sessions separated by one week (7.1 ± 0.3 days later). Patients followed their usual routine between the two sessions. The study included three sets of spinal movement measurement: two sets during the first session (S1 and S2) and one set during the second session (S3). During the first session, participants with CLBP completed questionnaires to document disability, kinesiophobia and catastrophizing using the Oswestry Disability Index (ODI), the Tampa Scale of Kinesiophobia (TSK) and the Pain Catastrophizing Scale (PCS), respectively [23–26]. Mean pain intensity during the last 24 h was measured at the start of both sessions with the Numeric Pain Rating Scale (NPRS-24 h) [27].

Spinal movement was measured following a previously described methodology [7–9,11]. In brief, at the beginning of each session, two pairs of electrodes were attached on the erector spinae muscles. They were placed 3 cm left and right to the spine at the level of the L3 spinous process. Next, participants performed one submaximal voluntary contraction in crook lying for the normalisation of the muscle activity signals. For that, they were instructed to bend their knees to 90° and lift their thighs 0.05 m off the table during three seconds. Submaximal contraction was chosen for the normalisation because its reliability was shown to be superior to maximal contraction in patients with CLBP [28]. Reflective markers were then attached to the pelvis, lumbar and thoracic segments following prior publications [7–9,29] (Fig. 1). To decrease placement errors between sessions, the marker-to-marker distances as well as the distances between the pelvis markers and the floor were documented during the first session and used when placing the markers during the second session. A single experienced physiotherapist conducted all the experiments.

Once participants were equipped (S1 and S3), five daily-life tasks were recorded in the following order: standing flexion, sit-to-stand, stepping-up on a 36 cm high step, picking-up a sponge from the floor and lifting a 4.5 kg box from the floor. Each functional activity was recorded three times, except for picking-up that was recorded ten times for the purpose of another study. Marker trajectories and muscle activities were measured using an optoelectronic motion capture system (Vicon, Oxford Metrics, Oxford, UK) and an electromyography device (Myon, Schwarzenberg, CH) recording synchronously at 120 Hz and 1200 Hz, respectively. Details on the tasks and the instructions given to the participants are available in Supplementary Materials. At the end of each task, the participants rated their mean pain during the task with a Numeric Pain Rating Scale (NPRS-mov). In session 1, participants repeated the measurements of the five tasks without replacement of the electrodes or markers (S2).

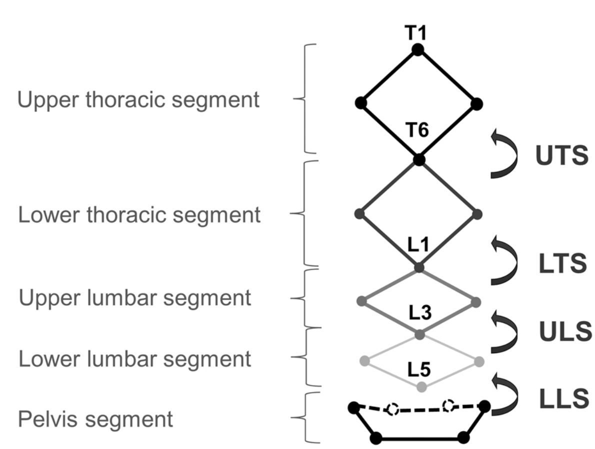


**Fig. 1.** Markers' placement and model description. Central spine markers were placed on the spinous processes of L5, L3, L1, T6 and T1. Lateral markers were placed in-between central markers 5 cm on each side of the spine. Pelvis markers were placed at the posterior superior iliac spines, anterior superior iliac spines and tip of each iliac crest. LLS: Lower lumbar joint; ULS: upper lumbar joint; LTS: lower thoracic joint; UTS: upper thoracic joint.

### 2.3. Data processing

Spinal angles and angular velocities were calculated using a five-segment biomechanical model [7–9] (Fig. 1). Specifically, the flexion-extension angle curves at the lower lumbar (LLSa), upper lumbar (ULSa), lower thoracic (LTSa) and upper thoracic (UTSa) joints were calculated for the entirety of the tasks based on the marker trajectories. Angular velocity curves (LLSv, ULSv, LTSv and UTSv) were obtained by numerical differentiation of the angle curves.

Electromyography recordings were band-pass filtered (Butterworth 20–450 Hz) and rectified. The signals were then normalised for each set of measurement using the minimal amplitude recorded during the set as 0% and the amplitude recorded during the submaximal voluntary contraction as 100% (see [11] for details).

Curves were time-normalised to 0–100% for each repetition of each task. The start and end of the tasks were determined visually using strict criteria based on marker trajectories [7,9]. Discrete measures were extracted from the angular amplitude, angular velocity and muscle activity curves to describe the movements. Following prior publications, [7,9,11], up to 8 measures of angular amplitude, 12 measures of angular velocity and 2 measures of muscle activity were obtained per recording (Table 1). The measures obtained for each of the task were averaged over all task repetitions in order to have only one value per measure, task and participant. For muscle activity, the maximal value observed in the left or right erector spinae muscles during each session and task was selected for analysis. This handling of left and right muscle data was done following prior publications to match the understanding of CLBP physiopathology, with higher levels of trunk muscle activity with CLBP, and simplify the analyses [11,30]. All calculations were performed with Matlab (R2019b, MathWorks, Inc, Natick, MA).

Task-independent measures were obtained by averaging the measures obtained in the diverse tasks, as proposed in [11]. The averaging

**Table 1**

Description of spinal movement measures. Check marks (✔) indicate the measures that were extracted for each task. Cross marks (✘) indicate the measures that could not be extracted because no such relevant feature exists for the task of interest. Range of angular motion or angular velocity are the difference between the minimum and maximum values of the curve.

| | Definition | Flexion | Lifting | Picking-up | Stepping-up | Sit-to-Stand |
|---|---|---|---|---|---|---|
| ***Angular amplitude*** | | | | | | |
| $LLSa_{flex}$ | Maximal flexion angle at the LLS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $LLSa_{range}$ | Sagittal-plane range of angular motion at the LLS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $ULSa_{flex}$ | Maximal flexion angle at the ULS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $ULSa_{range}$ | Sagittal-plane range of angular motion at the ULS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $LTSa_{flex}$ | Maximal flexion angle at the LTS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $LTSa_{range}$ | Sagittal-plane range of angular motion at the LTS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $UTSa_{flex}$ | Maximal flexion angle at the UTS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $UTSa_{ext}$ | Maximal extension angle at the UTS joint | ✗ | ✗ | ✗ | ✓ | ✓ |
| $UTSa_{range}$ | Sagittal-plane range of angular motion at the UTS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| ***Angular velocity*** | | | | | | |
| $LLSv_{flex}$ | Maximal angular velocity in flexion at the LLS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $LLSv_{ext}$ | Maximal angular velocity in extension at the LLS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $LLSv_{range}$ | Sagittal-plane range of angular velocity at the LLS joint | ✓ | ✓ | ✓ | ✓ | ✓ |
| $ULSv_{flex}$ | Maximal angular velocity in flexion at the ULS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $ULSv_{ext}$ | Maximal angular velocity in extension at the ULS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $ULSv_{range}$ | Sagittal-plane range of angular velocity at the ULS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $LTSv_{flex}$ | Maximal angular velocity in flexion at the LTS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $LTSv_{ext}$ | Maximal angular velocity in extension at the LTS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $LTSv_{range}$ | Sagittal-plane range of angular velocity at the LTS joint | ✓ | ✓ | ✓ | ✗ | ✗ |
| $UTSv_{flex}$ | Maximal angular velocity in flexion at the UTS joint | ✓ | ✗ | ✗ | ✓ | ✓ |
| $UTSv_{ext}$ | Maximal angular velocity in extension at the UTS joint | ✓ | ✗ | ✗ | ✓ | ✓ |
| $UTSv_{range}$ | Sagittal-plane range of angular velocity at the UTS joint | ✓ | ✗ | ✗ | ✓ | ✓ |
| ***Muscle activity*** | | | | | | |
| $ES_{peak1}$ | First maximal activity level of the erector spinae muscles | ✓ | ✓ | ✓ | ✓ | ✓ |
| $ES_{peak2}$ | Second maximal activity level of the erector spinae muscles | ✓ | ✓ | ✓ | ✗ | ✗ |

was done independently for each measure (i.e. $LLS_{aflex}$), participant and session. Up to 26 task-independent measures were calculated for each measure, corresponding to all possible task combinations (10 combinations of two tasks, 10 combinations of three tasks, 5 combinations of four tasks and 1 combination of five tasks). To give similar weight to all the tasks, a Z-score transformation, based on the means and standard deviations of the asymptomatic participants, was applied to the measures before averaging over the tasks. Consequently, the task-independent measures are dimensionless. They indicate how an individual moves, in general for the included tasks, compared to the asymptomatic population.

### 2.4. Statistical analysis

Differences in NPRS-24 h between S1 and S3, as well as differences in NPRS-mov between S1 and S2 and between S1 and S3, were tested with paired sample t-tests to determine if pain intensity changed between the different sets of measurement. Between-session reliability was assessed by the comparison of S1 and S3 measures, and within-session reliability by the comparison of S1 and S2 measures. Relative reliability was assessed using the two-way random effects Intraclass Correlation Coefficient (ICC 2,1), interpreted as poor (ICC<0.5), moderate (0.5 ≤ICC<0.75), good (0.75 ≤ICC<0.9) or excellent (ICC≥0.9) [31]. To compare the ICCs of task-specific and task-independent measures, we calculated the Pearson correlation coefficient between the ICC of the task-independent measures and the median ICC of the tasks included in the task-independent measure calculations. A paired sample t-test was also performed to compare the ICCs of the task-independent measures with the median ICCs of the tasks included in the task-independent measure calculations. The Pearson correlation and t-test analyses were conducted based on all task-independent measures from both groups and within/between-session settings.

Absolute reliability (also named agreement) was quantified using the standard error of measurement (SEM, Eq. 1) and the minimal detectable change (MDC, Eq. 2) [32,33]. Ninety-five percent limits of agreement (LOA) were also calculated [34,35]. Statistical analyses were performed with SPSS (Version 25, IBM, NY, USA), considering a significance level at $\alpha < 0.05$.

$$SEM = SD * \sqrt{1 - ICC} \quad (1)$$

Where SD is the standard deviation of the group.

$$MDC = SEM * 1.96 * \sqrt{2} \quad (2)$$

## 3. Results

There were two drop-outs for S2 and two drop-outs for S3 in the CLBP group. The mean (± SD) TSK, PCS and ODI scores of the patients were 45.2 ± 7.9, 27.7 ± 10.7 and 36.2 ± 11.4, respectively. The mean NPRS-24 h was 5.8 ± 2.2 in session 1 and 5.3 ± 2.4 in session 2 (p = 0.2). Pain during movement was not statistically different between sets of spinal movement measurement, except for stepping-up between S2 and S1 (mean difference of 0.63, p = 0.03). The mean and SD of all movement measures during S1 are reported in Supplementary Materials.

Median between-session angular amplitude ICCs in patients with CLBP were 0.8, 0.65, 0.72, 0.68 and 0.60 for flexion, lifting, picking-up, stepping-up and sit-to-stand, respectively (Table 2, Fig. 2). For maximal angular amplitude measures, 10%, 70% and 20% of the measures at the lumbar joints had moderate, good and excellent ICC, respectively. At the thoracic joints, 60%, 40% and 0% of the measures reported such ICCs. ICCs were poor (35%), moderate (45%) and good (20%) for range of angular motion. For angular velocity measures, ICCs were poor (45%), moderate (43%) and good (12%). Moderate (50%) to good (50%) ICCs were observed for the muscle activity measures. MDCs ranged from 3.9° to 26.5° (median of 9.6°), from 4.4°/s to 50.7°/s (median of 18.3°/s) and from 0.5 to 1.7 (median of 1.0) for angular amplitude, angular velocity and muscle activity measures, respectively. LOA intervals are reported in Supplementary Materials.

Within-session reliability was generally higher than between-session reliability for angular amplitude measures (85% of ICCs≥0.75, median MDC of 4.7°) and muscle activity measures (90% of ICCs≥0.9, median MDC of 0.4) (Supplementary Materials). However, within-session reliability of angular velocity measures remained mostly poor (21%) and moderate (58%). Between-session median ICCs and MDCs for all measures were 0.48 and 11.95 in asymptomatic individuals compared to 0.61 and 10.4 in patients with CLBP, respectively (Table 3, Fig. 2).

The ICCs of the task-independent measures were strongly correlated with the median ICCs of the tasks included in the task-independent measure calculations ($r = 0.91$, $p < 0.001$, Fig. 3). The ICCs of the task-independent measures were statically significantly higher than the median ICCs of the tasks included in the task-independent measure calculations (mean difference of 0.053 (95%CI: 0.049–0.058), $p < 0.001$). Similarly to the task-specific ICCs, the ICCs of the task-independent measures in patients with CLBP were generally higher for angular amplitude (78% of ICCs≥0.75) and muscle activity (100% of ICCs≥0.75) measures than for angular velocity (67% of ICCs<0.75) measures (Fig. 2, Table 2&3).

## 4. Discussion

This study showed mostly moderate to good between-session ICCs for sagittal-plane maximal angular amplitude and erector spinae activity measures in patients with CLBP. While there is no universal thresholds to interpret these values, it is frequently admitted that ICCs above 0.7, which was the case for 71% of the sagittal-plane maximal angular amplitude and erector spinae activity measures, indicate acceptable reliability [36]. In contrast, range of angular motion and angular velocity measures demonstrated mainly poor to moderate ICCs. Furthermore, we found no consistent differences in ICCs between tasks, prohibiting any recommendation to be made regarding which daily-activities to analyse in priority. These results suggest that several angular amplitude and erector spinae activity measures may be considered for longitudinal research in patients with CLBP. Yet, it is important to note that MDC and LOA intervals were relatively large for all measures, indicating that a substantial difference might be necessary to be detectable and considered relevant. Therefore, it is important to interpret these assessments with respect to their contexts of use. For example, depending on the application, it could be useful to contrast them with the minimally clinical important difference or the range of motion [37].

The differences between ICC and MDC findings are likely due to the influence of between-subjects variance on the ICC, but not on the MDC [32]. This may also explain the lower ICCs found in asymptomatic individuals compared to patients, as the variations are generally higher among individuals with CLBP [6,11]. Therefore, these findings strengthen the need for reliability studies in patients with CLBP, as reliability cannot be assumed to be similar in asymptomatic individuals and patients with CLBP.

Within-session reliability were generally higher than between-session reliability in patients with CLBP, as also noticed in previous work [38]. These results may be particularly useful for future cross-sectional studies. Moreover, the specific design in the present study without influence from experimental factors, such as different investigators or marker placements between S1 and S2, provided interesting insight into movement control. On one hand, the high within-session reliability for angular amplitude and muscle activity measures indicated that patients were consistent in how much they moved and in the way their muscles contributed to the movements when repeating the tasks. This concurs with ongoing theories of reduced variability of movement in patients with CLBP [39]. On the other hand, the reliability remained lower for angular velocity measures, even

**Table 2**
Between-session relative and absolute reliability of spinal movement measures in patients with CLBP. Task-independent measures in this table are calculated based on the five tasks, as available (see Table 1). For SEM and MDC: task-specific angular amplitude data are reported in degree, task-specific angular velocity data are reported in degree/second, and muscle activity measures as well as task-independent data are reported in percent.

| | Flexion | | | | Lifting | | | | Picking-up | | | | Stepping-up | | | | Sit-to-Stand | | | | Task-independent | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC |
| ***Angular amplitude*** | | | | | | | | | | | | | | | | | | | | | | | | |
| LLSa$_{flex}$ | 0,77 | (0,48–0,90) | 3,6 | 10,0 | 0,81 | (0,56–0,92) | 3,7 | 10,3 | 0,81 | (0,54–0,93) | 3,8 | 10,5 | 0,83 | (0,58–0,93) | 3,5 | 9,8 | 0,82 | (0,6–0,93) | 3,7 | 10,3 | 0,82 | (0,58–0,93) | 0,9 | 2,5 |
| LLSa$_{range}$ | 0,47 | (0,02–0,76) | 3,1 | 8,5 | 0,51 | (0,10–0,78) | 3,4 | 9,5 | 0,7 | (0,35–0,88) | 2,7 | 7,4 | 0,32 | (−0,19–0,69) | 2,6 | 7,2 | 0,19 | (−0,29–0,60) | 3,5 | 9,8 | 0,45 | (0,02–0,75) | 0,5 | 1,5 |
| ULSa$_{flex}$ | 0,96 | (0,91–0,99) | 1,4 | 3,9 | 0,92 | (0,78–0,97) | 2,3 | 6,3 | 0,87 | (0,64–0,95) | 2,7 | 7,4 | 0,7 | (0,36–0,87) | 3,1 | 8,6 | 0,89 | (0,73–0,96) | 2,8 | 7,8 | 0,94 | (0,81–0,98) | 0,3 | 0,7 |
| ULSa$_{range}$ | 0,75 | (0,45–0,90) | 3,5 | 9,8 | 0,73 | (0,42–0,89) | 3,5 | 9,8 | 0,64 | (0,27–0,84) | 3,9 | 10,8 | 0,51 | (0,07–0,78) | 4,2 | 11,6 | 0,6 | (0,12–0,83) | 5,4 | 14,8 | 0,76 | (0,47–0,90) | 0,5 | 1,3 |
| LTSa$_{flex}$ | 0,82 | (0,59–0,93) | 1,5 | 4,2 | 0,85 | (0,64–0,94) | 2,1 | 5,9 | 0,82 | (0,58–0,93) | 2,3 | 6,4 | 0,82 | (0,57–0,93) | 2,7 | 7,4 | 0,60 | (0,19–0,83) | 3,6 | 10,0 | 0,82 | (0,59–0,93) | 0,4 | 1,2 |
| LTSa$_{range}$ | 0,83 | (0,58–0,93) | 1,9 | 5,2 | 0,57 | (0,18–0,81) | 9,5 | 26,5 | 0,41 | (−0,08–0,73) | 3,0 | 8,3 | 0,65 | (0,29–0,85) | 2,0 | 5,6 | 0,37 | (−0,13–0,71) | 2,9 | 8,1 | 0,70 | (0,36–0,88) | 0,3 | 0,9 |
| UTSa$_{flex}$ | 0,65 | (0,27–0,85) | 4,4 | 12,2 | 0,55 | (0,12–0,81) | 7,9 | 21,8 | 0,60 | (0,20–0,83) | 4,4 | 12,3 | | | | | | | | | 0,60 | (0,19–0,83) | 0,7 | 2,0 |
| UTSa$_{ext}$ | | | | | | | | | | | | | 0,51 | (0,05–0,78) | 4,9 | 13,6 | 0,70 | (0,35–0,88) | 4,0 | 11,1 | 0,60 | (0,19–0,83) | 0,6 | 1,8 |
| UTSa$_{range}$ | 0,87 | (0,70–0,95) | 1,2 | 3,2 | 0,43 | (−0,05–0,74) | 7,0 | 19,5 | 0,74 | (0,43–0,90) | 1,4 | 3,8 | 0,76 | (0,47–0,90) | 1,0 | 2,7 | 0,00 | (−0,51–0,48) | 3,8 | 10,4 | 0,81 | (0,56–0,93) | 0,3 | 0,9 |
| ***Angular velocity*** | | | | | | | | | | | | | | | | | | | | | | | | |
| LLSv$_{flex}$ | 0,27 | (−0,22–0,64) | 4,1 | 11,4 | 0,43 | (0–0,73) | 7,2 | 20,1 | 0,54 | (0,05–0,81) | 7,8 | 21,7 | 0,6 | (0,2–0,83) | 6,4 | 17,7 | 0,35 | (−0,15–0,7) | 5,2 | 14,6 | 0,49 | (0,03–0,77) | 0,4 | 1,0 |
| LLSv$_{ext}$ | 0,36 | (−0,13–0,71) | 2,8 | 7,7 | 0,39 | (−0,1–0,72) | 4,1 | 11,4 | 0,53 | (0,08–0,80) | 5,4 | 14,9 | 0,48 | (0–0,78) | 6,5 | 18,1 | 0,41 | (−0,07–0,73) | 7,7 | 21,2 | 0,57 | (0,14–0,82) | 0,4 | 1,1 |
| LLSv$_{range}$ | 0,35 | (−0,14–0,70) | 6,6 | 18,4 | 0,45 | (0,01–0,75) | 12,0 | 33,3 | 0,61 | (0,18–0,85) | 11,2 | 31,0 | 0,63 | (0,22–0,85) | 9,1 | 25,2 | 0,39 | (−0,09–0,72) | 10,9 | 30,3 | 0,52 | (0,07–0,79) | 0,4 | 1,1 |
| ULSv$_{flex}$ | 0,53 | (0,12–0,79) | 6,3 | 17,6 | 0,56 | (0,16–0,81) | 9,3 | 25,9 | 0,36 | (−0,06–0,69) | 16,8 | 46,7 | | | | | | | | | 0,56 | (0,11–0,81) | 0,5 | 1,5 |
| ULSv$_{ext}$ | 0,80 | (0,55–0,92) | 4,1 | 11,4 | 0,66 | (0,29–0,86) | 8,2 | 22,7 | 0,70 | (0,36–0,88) | 11,5 | 31,9 | | | | | | | | | 0,85 | (0,65–0,94) | 0,3 | 0,9 |
| ULSv$_{range}$ | 0,77 | (0,48–0,91) | 8,7 | 24,1 | 0,77 | (0,47–0,91) | 10,9 | 30,3 | 0,62 | (0,21–0,84) | 18,3 | 50,7 | | | | | | | | | 0,78 | (0,44–0,92) | 0,5 | 1,3 |
| LTSv$_{flex}$ | 0,42 | (−0,05–0,74) | 3,4 | 9,6 | 0,04 | (−0,46–0,50) | 9,7 | 26,8 | 0,51 | (0,05–0,79) | 6,3 | 17,5 | | | | | | | | | 0,42 | (−0,07–0,74) | 0,4 | 1,2 |
| LTSv$_{ext}$ | 0,65 | (0,27–0,85) | 3,3 | 9,1 | 0,69 | (0,32–0,87) | 4,6 | 12,8 | 0,46 | (−0,01–0,76) | 6,1 | 16,9 | | | | | | | | | 0,68 | (0,33–0,86) | 0,3 | 0,9 |
| LTSv$_{range}$ | 0,57 | (0,14–0,82) | 6,3 | 17,4 | 0,35 | (−0,13–0,69) | 13,0 | 35,9 | 0,61 | (0,21–0,84) | 10,1 | 27,9 | | | | | | | | | 0,55 | (0,11–0,80) | 0,5 | 1,5 |
| UTSv$_{flex}$ | 0,41 | (−0,01–0,72) | 2,6 | 7,3 | | | | | | | | | 0,52 | (0,08–0,79) | 2,4 | 6,7 | 0,1 | (−0,38–0,54) | 7,2 | 19,9 | 0,5 | (0,09–0,78) | 0,4 | 1,1 |
| UTSv$_{ext}$ | 0,74 | (0,42–0,89) | 1,6 | 4,4 | | | | | | | | | 0,82 | (0,59–0,93) | 2,5 | 6,9 | 0,13 | (−0,37–0,57) | 8,2 | 22,6 | 0,71 | (0,37–0,88) | 0,3 | 0,9 |
| UTSv$_{range}$ | 0,59 | (0,21–0,82) | 3,8 | 10,4 | | | | | | | | | 0,83 | (0,6–0,93) | 3,4 | 9,4 | 0,08 | (−0,44–0,54) | 14,0 | 38,7 | 0,7 | (0,38–0,88) | 0,4 | 1,0 |
| ***Muscle activity*** | | | | | | | | | | | | | | | | | | | | | | | | |
| EMG$_{peak1}$ | 0,76 | (0,47–0,90) | 0,2 | 0,5 | 0,67 | (0,33–0,86) | 0,5 | 1,3 | 0,81 | (0,56–0,92) | 0,3 | 0,8 | 0,84 | (0,63–0,94) | 0,4 | 1,0 | 0,6 | (0,19–0,83) | 0,4 | 1,1 | 0,81 | (0,58–0,93) | 1,0 | 2,7 |
| EMG$_{peak2}$ | 0,83 | (0,61–0,93) | 0,3 | 0,9 | 0,65 | (0,29–0,85) | 0,6 | 1,7 | 0,71 | (0,38–0,88) | 0,4 | 1,2 | | | | | | | | | 0,76 | (0,47–0,90) | 1,3 | 3,6 |

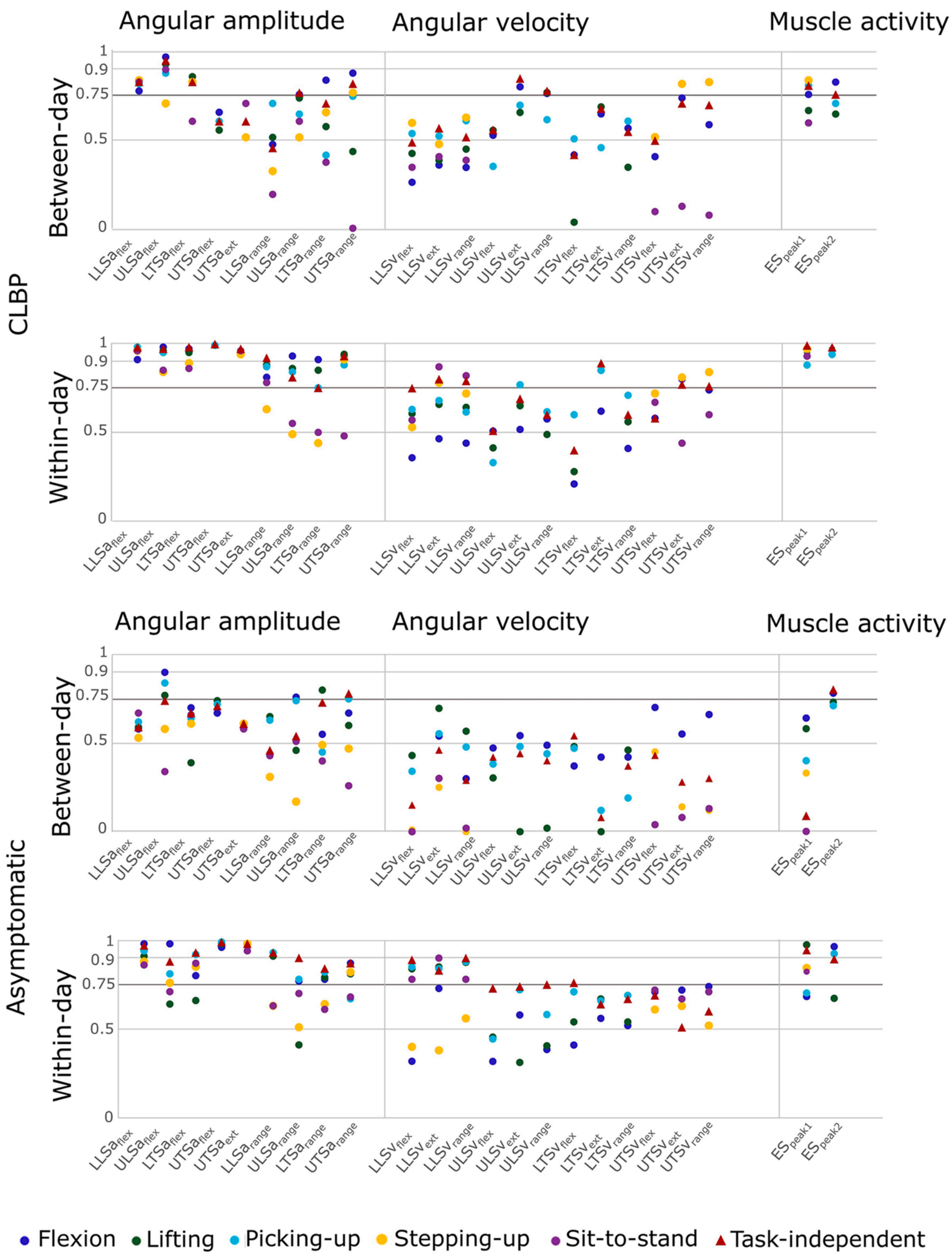


**Fig. 2.** Reliability of spinal movement measures (ICC values) in patients with CLBP and asymptomatic individuals. For clarity, the graphs are bounded between 0.0 and 1.0, with negative ICC displayed at the lower limit. Numerical values are reported in Table 2 & 3. Task-independent measures in this figure are calculated based on the five tasks, as available (see Table 1).

within-session, suggesting variations in the dynamic of the movements. Additional studies will be necessary to understand the variability, particularly in angular velocity, and determinate if it would be an important aspect to consider in CLBP.

The ICCs of the task-independent measures were strongly correlated and slightly higher than the median ICCs of the tasks included in the task-independent measure calculations. Together with the finding that no task consistently demonstrated better ICCs than the others, these results support the use of task-independent measures in CLBP research. Now that task-independent measures have been shown to have similarly acceptable ICCs than task-specific measures, further works will be necessary to determine the benefits of analysing the individual movement signature through task-independent measures [11].

Some limitations should be discussed. First, participants with CLBP had high level of disability, kinesiophobia and catastrophizing. As psychological factors, pain intensity and disability might be associated with spinal movement measures [40,41], the results of this study might not be transferable to less disabled population. Nevertheless, patients included in this study are representative of the patients who need treatments and who would likely be included in longitudinal studies. Second, the original sample size was not fully reached, with a few drop-outs and isolated corrupted data. While the major findings were likely not affected by this reduction, it is possible that analyses performed on bigger populations could result in narrower confidence intervals. Similarly, further investigations could be necessary to get a more specific characterization of the measures reporting heteroscedasticity in the limit of agreement analyses. Third, additional research will be necessary to understand the general decrease in reliability between-session compared to within-session. It would be particularly interesting to isolate the effects of variations in movement execution

**Table 3**
Between-session relative and absolute reliability of spinal movement measures in asymptomatic individuals. Task-independent measures in this table are calculated based on the five tasks, as available (see Table 1). For SEM and MDC: task-specific angular amplitude data are reported in degree, task-specific angular velocity data are reported in degree/second, and muscle activity measures as well as task-independent data are reported in percent.

| | Flexion | | | | Lifting | | | | Picking-up | | | | Stepping-up | | | | Sit-to-Stand | | | | Task-independent | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC | ICC | (95%CI) | SEM | MDC |
| ***Angular amplitude*** | | | | | | | | | | | | | | | | | | | | | | | | |
| $\text{LLSa}_{\text{flex}}$ | 0,58 | (0,19–0,81) | 2,6 | 7,3 | 0,59 | (0,15–0,83) | 2,9 | 7,9 | 0,62 | (0,25–0,83) | 2,6 | 7,3 | 0,53 | (0,12–0,79) | 3,4 | 9,4 | 0,67 | (0,35–0,86) | 2,7 | 7,5 | 0,59 | (0,21–0,81) | 0,7 | 1,9 |
| $\text{LLSa}_{\text{range}}$ | 0,44 | (0,04–0,72) | 3,9 | 10,7 | 0,65 | (0,27–0,85) | 3,2 | 8,9 | 0,63 | (0,23–0,85) | 3,1 | 8,7 | 0,31 | (−0,16–0,67) | 3,1 | 8,5 | 0,43 | (−0,02–0,73) | 3,2 | 8,9 | 0,46 | (0,06–0,74) | 0,6 | 1,8 |
| $\text{ULSa}_{\text{flex}}$ | 0,90 | (0,77–0,96) | 1,9 | 5,2 | 0,77 | (0,49–0,90) | 2,4 | 6,8 | 0,84 | (0,61–0,93) | 2,5 | 7,1 | 0,58 | (0,21–0,81) | 3,8 | 10,6 | 0,34 | (−0,08–0,67) | 5,4 | 15,1 | 0,74 | (0,45–0,89) | 0,5 | 1,3 |
| $\text{ULSa}_{\text{range}}$ | 0,76 | (0,49–0,90) | 2,5 | 6,9 | 0,46 | (0,02–0,75) | 4,1 | 11,5 | 0,74 | (0,46–0,89) | 3,2 | 8,8 | 0,17 | (−0,3–0,57) | 3,8 | 10,7 | 0,51 | (0,11–0,77) | 6,2 | 17,2 | 0,54 | (0,12–0,79) | 0,5 | 1,3 |
| $\text{LTSa}_{\text{flex}}$ | 0,70 | (0,38–0,87) | 2,1 | 5,8 | 0,39 | (−0,08–0,71) | 3,4 | 9,5 | 0,64 | (0,28–0,84) | 2,6 | 7,2 | 0,61 | (0,24–0,83) | 3,2 | 8,8 | 0,66 | (0,30–0,85) | 3,9 | 10,9 | 0,67 | (0,33–0,86) | 0,5 | 1,4 |
| $\text{LTSa}_{\text{range}}$ | 0,55 | (0,15–0,80) | 3,1 | 8,5 | 0,80 | (0,56–0,92) | 6,7 | 18,5 | 0,45 | (0,02–0,74) | 3,2 | 8,9 | 0,49 | (0,07–0,76) | 2,9 | 8,0 | 0,40 | (−0,05–0,71) | 3,6 | 9,9 | 0,73 | (0,42–0,88) | 0,4 | 1,0 |
| $\text{UTSa}_{\text{flex}}$ | 0,67 | (0,34–0,86) | 4,4 | 12,2 | 0,74 | (0,44–0,89) | 6,0 | 16,7 | 0,72 | (0,42–0,88) | 4,0 | 11,0 | | | | | | | | | 0,71 | (0,40–0,87) | 0,6 | 1,8 |
| $\text{UTSa}_{\text{ext}}$ | | | | | | | | | | | | | 0,61 | (0,29–0,82) | 4,3 | 11,9 | 0,58 | (0,19–0,81) | 5,0 | 14,0 | 0,61 | (0,25–0,83) | 0,7 | 1,9 |
| $\text{UTSa}_{\text{range}}$ | 0,67 | (0,35–0,85) | 1,8 | 5,1 | 0,60 | (0,20–0,82) | 5,2 | 14,3 | 0,75 | (0,46–0,89) | 1,1 | 3,1 | 0,47 | (0,04–0,75) | 1,3 | 3,5 | 0,26 | (−0,22–0,63) | 2,4 | 6,7 | 0,78 | (0,52–0,91) | 0,3 | 0,9 |
| ***Angular velocity*** | | | | | | | | | | | | | | | | | | | | | | | | |
| $\text{LLSv}_{\text{flex}}$ | -0,07 | (−0,49–0,37) | 6,4 | 17,8 | 0,43 | (−0,05–0,75) | 10,5 | 29,2 | 0,34 | (−0,13–0,68) | 11,0 | 30,4 | 0,01 | (−0,48–0,46) | 12,8 | 35,4 | -0,2 | (−0,59–0,32) | 16,1 | 44,7 | 0,15 | (−0,31–0,55) | 0,7 | 1,8 |
| $\text{LLSv}_{\text{ext}}$ | 0,54 | (0,15–0,79) | 4,3 | 12,0 | 0,70 | (0,34–0,88) | 5,5 | 15,4 | 0,55 | (0,15–0,80) | 6,0 | 16,7 | 0,25 | (−0,24–0,63) | 6,9 | 19,0 | 0,3 | (−0,15–0,65) | 10,5 | 29,1 | 0,46 | (0,05–0,74) | 0,5 | 1,4 |
| $\text{LLSv}_{\text{range}}$ | 0,30 | (−0,14–0,64) | 9,4 | 26,1 | 0,57 | (0,14–0,82) | 13,6 | 37,6 | 0,48 | (0,07–0,76) | 15,4 | 42,6 | -0,1 | (−0,57–0,35) | 17,4 | 48,2 | 0,02 | (−0,44–0,46) | 20,6 | 57,2 | 0,29 | (−0,16–0,64) | 0,6 | 1,7 |
| $\text{ULSv}_{\text{flex}}$ | 0,47 | (0,05–0,75) | 6,6 | 18,4 | 0,30 | (−0,19–0,66) | 14,1 | 39,0 | 0,38 | (−0,06–0,70) | 18,1 | 50,2 | | | | | | | | | 0,42 | (−0,04–0,72) | 0,6 | 1,7 |
| $\text{ULSv}_{\text{ext}}$ | 0,54 | (0,15–0,79) | 4,4 | 12,1 | -0,17 | (−0,57–0,3) | 12,3 | 34,1 | 0,48 | (0,07–0,75) | 7,9 | 21,8 | | | | | | | | | 0,44 | (0,03–0,73) | 0,5 | 1,4 |
| $\text{ULSv}_{\text{range}}$ | 0,49 | (0,08–0,76) | 9,6 | 26,7 | 0,02 | (−0,45–0,47) | 22,9 | 63,4 | 0,44 | (−0,01–0,74) | 21,8 | 60,4 | | | | | | | | | 0,4 | (−0,05–0,71) | 0,6 | 1,6 |
| $\text{LTSv}_{\text{flex}}$ | 0,37 | (−0,09–0,69) | 5,1 | 14,2 | 0,48 | (0,06–0,76) | 10,1 | 27,9 | 0,47 | (0,04–0,75) | 9,2 | 25,4 | | | | | | | | | 0,54 | (0,14–0,79) | 0,5 | 1,5 |
| $\text{LTSv}_{\text{ext}}$ | 0,42 | (−0,02–0,72) | 4,0 | 11,2 | -0,02 | (−0,5–0,44) | 9,7 | 27,0 | 0,12 | (−0,36–0,54) | 10,1 | 28,1 | | | | | | | | | 0,08 | (−0,39–0,51) | 0,6 | 1,5 |
| $\text{LTSv}_{\text{range}}$ | 0,42 | (−0,02–0,72) | 7,7 | 21,4 | 0,46 | (0,03–0,75) | 13,3 | 36,9 | 0,19 | (−0,29–0,59) | 17,6 | 48,8 | | | | | | | | | 0,37 | (−0,08–0,70) | 0,7 | 1,8 |
| $\text{UTSv}_{\text{flex}}$ | 0,70 | (0378–0,87) | 2,2 | 6,1 | | | | | | | | | 0,45 | (0,05–0,74) | 2,9 | 8,1 | 0,04 | (−0,41–0,47) | 10,0 | 27,7 | 0,43 | (−0,03–0,73) | 0,5 | 1,3 |
| $\text{UTSv}_{\text{ext}}$ | 0,55 | (0,14–0,79) | 2,9 | 8,1 | | | | | | | | | 0,14 | (−0,28–0,53) | 4,6 | 12,7 | 0,08 | (−0,39–0,51) | 10,4 | 29,0 | 0,28 | (−0,19–0,64) | 0,6 | 1,6 |
| $\text{UTSv}_{\text{range}}$ | 0,66 | (0,32–0,85) | 4,4 | 12,1 | | | | | | | | | 0,12 | (−0,3–0,51) | 7,1 | 19,8 | 0,13 | (−0,33–0,54) | 17,8 | 49,4 | 0,3 | (−0,17–0,65) | 0,6 | 1,6 |
| ***Muscle activity*** | | | | | | | | | | | | | | | | | | | | | | | | |
| $\text{EMG}_{\text{peak1}}$ | 0,64 | (0,27–0,85) | 0,1 | 0,2 | 0,58 | (0,16–0,82) | 0,2 | 0,6 | 0,4 | (−0,05–0,72) | 0,2 | 0,6 | 0,33 | (−0,07–0,66) | 0,3 | 0,8 | 0 | (−0,45–0,45) | 2,5 | 6,8 | 0,09 | (−0,4–0,52) | 1,6 | 4,5 |
| $\text{EMG}_{\text{peak2}}$ | 0,78 | (0,48–0,91) | 0,2 | 0,4 | 0,73 | (0,4–0,89) | 0,2 | 0,5 | 0,71 | (0,38–0,88) | 0,1 | 0,4 | | | | | | | | | 0,8 | (0,56–0,92) | 0,4 | 1,1 |

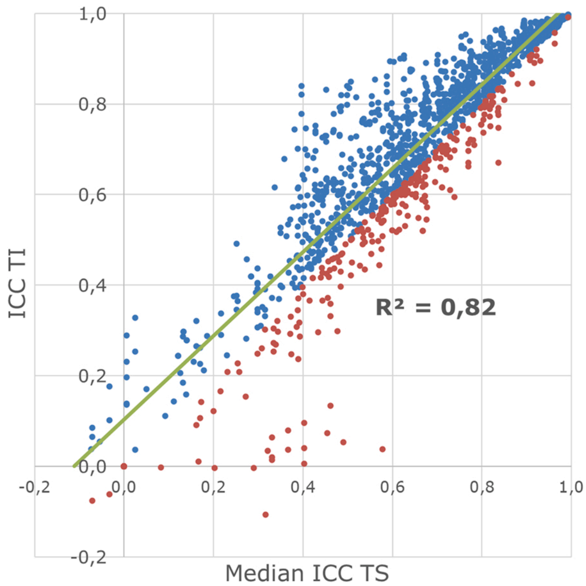


**Fig. 3.** Relationship between reliability (ICC values) of task-independent and task-specific measures. This figure presents the ICC of the task-independent measures (ICC TI) with respect to median ICC of the tasks included in the task-independent measure calculations (Median ICC TS). The Pearson coefficient of determination ($R^2$) is also reported. Blue dots indicate ICC TI $\geq$ median ICC TS, and red dots: ICC TI $<$ median ICC TS. The linear regression line is displayed in green.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

from experimental factors. Finally, additional studies will be needed to assess the effect of having different investigators performing the measurement.

## 5. Conclusion

This study showed mostly moderate to good between-session reliability for sagittal-plane maximal angular amplitude and erector spinae activity measures during daily-activity tasks. However, MDCs suggested that large changes are needed to be detectable. Caution is also needed with range of angular motion and angular velocity measures, which reported large between-session variations. No task demonstrated consistently better or worse reliability, prohibiting any recommendation to be made regarding which daily-activities to analyse in priority. The similarly acceptable reliability obtained for task-independent and task-specific measures support the use of task-independent measures in future spinal movement studies.

## Conflict of interest statement

The authors have no conflict of interest to declare.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2022.04.008.

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