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Exploring real-world lumbar posture behaviour. A whole day comparison of individuals with low back pain and healthy controls

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ABSTRACT

Background: Previous research of lumbar posture on individuals with low back pain (LBP) has produced conflicting findings compared to control groups. This research has been limited by environmental or task constraints. Real-world postural behaviour across an entire day remains poorly understood. This study examined whole-day lumbar posture characteristics in people with and without LBP using wearable sensors.
Methods: 13 people with LBP and 11 healthy controls volunteered for this study. A three-accelerometer setup was used to measure real-world lumbar posture classifying sitting and standing. Data were normalised to individual maximum ranges. Differences in measures of mean posture, variability, fidgeting, and posture-use frequency distributions, were derived.
Findings: An average of 350 min of data per person was available for analysis. Overall, between group differences were small. LBP demonstrated more flexed posture use in standing and a more flexed sitting frequency distribution.
Interpretation: Real-world posture behaviour was similar between individuals with and without LBP. Where differences were determined they related to temporal components such as frequencies which are masked with traditional postural estimates. These findings suggest that posture-pain relationships may vary substantially between individuals, emphasising the need for person-specific analysis in future research.

1. Introduction

Low back pain (LBP) is a leading cause of disability worldwide, responsible for the most years of lived disability with high societal and economic burden (Vos et al., 2020). Furthermore, LBP is responsible for a large amount of absenteeism among the working age population, with estimates ranging from 4% to 27% (Carregaro et al., 2020; Serranheira et al., 2020), with a reported 15 million days absent from work between 2012 and 2016 in Brazil alone (Carregaro et al., 2020).

Prolonged sitting and standing are often reported as provocative by individuals with LBP. Sitting and standing have been linked to the development of transient low back pain (Greene et al., 2019; Sorensen et al., 2015), provocation of existing LBP (De Carvalho et al., 2020; Mendelek et al., 2011), reoccurrence of LBP (da Silva et al., 2019), and is a common presenting complaint by care seekers with LBP (Alghadir et al., 2017; Dankaerts et al., 2006). Despite this, little consensus exists describing the relationship between specific postures and LBP. Postural analysis of the lumbar spine of individuals with LBP in sitting compared to pain-free groups have yielded mixed results, with some studies showing differences (Christie et al., 1995), and others no difference (Laird et al., 2016). Moreover, some studies demonstrate differences describing greater lordosis/extension-based sitting (Dankaerts et al., 2006) and some reduced lordosis/flexion based sitting postures (Kandil et al., 2024). Regarding standing, again the literature is conflicted, with some studies demonstrating individuals with LBP stand with greater lordosis (Christie et al., 1995) and others showing reduced lordosis (Hultman et al., 1993), or no difference (Laird et al., 2016) when compared to healthy controls. In addition to studies on individuals with low back pain, previous studies have explored so called 'pain developers', defined as individuals not care-seeking for LBP but who develop transient pain in response to specific tasks, e.g., prolonged sitting. Within this group, a metanalysis demonstrates overall no

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difference in lumbar lordosis in standing, but with large confidence intervals for effect sizes, and fewer lumbar standing 'fidgets' in pain developers (Khoshroo et al., 2023). In sitting pain-developers demonstrate a lower number of spine fidgets ($p = 0.004$) but no difference in posture (Greene et al., 2019).

There are several limitations to the above research. First is the assumption that posture is a fixed entity which can be represented by a single value. Our previous work has demonstrated that, in the real-world, sitting and standing lumbar posture varies depending on the individual and the task, with each person demonstrating a unique postural signature often with large variability (McClintock et al., 2024a; Muñoz-Gómez et al., 2025). Second is the use of environmental or task constraints, unrepresentative of the real-world by failing to consider the normal environmental and task variability of usual daily living.

The study of lumbar posture in real-world environments and across prolonged periods is limited in the existing literature. A recent investigation of prolonged lumbar sitting postures was completed by Davidson & Callaghan (Davidson and Callaghan, 2025), where lumbar posture was monitored in 20 individuals without LBP across 5 days. In those individuals who developed transient pain ($n = 6$), less frequent use of posterior pelvic tilt and forward thoracic inclination at the 90% percentile of the amplitude probability distribution was observed. Moreover, less frequent lumbar movements were observed in the pain development group. Despite this study making a major contribution to our understanding of pain developers, this study was limited to sitting, did not explore individuals with LBP and the resulting pain developers' group was small. In another real-world study not limited to sitting, Gombatto and colleagues (Gombatto et al., 2024) looked at defining clinical LBP phenotypes from multiple variables including 8-h of posture and movement data. Two sub-groups were established with movement frequency, time in standing and time in sitting being part of the discriminatory measures. Both field-based studies suggest time-based variables are important along with frequency of use of specific postures however, to date, no studies have compared whole day, real-world lumbar posture behaviour in individuals with and without LBP.

The aim of this study was to compare real-world sitting and standing lumbar postures between individuals with LBP and healthy controls across a whole day. By examining lumbar posture throughout an unconstrained day, this research seeks to clarify whether characteristic postural behavioural differences exist when measurements are taken outside of laboratory settings.

2. Materials and methods

2.1. Study design

This study adopted a cross-sectional, observational study design. The study followed the principle of the declaration of Helsinki and was approved by the Ethics Committee of Najran University, Saudi Arabia [202312–076–016107-037172]. The reporting of the study follows the guidelines of STROBE (von Elm et al., 2008).

2.2. Setting

Data were collected in a real-world setting, with participants recruited from healthcare facilities and academic institutions. Data collection extended from 27/12/2023 to 26/12/2024.

2.3. Participants

Thirteen participants with LBP were recruited from clinic attendance and inclusion criteria were as follows: Physician diagnosed LBP with pain confined to the region between the 12th rib and inferior gluteal folds, pain for at least three months, and pain evoked by postures, prolonged activity, movements, or tasks throughout the day (movement evoked pain). Individuals were excluded if they had symptoms below the inferior gluteal folds or neurological symptoms, any Neurological or Rheumatological disorder or a history of spinal surgery. Average and worst pain in the preceding 2 weeks were collected using a visual analogue scale (VAS), fear of pain, and subsequent avoidance of movement was assessed using the fear-avoidance beliefs questionnaire (FABQ) (Waddell et al., 1993), and disability was assessed using the Roland–Morris disability questionnaire (RMDQ) (Roland and Fairbank, 2000). All participants were screened by a Physiotherapist for inclusion and exclusion criteria and provided written informed consent. Eleven healthy controls, with no history of care seeking for low back pain and no LBP reported in the preceding 12 months, were recruited from healthcare facilities and academic institutions. This sample size was based on effect size data from Chun et al. (Chun et al., 2017), alpha of 5% and beta 80%.

2.4. Instrumentation and procedure

Three IMUs (Movella Xsens Dots, Enschede, The Netherlands) were attached to the skin over the L1, S1 and lateral thigh following the procedure outlined in McClintock et al., (McClintock et al., 2024a). Once sensors were attached, participants completed full range of motion (ROM) testing to serve as a method of normalisation the data to their biomechanical maximums, before being asked to carry out their normal activities of daily living. Sensors captured data at 15 Hz, and at the end of the day were removed and data downloaded. The battery life determined the exact duration of data collection and was usually ~7 h. This method of data collection has been shown to be acceptable, with individuals able to forget that they were wearing sensors most of the time (McClintock et al., 2024a).

2.5. Data analysis

Raw accelerometer data were exported to MATLAB (2023b, MathWorks, Natick, MA, USA), where custom algorithms used acceleration data to calculate the absolute tilt angle of each sensor relative to the gravitational vertical. The tilt angle of adjacent sensors was then used to derive relative angles representing the lumbar spine (between sensors placed over L1 and S2) and the hip (between the S2 and thigh sensors), using the ATAN2 function (McClintock et al., 2024b). All angle data were filtered using a fourth-order low-pass Butterworth filter with a 1 Hz cut-off frequency prior to further analysis. The validity of deriving sagittal plane angles from accelerometers in this way has been previously established (McClintock et al., 2024a).

Prior to whole-day data collection, each participant completed three cycles of full lumbar flexion-extension in standing and fully slouched to fully erect sitting, from which the individual's peak flexion ROM for both standing and sitting was determined. The maximal ROM recorded during this initial calibration procedure at the start of the day was used to normalise all subsequent lumbar spine angle data, expressed as a percentage of the individual's maximum flexion ROM. This normalisation allowed meaningful comparison of lumbar posture between participants who differed in their absolute ROM.

2.6. Activity classification and window extraction

Whole-day data were classified using multi-level conditional statements applied to hip angle, thigh angle, and lumbar spine angle simultaneously, to determine periods of sitting and standing, following the approach described in our previous work (McClintock et al., 2024a; Muñoz-Gómez et al., 2025). For example, sitting was identified when the absolute thigh angle and the relative hip angle jointly exceeded defined thresholds indicative of seated hip flexion. Any data not classified as sitting or standing were excluded from further analysis. To avoid postural transitions and dynamic movement behaviour confounding the analysis, a second conditional step was applied, retaining only sustained periods of sitting or standing exceeding 60 s in duration. This produced multiple discrete time-windows, each representing an unbroken bout of either sitting or standing, where window length is defined as the duration of that sustained, unbroken posture.

2.7. Summary variables

From this data, several summary variables were calculated following our previous work (McClintock et al., 2024a; Muñoz-Gómez et al., 2025), defined in Table 1 and described briefly here. These variables characterise how an individual has spent their day in terms of time sitting and standing, the habitual lumbar posture adopted, and the degree of fidgeting, defined as the standard deviation of the lumbar angle within a sitting or standing window and representing postural variability around the individual's habitual posture.

2.8. Postural frequency analysis

The frequency of use of specific lumbar postures was determined by converting all lumbar angle data into an amplitude probability distribution function (APDF) with 1% postural bins. This approach quantifies the proportion of time spent at each percentage of sagittal ROM across the day, following the method of Dunk and Callaghan (2010) (Dunk and Callaghan, 2010). The 1% bins were subsequently collapsed into bins representing 25% of ROM to aid interpretation. The frequency of use of postures within each 25% ROM bin was then calculated. For sitting, four quartile bins were used (Q1: 0–25%, Q2: 26–50%, Q3: 51–75%, Q4: 76–100% flexion ROM), as no lumbar extension angles were observed during sitting. For standing, six sextile bins spanning from 50% extension ROM to 100% flexion ROM were used to capture the broader postural range observed in this posture.

A cumulative distribution function (CDF) was also calculated for sitting and standing lumbar angle data, following the methods described in (McClintock et al., 2024a; Muñoz-Gómez et al., 2025). Postural values at the 10th, 50th, and 90th percentiles of the CDF were extracted and used for between-group comparison, representing the lower, median, and upper boundaries of the habitual postural range.

Table 1
Descriptions of variables calculated.

Variable	Description
Total Recorded Time (mins)	The overall time of data recorded throughout the day.
Time Sitting (mins)	The sum of all sitting window durations.
Time Standing (mins)	The sum of all standing window durations.
Mean Number of Sitting Windows	The mean number of sitting 'windows' detected during the day.
Mean Number of Standing Windows	The mean number of standing 'windows' detected during the day.
Lumbar Range of Motion (°)	The range of motion of the lumbar spine taken from the calibration movements at the start of the day from the recording.
Average Sitting Posture (%)	The weighted mean of all the sitting-window means. This represents an individual's average posture for the day, considering the duration of each posture.
Average Standing Posture (%)	The weighted mean of all the standing-window means. This represents an individual's average posture for the day, considering the duration of each posture.
Average Sitting fidgeting (%)	The weighted mean of the standard devia-tions of each sitting-window. This represents the average 'fidgeting' or variability within the sitting window.
Average Standing fidgeting (%)	The weighted mean of the standard de-via-tions of each standing-window. This represents the average 'fidgeting' or varia-bility within the sitting window.
Average Sitting Lumbar Exposure	The relationship between the lumbar angle, duration, and fidgeting (McClintock 2024, et al). Shows a high value when an individual spends a long duration at a high percentage of their maximum lumbar flexion (or extension) range of motion, while also remaining stationary around this lumbar posture.

2.9. Statistical analysis

Statistical analyses were completed in MATLAB (2023b). Data normality was confirmed via Shapiro-Wilk testing, and between-group comparisons were made using independent *t*-tests with a significance level of $p = 0.05$. Given the number of comparisons performed, Bonferroni correction was applied, yielding adjusted alpha levels of 0.0045 for the summary variables, 0.0125 for sitting variables, and 0.008 for standing variables. Given the small sample sizes, Cohen's d was calculated to quantify the magnitude of between-group differences, with values greater than 0.8 interpreted as a large effect (Cohen, 1977).

3. Results

Thirteen LBP participants (age 37.39 ± 10.29 years, weight 79.15 ± 14.52 kg, height 1.69 ± 0.08 m, 9 male and 4 female, Table 2) and eleven healthy controls (age 28.27 ± 11.90 years, weight 62.36 ± 12.38 kg, height 1.70. ± 0.06 m, 9 male and 2 female), full participant characteristics can be found in Table 2, completed the full day of data collection producing an average recording time of 376.05 ± 46.43 min for LBP group and 324.26 ± 94.40 min for the control group (Table 3). Figs. 1 and 2 show three typical examples of individual frequency distributions of lumbar posture in sitting and standing respectively. Commonly graphs seem to show a skewed normal (Fig. 1, top-left), a bimodal (Fig. 1, bottom-middle) or a varied distribution (Fig. 1, bottom-left).

Data collection was completed for all individuals, however due to the nature of unconstrained through day data collection, three participants in the LBP group had no standing windows for greater than one minute so were discounted from the group based standing calculations.

No statistically significant differences in the summary variables were observed between groups following Bonferroni correction (Table 3). Although the LBP group spent more time sitting (163.94 vs. 130.78 mins) with a greater number of sitting windows (24.08 vs. 20.64), these differences were not statistically significant and effect sizes were moderate to small ($d = 0.54$ and $d = 0.30$, respectively). Mean sitting and standing postures were broadly similar between groups, with small effect sizes ($d = 0.24$ and $d = 0.04$, respectively), suggesting that average lumbar position alone may not distinguish the groups. The most notable observation was for fidgeting in sitting, where the LBP group demonstrated greater postural variability during sitting (29.67 ± 18.13%) compared to controls (18.09 ± 6.95%), producing a large effect size ($d = 0.82$) that approached but did not reach statistical significance following Bonferroni correction ($p = 0.05$). While this finding should be

Table 2
Baseline characteristics for both groups participants. (mean (SD)).

	Low Back Pain ($n = 13$)	Control Group
Age (Years)	37.38 (10.29)	28.27 (11.90)
Weight (Kg)	79.15 (14.53)	62.36 (12.38)
Height (m)	1.69 (0.08)	1.70 (0.06)
Sex		
Male	9	9
Female	4	2
Duration of LBP (years)	4.62 (3.98)	–
Average pain (VAS)	3.49 (1.68)	–
Worst pain (VAS)	4.74 (1.85)	–
FABQ Physical activity subscale	11.83 (5.29)	–
FABQ Work subscale	15.83 (7.07)	–
RMDQ	8.92 (3.75)	–
Occupation[a]		
Military	5	–
Housewife	2	–
Taxi driver	1	–
Office work	3	3
Student	1	6
Academic	1	–
No Occupation	–	2

Table 3
Descriptive statistics for lumbar posture variables (mean (SD)).*

	Low Back Pain (n = 13)	Control Group (*n* = 11)	p-value	Effect Size
Time (mins)	376.05 (46.43)	324.26 (94.40)	0.12	0.72
Time Sitting (mins)	163.94 (61.76)	130.78 (61.22)	0.20	0.54
Time Standing (mins)	51.49 (32.07)	68.96 (75.49)	0.50	0.3
Mean Number of Sitting Windows	24.08 (11.92)	20.64 (11.15)	0.47	0.3
Mean Number of Standing Windows	13.9 (7.45)	12.64 (6.65)	0.69	0.18
Lumbar Range of Motion (°)	59.64(18.63)	61.01 (14.18)	0.85	0.08
Mean Sitting Posture (%)	60.85 (16.74)	66.13 (27.23)	0.58	0.24
Mean Standing Posture (%)	−0.13 (16.60)	0.58 (17.91)	0.93	0.04
Mean Sitting fidgeting (%)	29.67 (18.13)	18.09 (6.95)	0.05	0.82
Mean Standing fidgeting (%)	11.41 (5.93)	12.12 (7.43)	0.81	0.11
Mean Sitting Lumbar Exposure	460.71 (490.77)	676.04 (518.61)	0.31	0.43

[*] significant difference between groups independent t-test.

interpreted cautiously given the small sample size, it tentatively suggests that postural variability during sitting may be a more sensitive indicator of difference between groups than mean posture. No meaningful differences were observed for standing variables.

The duration of time spent in each postural percentage during sitting and standing is presented in Tables 4 and 5, respectively. For sitting, no statistically significant between-group differences were found across any quartile following Bonferroni correction, and effect sizes were small to moderate (d = 0.08–0.46).

For standing, two sextiles demonstrated statistically significant between-group differences with large effect sizes. The LBP group spent considerably less time in slight lordotic postures (−25% to −1% extension; 15.99 ± 12.32% vs. 58.04 ± 27.62%, $p < 0.001$, d = 1.91), while spending significantly more time in moderate forward flexion (26–50% flexion; 24.73 ± 19.22% vs. 4.19 ± 9.48%, p < 0.001, d = 1.39). The remaining sextiles did not reach statistical significance, though the 0–25% flexion sextile showed a moderate effect size (d = 0.67), suggesting the LBP group also tended to spend more time in neutral-to-slightly-flexed standing postures. Collectively, these findings suggest that individuals with LBP adopt a more stooped standing posture, spending more time in forward flexion, while controls preferentially adopt a mildly lordotic standing position.

CDF postures for sitting and standing are presented in Table 6. For standing, no statistically significant differences were observed at any percentile, and effect sizes were small (d = 0.15–0.40), suggesting broadly comparable standing posture distributions between groups. For sitting, no significant differences were found at the 10th or 50th percentiles ($p = 0.57$ and $p = 0.10$, respectively), with small to moderate effect sizes (d = 0.08 and d = 0.65, respectively). However, the 50th percentile data tentatively suggest that the LBP group tends to sit at a higher percentage of their flexion ROM at the median (86.89 ± 31.46% vs. 65.25 ± 29.30%), indicating a trend towards greater overall sitting flexion. A statistically significant difference was observed at the 90th percentile ($p = 0.04$, d = 0.90), where the LBP group reached 102.00 ± 15.53% of their lumbar flexion ROM compared to 85.19 ± 21.25% in controls. This suggests that individuals in this study with LBP spent a meaningful proportion of their sitting time at or close to maximal measured flexion ROM, suggesting that the upper end of their postural distribution is dominated by end-range flexion postures. In contrast, the control group's 90th percentile remained notably below their maximum ROM. Together, the CDF data tentitively suggest that individuals with LBP not only sit at higher average levels of lumbar flexion, but also exhibit a broader spread of postures towards greater flexion range compared to controls, though these observations should be interpreted with caution given the small sample size.

4. Discussion

This study aimed to explore lumbar spine postural differences between individuals with LBP and healthy controls using real-world whole day data. Overall, few differences were determined, suggesting broadly similar through-day lumbar postural behaviours between the two groups. This is the first time a validated approach has been used to investigate real-world posture in individuals with LBP compared to those without, offering novel preliminary insights into this under-researched area.

Few differences were observed between groups, which is consistent with previous literature reporting similar single postural estimates between individuals with and without LBP (Laird et al., 2016), and with Davidson and Callaghan (Davidson and Callaghan, 2025), who likewise found few postural differences in healthy individuals who subsequently

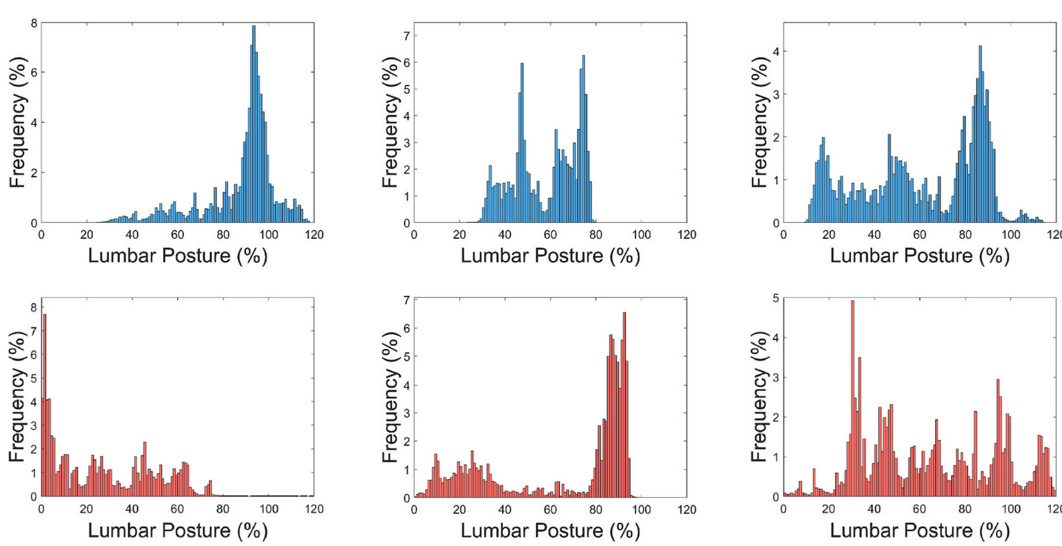

Fig. 1. Three individuals with Low back pain (red) and three healthy controls (blue) sitting posture frequency graph examples. Each graph is a separate individual with their posture normalised to their maximum ROM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

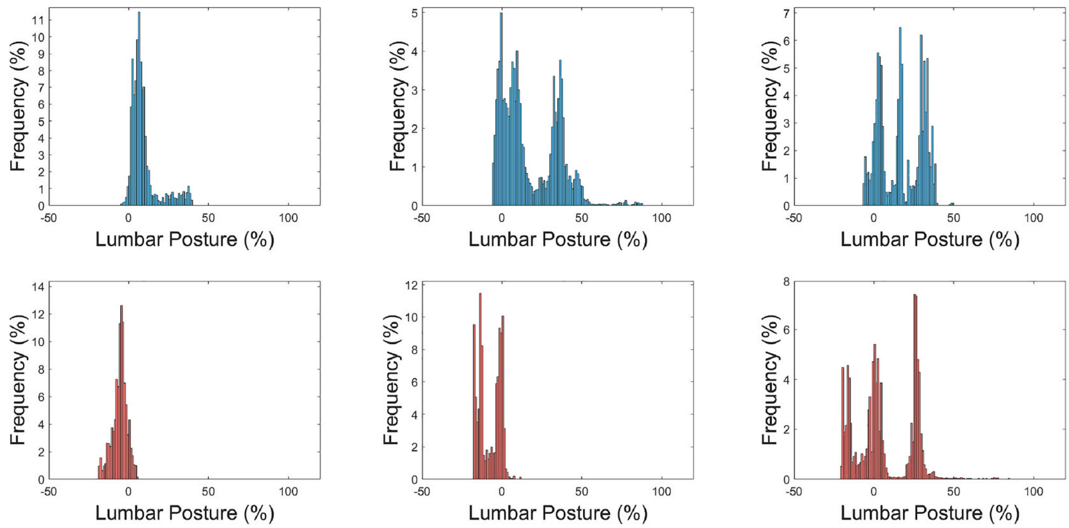

Fig. 2. Three individuals with Low back pain (red) and three healthy controls (blue) standing posture frequency graph examples. Each graph is a separate individual with their posture normalised to their maximum ROM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Probability frequency distribution group means percentage time spent in each range of posture through day sitting (mean (SD)).

Percentage Posture Quartile	Low Back Pain Sitting (%)	Control Sitting (%)	p-value	Effect size
0: 25	11.20 (14.69)	5.67 (13.49)	0.27	0.41
26: 50	17.50 (14.59)	19.19 (18.61)	0.97	0.08
51: 75	32.45 (22.88)	38.26 (26.27)	0.29	0.46
76 +	38.85 (31.36)	36.88 (41.91)	0.79	0.18

Table 5
Probability frequency distribution group means percentage time spent in each range of posture through day standing (mean (SD)).

Percentage Posture Sextile	Low Back Pain Standing (%)	Control Standing (%)	p-value	Effect size
−50: −26	1.95 (6.46)	0.10 (0.19)	0.37	0.42
−25: −1	15.99 (12.32)*	58.04 (27.62)*	<0.001	1.91
0: 25	53.68 (24.29)	37.52 (24.27)	0.12	0.67
26: 50	24.73 (19.22)*	4.19 (9.48)*	<0.001	1.39
51: 75	3.30 (9.59)	0.12 (0.33)	0.29	0.49
76 +	0.34 (0.94)	0.03 (0.07)	0.28	0.49

* significant difference between groups independent *t*-test.

Table 6
Cumulative distribution function postures for each group and different percentiles (mean (SD)).*

Percentage CDF	Low Back Pain Standing (%)	Control Standing (%)	p-value	Effect size
Stand 10%	−14.49 (12.39)	−26.25 (38.41)	0.35	0.40
Stand 50%	6.72 (12.81)	3.35 (27.52)	0.72	0.15
Stand 90%	32.79 (10.83)	37.75 (18.88)	0.45	0.33
Sit 10%	43.69 (27.44)	36.85 (30.25)	0.57	0.08
Sit 50%	86.89 (31.46)	65.25 (29.30)	0.10	0.65
Sit 90%	102.00 (15.53)	85.19 (21.25)	0.04	0.90

* significant difference between groups independent t-test.

developed transient pain. Where differences were observed these differences appear to contradict existing studies. Davidson and Callaghan (Davidson and Callaghan, 2025) reported less posterior pelvic tilt and forward trunk inclination angle at the 90th percentile of their CDF, suggestive of less frequent flexed sitting postures, which contradicts the findings of our study where more flexed sitting postures were evident at the 90th percentile. This difference may be explained by the different populations used in these studies, where the current study investigated individuals with LBP as opposed to healthy individuals who went on to develop pain. Conflicting findings were also observed with respect to lumbar movement variability. Davidson and Callaghan (Davidson and Callaghan, 2025) and Greene et al. (Greene et al., 2019) reported less fidgeting in pain developers, whereas the present study found greater sitting fidgeting in the LBP group, consistent with wider literature reporting increased fidgeting in individuals with LBP (De Carvalho and Callaghan, 2023; Dunk and Callaghan, 2010). The inconsistency across studies may suggest that fidgeting behaviour is more nuanced at the individual level than a uniform group-level response and may not represent a consistent characteristic of either pain developers or individuals with LBP more broadly.

Real-world studies of standing posture across the day are limited, and the findings of this study offer preliminary insights into standing postural behaviour and LBP that are not currently available in the existing literature, with this study finding some differences for the frequency of use of certain postures. The LBP group utilised a slightly flexed standing posture with greater frequency than the healthy controls who in turn used a slightly more lordotic standing posture more frequently. Embedding these findings within the existing literature is difficult as this relates to frequency of use and needs continuous measurement over a prolonged period. Previous studies investigating healthy individuals standing for 2 h demonstrated pain developers stood with more lordosis (Fewster et al., 2024), however systematic reviews of lordosis in individuals with LBP show reduced lordosis compared to controls (Chun et al., 2017). It is also worth noting that these previous studies report posture as a single summary value rather than a distribution of postures across the day. Such estimates are likely to reflect both the individual's habitual posture but also the constraints imposed by the specific task or environment in which they were measured and may therefore fail to capture the full breadth of postural behaviour exhibited across a free-living day.

The findings of the current study overall demonstrate many similarities between individuals with LBP and those without. This could be due to several reasons. Firstly, it may suggest small sample sizes limiting the statistical power. In such cases it is suggested to calculate post hoc power or observed power; however, due to the relationship between observed power and the *p*-value this fails provide insights beyond those observed by the statistical tests (Hoenig and Heisey, 2001; Lenth, 2001). This approach is, therefore, not recommended (Levine and MHH, 2001). Secondly the lack of overall difference could be due to the large variability between individuals, which can be evidenced in the large standard deviations evident in the tables above. This suggests that group level estimates and comparisons may not be the optimal approach due to such large heterogeneity within the group and suggests future approaches could either look to homogenise and subcategories the groups (Bacon et al., 2020), for example through tighter inclusion criteria, or explore individuals at the individual level.

Lastly, the few differences observed between groups may reflect similarity in through-day postural behaviour between those with and without LBP, though this interpretation must be treated with considerable caution given the small sample size and the large inter-individual variability observed (Davidson and Callaghan, 2025). It is possible that similar postures can result in being provocative for some and non-provocative for others. This could be explained by specific tissues being 'sensitised' and subsequently having reduced postural loading tolerance. Previous authors have identified focal loading of specific anatomical structures in specific postures (McGill and Kippers, 1994; Shirazi-Adl and Drouin, 1987). If such tissues were sensitised, it may be a pathway to mechanical provocation. For example, a slight increase of extension at a single motion segment increased the compressive load borne by the zygapophyseal joints by 16% (Adams and Hutton, 1980), therefore if these joints were sensitive this increased load may result in the provocation pain.

There are several strengths and limitations to this work. Firstly, this work employed a user accepted whole day approach to the monitoring of lumbar kinematics. Secondly it explored postural behaviour of both sitting and standing in the real-world offering comparisons between individuals with and without LBP. However, whilst attempts were made through the inclusion criteria to select individuals with mechanically evoked LBP, it is likely this group contained diagnostic heterogeneity. Individuals had relatively low levels of pain and disability, and it is not known if similar findings would be had for individuals with different pain experiences. Even though all individuals reported pain provocation, it is not known if the day of data collection was representative of a typical day for the individuals. A small sample size was used; therefore, a larger sample may have revealed additional insights. Moreover, no sex differences were explored due to the small sample size. Whilst statistically significant differences in age ($p = 0.043$) and weight ($p = 0.0084$) were observed between groups, evidence suggests that within the age range of participants in this study these variables have a negligible effect on lumbar posture (Youdas et al., 2006); nevertheless, future studies should seek to match groups on these characteristics or incorporate them as covariates.

5. Conclusions

This study is the first to compare whole-day, real-world lumbar posture in individuals with and without LBP. Overall, sitting and standing postural behaviours were broadly similar between groups, though individuals with LBP demonstrated a tendency towards greater sitting fidgeting and more frequent use of flexed postures during standing. Importantly, substantial within-group variability was evident across all participants, reinforcing that a single 'typical' spinal posture is unlikely to be representative of any individual's postural behaviour across a full day.

These findings tentatively suggest that mean posture alone may be insufficient to differentiate those with and without LBP, and that temporal aspects of postural behaviour, such as fidgeting and the frequency of use of specific postural ranges, may warrant further investigation. However, given the small sample size and the large inter-individual variability observed, these findings should be considered preliminary and interpreted with caution. Future work with larger, more homogeneous samples should seek to explore individualised relationships between posture and the provocation of pain, which may ultimately provide a more meaningful basis for informing clinical assessment and treatment strategies.

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CRediT authorship contribution statement

Frederick A. McClintock: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrew J. Callaway:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Carol J. Clark:** Writing – review & editing, Investigation, Conceptualization. **Elena Muñoz-Gómez:** Writing – review & editing, Software. **Raee S. Alqhtani:** Writing – review & editing, Data curation. **Jonathan M. Williams:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization.

Informed consent statement

Informed consent was obtained from all participants involved in the study.

Institutional review board statement

This study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Najran University.

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Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data can be obtained by request from authors.

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