A Comparison of Lumbosacral Kinematics during Prolonged Sitting in Non-specific Chronic Low Back Pain Subgroups; a cross-sectional study

Mansoor Alameri (Malameri@llu.edu)
Loma Linda University https://orcid.org/0000-0002-7986-5765
Everett Lohman III
Loma Linda University
Noha Daher
Loma Linda University School of Public Health
Robert Dudley
Azusa Pacific University
Amjad Shallan
Loma Linda University
Hatem Jaber
Saint Augustine university

Research article

Keywords: Low back pain, Motor control impairment, Flexion pattern disorder, Active extension pattern disorder, Prolonged sitting, Lumbosacral kinematics.

Posted Date: August 16th, 2019

DOI: https://doi.org/10.21203/rs.2.13079/v1

Abstract

Abstract Background: Although, non-specific chronic low back pain (NSCLBP) has been associated with abnormal lumbosacral kinematics, little is known about the possible driving mechanisms of pain development overtime during prolonged sitting period. Therefore, the purpose of this study was to examine the differences in lumbosacral postures in adults with and without NSCLBP, and their role on pain development during a 1-hour of prolonged sitting task. Methods: Twenty NSCLBP subjects with motor control impairment (MCI) [10 classified as having flexion pattern (FP) disorder, and 10 with active extension pattern (AEP) disorder], and 10 healthy controls participated in the study. Subjects underwent a 1-hour sitting protocol on a standard office chair. Lumbosacral postures including: sacral tilt (ST), third lumbar vertebrae (L3) position, and relative lower lumbar angle (RLLA) were recorded using a two-dimensional inclinometer over the 1-hour period. Perceived back pain intensity was recorded using a numeric pain rating scale every 10 minutes throughout the sitting period. Results: All study groups presented with significantly distinctive lumbosacral kinematics at the lowest level of pain (the beginning of the sitting period) ($p<0.05$), as well as at the highest level of pain (the end of the sitting period) (p£0.05). The MCI subgroups showed a significant deterioration in lumbosacral kinematics and pain levels overtime ($p<0.01$). The directions of deterioration in lumbosacral kinematics over the 1-hour sitting period occurred in the direction of the motor control impairment (kyphosis for FP subgroup or lordosis for the AEP subgroup). Both MCI subgroups reported a similarly significant increase in pain through mid-sitting ($p<0.001$). However, after mid-sitting, the AEP subgroup displayed a significantly reversed decrease in the lordotic postures ($p=0.001$) which was accompanied by much less increase in pain level compared to the FP subgroup. Conclusion : The present study's findings suggest that MCI subgroups presented with distinctive underlying maladaptive postural patterns. However, the significant increase in pain over the 1-hour sitting might not be only attributed to the inherent maladaptive postures, also it may be related to the directional deterioration in lumbosacral postures overtime.

Background

Low back pain (LBP) is a common health condition associated with physical, social and economic burden, and it has been identified as the leading cause of disability globally (1, 2). Its prevalence per month is estimated to be 23% in general population and continue to exponentially rise (3). Although, most LBP cases recover within 3 to 4 weeks (4-6), a quarter to a third continue to report pain which becomes chronic (6-8). Previous research reported that approximately 85% of chronic LBP (CLBP) conditions have unrecognizable cause or specific pathology and are often identified as non-specific CLBP (NSCLBP) disorder (6, 7). The inability to define an underlying cause of NSCLBP disorder has been primarily attributed to the heterogeneity, multidimensionality, and complexity of the disorder (9, 10). Thus, defining homogenous subgroups as well as considering a broad biopsychosocial model of this pain disorder have been ranked as a top priority in spine pain management research (9, 11-14).

A multidimensional classification system (MDCS) has been proposed to classify NSCLBP disorders based on biomechanical and psychosocial constructs of the disorder in an attempt to understand the

possible underlying mechanisms of pain (9, 11-13, 15, 16). This system has been widely accepted in literature (9), but most importantly, treatment approaches based on this system have been shown to be effective in reducing back pain (9, 14, 17). In this system, a large number of NSCLBP patients are classified as motor control impairment (MCI) subgroups, in which a maladaptive motor response is reported as the main possible driver of pain (9). This motor dysfunction is thought to be secondary to the loss of motor control of the moving segment around the neutral zone resulting in a non-physiological spinal loading or movement (9, 11, 13, 15).

Previous researches have reported that individuals with NSCLBP with MCI exhibited high levels of fear avoidance behavior, abnormal activation of trunk muscles (13, 16), altered spinal position sense (18), and assumed spinal end ranges toward the direction of pain provocation - commonly flexion [called flexion pattern subgroup (FP)] or extension [called active extension pattern subgroup (AEP)] (17, 19). Previous studies reported that during 5-10 seconds sitting, patients with FP subgroup assumed an end-range flexion position (kyphosis) of the lumbar spine, whereby, AEP patients actively postured themselves into lordosis and showed high levels of activation of trunk muscles (13, 15). Although the suggested postural faults, in the studies cited above, were inherent and displayed prior to the actual onset of pain (9, 11, 13, 15), they are thought to predispose one to pain development over time. Therefore, studies examining how MCI subgroups operate over an extended period of time might be needed to confirm this notion.

In an attempt to address the postural behaviors inherently adopted by the MCI subgroups, O'Keeffe, Dankaerts (17), (20) examined the effect of altering sitting kinematics using chairs with adjustable seatpan inclinations on back discomfort levels. Results of both studies showed that the level of discomfort significantly decreased during sitting on a standardized chair for the AEP subgroup, and during sitting on a forward-inclined chair for the FP subgroup (17). Although these findings are viable means for providing answers regarding pain development over time, no study has yet examined the postural behavioral patterns of the lumbosacral region and their influence on pain during the exposure to prolonged tasks such as siting. Therefore, studies examining lumbosacral kinematics at lowest and highest levels of pain provoked by means of prolonged sitting are needed to further understand the nature of the relationship between lumbosacral kinematics and pain development over time among the MCI subgroups.

Prolonged sitting is widely accepted as a risk factor in developing LBP (21), and frequently reported to aggravate pain in the NSCLBP population (17, 19, 22). Because the prevalence of occupations that requires sitting for an extended period of time increases (13, 15, 16, 23), research examining prolonged sitting posture in homogenous NSCLBP patients might be relevant. Identifying distinctive postural patterns among the NSCLBP subgroups in presence of pain, using the validated MDCS, will facilitate further understanding of the mechanism of pain development, and eventually support the ability of clinicians to provide customized, subgroup-specific interventions to optimize outcomes. Furthermore, because MCI subgroups reported pain during the exposure to prolonged tasks, the present study focused on the MCI subgroups with either FP or AEP disorder. Therefore, the purpose of this study was to examine whether the lumbosacral spine postures a) differed among FP, AEP subgroups and healthy controls, b)

changed overtime when pain is at its lowest and at its highest over a 1-hour sitting task. It was hypothesized that subjects with FP disorder would display lumbosacral kyphotic postures whereas those with AEP would assume lumbosacral lordosis as the pain is at its lowest level, and that these postures would deteriorate toward the end ranges over the 1-hour sitting period as the pain is at its highest level.

Methods

Study's aim, design and sitting

The aim of this cross-sectional study was to examine the differences and overtime changes in lumbosacral postures in adults with and without NSCLBP, and their role on pain development during a 1-hour of prolonged sitting task at a work-simulated laboratory setting.

Participants

A total of 38 subjects; 27 NSCLBP with MCI and 11 healthy controls were recruited from private outpatient physical therapy clinics and Loma Linda University Health (LLUH). Because of the strict inclusion criteria, 5 NSCLBP subjects were excluded due to low pain level in the NPRS (<2/10); 2 NSCLBP subjects due to the inability to establish mechanical basis of the disorder, and 1 healthy control was also excluded due to pain development after 40 minutes of sitting. The recruitment of NSCLBP subjects was completed by two therapists (MA and AS) independently via a comprehensive subjective assessment and physical examination described elsewhere (9, 15, 24). Only subjects with FP or AEP, in which both therapists were in agreement, were included in the study. Previous research reported a substantial agreement between therapists upon the classification of NSCLBP with MCI advocating its intra-rater reliability (25, 26). Inclusion and exclusion criteria are summarized in **Table 1.** Ethical approval was obtained from the Institutional Review Board at LLUH #5180306. Since subjects often sit for prolonged periods and reported LBP during performing this, they were informed that they were likely to experience LBP during a 1-hour sitting period. However, they were informed that they could discontinue the testing protocol at any moment if they wished. All subjects read and signed a written informed consent prior to participation in the study.

Gender, age, anthropometric data [weight, height, and body mass index (BMI)], perceived pain using the Numeric Pain Rating Scale (NPRS) [in the past week, 24 hours and at baseline] (19, 23, 27), pain duration, pain-related disability [Ronald Morris Disability Questionnaire (RMDQ) (28)] and Tampa Scale of Kinesophobia (TSK) (29)] were compared by group in **Table 2.** Data collection were conducted at the Orthopedic and Manual Therapy Laboratory, Department of Physical Therapy, LLUH, California, United States.

Instrumentation

2-Dimensional Inclinometer (2D-Inclinmeter). 2D inclinometer sensors [4 × 2.5 × 1.4 cm x 45.5 g] (Noraxon USA, Inc, Scottsdale, AZ) were used to record lumbosacral angles during the 1-hour siting period. 2D

inclinometer is a noninvasive electromagnetic device, which measures the tilt level of the sensor to the ground in two planes expressed in degrees (30, 31). In alignment with previous studies, the postures the sacral tilt and third lumbar vertebrae (L3) were recorded. Also, the sum of the sacral tilt and its correspondent L3 position was manually calculated to indicate the global position of the lumbosacral region, namely as the relative lower lumbar angle (RLLA) (13, 15).

Perceived Pain. While it is challenging to measure pain intensity (19), perceived pain scores was measured using the open NPRS during the 1-hour sitting period. The NPRS consists of a 100 mm horizontal line, anchored by the descriptors “no pain” and “worst pain imaginable” (27).

Procedures

Placement of the 2D-Inclinometer Sensors. A pair of 2D-sensor was attached using double-sided tape to continuously measure the sacral tilt, L3 angles throughout the 1-hour sitting period. The therapist identified anatomical landmarks for each subject and positioned the sensors on the landmarks. Specifically, one sensor was placed over the spinous process of S2 while the other sensor was placed over the spinous process of L3. The same therapist positioned all sensors to ensure consistency.

Pain Measurement. Perceived pain was collected immediately prior to the beginning of the sitting protocol, and every 10 minutes throughout the 1-hour. Thus, a total of seven readings for each subject was taken. All subjects were asked to rate their pain by making a vertical line in the open NPRS at the point corresponding to their level of pain/discomfort. To avoid artificial increase in the NPRS scores, all subjects were asked to focus on pain intensity rather than the location of their pain (19, 23). Additionally, subjects were allowed to compare their current NPRS score with the preceding scores to minimize unintended rating variations when drawing lines correspondent to their pain (19).

1-Hour Sitting Protocol. Following sensor placements, all subjects underwent a 1-hour sitting protocol in which they sat on an office chair reading pre-selected passages. Prior to sitting, the chair was modified by removing the backrests and armrests so they do not interfere with data collection (23). Although, this might alter the sitting behavior of the subjects, previous study found no difference in back discomfort levels when sitting in an office chair with backrest or without backrest (20). Therefore, this modification is deemed to be appropriate. In addition, the height of the chair was adjusted so that the subjects sat with hips and knees approximately at 90^0 of flexion (23) and feet rested on the floor (17). Subjects were then provided with a standard office workstation setup, including a monitor, with the top of the screen at eye level, a keyboard and a mouse (23). Subjects were instructed to read and follow the text on the monitor with the mouse cursor using the right hand and pressing the ‘Shift’ key on the keyboard to move to the next paragraph using the left hand (23, 32). The subjects’ elbows were kept at $90–100^o$ of flexion while reading, thus the height of the keyboard and mouse was adjusted to maintain this elbow angle (17). The distance from the keyboard was standardized for all subjects, in which the edge of the keyboard was in line with the radial styloid process and a distance of approximately 30 cm to subjects’ greater trochanter (17). Thus, the potential for confounding variables to effect the study findings was minimized. Finally,

just prior to launching the 1-hour sitting protocol, all subjects were instructed to “sit as they normally will’ on their office chairs.

Over the 1-hour sitting period, the degree of tilt of the sacrum and lumbar spine (15, 30) were recorded. Pain levels (19, 23) were also recorded at baseline and every 10 minutes throughout the sitting protocol.

Data Processing

Sacral Tilt, Lumber 3 Position (L3), Relative Lower Lumbar Angles (RLLA). For the sacral tilt and L3 angle in relation to the ground, the angles were recorded for 45 seconds before the 1-hour sitting period and the mean recorded angle was selected as reference value and used for calibration (31). To measure the deviation of each sensor from sagittal plane, the sacral tilt and L3 angle were measured throughout the entire 1-hour sitting period and every 10 minutes then normalized by subtracting the mean tilt/angle from its reference value, expressed in degrees and used for analysis (15). For the sacral tilt, a positive value indicates an anterior sacral tilt while a negative value indicates a posterior sacral tilt. For the L3 angle, a positive value indicates an extension whereas a negative value indicates a flexion. Furthermore, the sum of calibrated sacral tilt and its correspondent L3 angle was used to manually calculate the RLLA over the entire 1-hour sitting period and every 10 minutes. The RLLA represents the position of pelvis in relation to lower lumbar spine and is formed from the intersection between the inclination of the sensors lines at L3 and S2 (15). A positive value of the RLLA indicates a lordosis and a negative value indicates a lower lumbar kyphosis. The mean sacral tilt, L3 and RLLA were selected over the entire 1-hour sitting, as well as at the beginning of the sitting period (baseline) and every 10 minutes throughout the 1-hour testing period (a total of 7 values) for analysis.

Numeric Pain Rating Scale (NPRS). Post-collection, the perceived pain (a total of 7 readings) was used for analysis. For the pain subgroups, the NPRS scores were used to determine which data to be used for the primary analysis for each subject. For example, if a subject reported the lowest level of pain at the beginning, and the highest pain level at the third 10-minute interval of the sitting period, then only lumbosacral angles at the beginning of the sitting period and third 10-minute intervals were used for comparison within the same group and between study’s groups. This way, we were able to compare the lumbosacral postures of each subject when the pain was at its lowest and highest levels.

Statistical analysis

Data was summarized using mean and standard deviation (SD) for quantitative variables and counts (%) for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk’s test and Q-Q normality plots. The distribution of the subjects’ characteristics by study group were evaluated using chi-square for gender, one-way Analysis of Variance (ANOVA) for age, height, mass and BMI, and independent t-test for duration of pain, NPRS (during past 24 hours, past week, and baseline), TSK and RMDI scores.

The primary analysis included a comparison of lumbopelvic kinematics (sacral tilt, L3 and RLLA) across groups at the lowest (baseline) and highest level of pain (minute 60) using one-way ANOVA (with post-hoc Bonferroni if results were significant). The secondary analysis included a comparison of lumbopelvic kinematics across groups over the entire 1-hour sitting using one-way ANOVA (with post-hoc Bonferroni). A third analysis included a 3x7 mixed factorial ANOVA (between factor: group; within factor: time) to examine changes in lumbopelvic kinematics and NPRS by study group over time. If the group x time interaction effect in the mixed factorial ANOVA was statistically significant, change from baseline was compared among groups at each time period (total of six “10-minute intervals”) using one-way ANOVA (with post-hoc Bonferroni). If the interaction was not statistically significant, the between-groups comparison was considered not statistically significant. However, if the main effect of time was significant in the mixed factorial ANOVA, a one-way repeated measures ANOVA (with post-hoc Bonferroni) was used to examine changes over time within-groups separately. The level of significance was set at $p \leq 0.05$. Statistical analysis was performed using IBM SPSS Software version 24 for Windows (Chicago, IL, USA).

Sample size estimate

For the primary and secondary analyses, a sample size of 30 subjects was estimated using a large effect size (h^2=0.26), level of significance (α= 0.05), and power of 0.80. For the third analysis, a sample size of 30 subjects was estimated using a moderate effect size for the group x time interaction (partial h^2=0.06), level of significance (α= 0.05), and power of 0.90.

Results

A sample of 30 subjects with mean age 27.6±4.9 years, mass151.9±30.3 lbs., height 5.4±0.4 feet, BMI 25.0 ±3.9 kg/m2 participated in this study. Fifty-seven percent of the subjects were males (n=17). The distribution of all quantitative variables was approximately normal. There was no significant difference in subjects’ characteristics by study group (p>0.05). Subjects' characteristics are summarized in **Table 2.**

Primary Analysis

Figure 1. shows the differences in lumbosacral kinematics between groups at the beginning and the end of 1-hour sitting. There was a significant difference in ST and L3 angle among the three study groups at the lowest level of pain, which was at beginning of the sitting period, (p=0.029, h^2= 0.23 for ST and p<0.001, h^2= 0.44 for L3 angle). Bonferroni post hoc comparisons showed that the difference in ST was only significant between the FP and AEP subgroups (p=0.031), namely, the FP subgroup had slight posterior sacral tilt (-0.45°±2.02°), while the AEP subgroup had an increased anterior sacral tilt (3.35° ±2.91°). In addition, the difference in L3 angle was only significant between FP subgroup and healthy controls (p=0.004), and between FP and AEP subgroups (p=0.001). Specifically, FP subgroup had greater L3 flexion (-3.11°±2.53°) compared to healthy controls (0.53°±2.48°) and AEP subgroup (1.19°±1.64°) who demonstrated slight L3 extension.

In contrast, all lumbosacral angles differed significantly among the three study groups at the highest level of pain, which was at minute 60 of sitting period ($p<0.001$, $h^2= 0.74$ for ST, $p<0.001$, $h^2= 0.72$ for L3 angle, and $p=0.013$, $h^2= 0.36$ for RLLA). Bonferroni post hoc comparisons revealed that the difference in ST was only significant between FP subgroup and healthy controls ($p<0.001$), and between FP and AEP subgroups ($p<0.001$). Namely, FP had greater posterior sacral tilt (-6.59°±2.95°) compared to healthy controls (1.04°±2.97°) and AEP subgroup (3.45°±2.02°) who exhibited anterior sacral tilt. Furthermore, the difference in L3 angle was significant among all study groups ($p<0.01$). The FP subgroup had greater L3 flexion compared to healthy controls (-6.82°±2.05° vs. 0.15°±4.24°, $p<0.001$) and AEP subgroup who demonstrated L3 extension (-6.82°±2.05° vs. 4.97°±2.94°, $p<0.001$). Also, the AEP had greater L3 extension compared to healthy controls (4.98°±2.94° vs. 0.15°±4.24°, $p=0.007$). Moreover, the difference in RLLA was only significant between FP subgroup and healthy controls ($p=0.020$), and between FP and AEP subgroups ($p=0.048$). The FP subgroup had greater lumbar kyphosis (-7.55°±10.0°) compared to healthy controls (1.20°±5.45°) and AEP subgroup (0.09°±1.56°) who assumed slightly lumbar lordosis.

Secondary Analysis

Figure 2. shows the mean of lumbosacral kinematics of all study groups over the 1-hour sitting. There was a significant difference in mean lumbosacral angles (ST and L3 angle) among the three study groups over the entire 1-hour sitting ($p<0.001$, $h^2= 0.43$, $p<0.001$, $h^2= 0.70$, respectively). Bonferroni post hoc comparisons showed that the difference in mean ST angle was only significant between the FP and AEP subgroups ($p<0.001$). Specifically, the FP subgroup displayed, at large, a posterior sacral tilt presentation (-1.65°±1.16°), whereas the AEP subgroup exhibited an increased anterior sacral tilt (3.90° ±2.70°). In addition, the difference in mean L3 was significant among all study groups ($p<0.01$). The FP subgroup had greater L3 flexion compared to healthy controls (-5.40°±1.60° vs. -0.47°±3.31°, $p<0.001$) and AEP subgroup who demonstrated L3 extension (-5.40°±1.60° vs. 2.92°±1.70°, $p<0.001$). In addition, the AEP had greater L3 extension compared to healthy controls (2.92°±1.70°, vs. -0.47°±3.31°, °, $p=0.009$). However, there was no significant difference in mean RLLA among all study groups ($p=0.412$).

The results of the analysis of time (min), expressed as a % of the total 1-hour of sitting period, spent in the available ranges of the studied lumbosacral angles showed that the FP subgroup spent more time sitting with posteriorly tilted pelvis (73.3%), whereas the AEP subgroup spent almost all of their sitting time in anterior pelvic tilt (91.1%). In contrast to the pain subgroups, the healthy controls spent 66.7% of their sitting time in anterior pelvic tilt compared to only 33.4% in the posterior direction. In addition, the FP subgroup sat with flexed L3 for 96.7% of the entire sitting period, in contrast, AEP subgroup spent 93.7% of the total sitting time in L3 extension. In comparison to pain subgroups, the healthy controls spent 65.1% of their sitting time in L3 flexion compared to 34.9% in extension. Furthermore, the FP subgroup spent, on average, 53.7% of their sitting time in lower lumbar kyphosis, while the AEP subgroup spent 71.1% of the sitting time in lordosis. Similar to the FP subgroup, healthy controls postured themselves in kyphosis for 53.3% of the sitting time compared to 46.7% in lordosis for the FP subgroup. Refer to **Figure 3.**

Third Analysis

Figure 4. shows the average pain scores of all groups over the 1-hour sitting. The mixed factorial analysis showed a significant group by time interaction effect for pain ($p<0.001$, $h^2=0.47$). Results of the one-way ANOVA indicated that the difference in the amount of change from baseline was significant among the three groups at all time periods ($p<0.001$). Specifically, Bonferroni post hoc comparisons revealed that both pain subgroups significantly differed from healthy controls at all time periods ($p<0.05$). However, during the first 30 minutes of sitting, pain subgroups did not differ from each other, whereby, during the last 30 minutes, both FP and AEP subgroups were significantly different ($p<0.01$). Namely, the FP subgroup reported a significant increase in pain scores compared to the AEP subgroup at minute 40 (38.10±15.03 vs. 20.00±9.53, $p=0.002$), minute 50 (45.50±18.29 vs. 24.50±16.09, $p=0.007$), and minute 60 (49.20±16.82 vs. 27.40±19.67, $p=0.009$). Similar results were found when adding pain at baseline as a covariate. The level of pain reported by the pain subgroups increased significantly over time ($p<0.001$, $h^2=0.80$ for FP and $h^2=0.44$ for AEP), whereby the pain peaked towards the end of the sitting period and increased significantly from baseline after 20 minutes of the sitting period (FP, $p<0.01$ and AEP, $p<0.05$).

There was a significant group by time interaction effect for ST after controlling for baseline ST angle ($p<0.001$, $h^2=0.45$). Results of the one-way ANOVA indicated that the difference in the amount of ST change from baseline was significant among the three groups at minute 20 until the end of the 60-minute sitting period ($p<0.05$). To narrow the results, the amount of ST change from baseline was only reported for the late phase of sitting (at minute 60). Bonferroni post hoc comparisons revealed that the FP subgroup significantly differed from the AEP subgroup ($P<0.001$), and healthy controls ($p=0.001$), but no significant difference was found between AEP subgroup and healthy controls. The degree of ST displayed by the pain subgroups increased significantly over time (FP; $p<0.001$, $h^2=0.57$; AEP; $p<0.001$, $h^2=0.36$). Specifically, the FP subgroup showed a significant increase in posterior sacral tilt from baseline at only minute 60 (the end of the sitting period) (-0.45°±2.02° vs. -6.59°±2.95°, $p=0.002$), but this change was not statistically significant during the first 50 minutes of sitting. In contrast, the AEP subgroup showed a significant increase in anterior sacral tilt from baseline only at minute 40 (3.35°±2.91° vs. 5.98° ±2.03°, $p=0.005$), which then followed by a significant decreased at minute 50 (5.98°±2.03° vs. 3.79° ±2.25°, $p<0.001$) and minute 60 (5.98°±2.03° vs. 3.45°±2.03°, $p=0.001$). However, there was no any significant change in ST over time in healthy controls ($p=0.153$, $h^2=0.16$). Refer to **Figure 5.a.**

In addition, there was a significant group by time interaction effect for L3 after controlling for baseline L3 angle ($p<0.001$, $h^2=0.34$). Results of the one-way ANOVA indicated that the difference in the amount of L3 change from baseline was significant among the three groups at all 6 time periods ($p<0.05$). Bonferroni post hoc comparisons revealed that at minute 60, all groups significantly differed from each other (FP vs. controls, $p=0.005$; AEP vs. controls, $p<0.001$; and FP vs. AEP, $p<0.001$). The degree of L3 displayed by the pain subgroups increased significantly over time (FP; $p=0.017$, $h^2=0.24$; AEP; $p<0.001$, $h^2=0.55$). Specifically, the FP subgroup showed a significant increase in L3 flexion from baseline to minute 60 (-3.12°±2.53° vs. -6.81°±2.05°, $p<0.001$). In contrast, the AEP subgroup showed a significant increase in

L3 extension from baseline to minute 60 (1.20°±1.64° vs. 5.01°±2.94°, p=0.001). However, the control group did not show any significant change in L3 over time and remained relatively close to the neutral range (p=0.294, h^2=0.12). Refer to **Figure 5.b.**

Furthermore, there was a significant group by time interaction effect for RLLA after controlling for baseline RLLA angle (p<0.001, h^2=0.36). Results of the one-way ANOVA showed that the difference in the amount of RLLA change from baseline was significant among the three groups at minute 20 and 40 (p<0.5). Bonferroni post hoc comparisons revealed that at minute 20, the FP subgroup significantly differed from healthy controls (p=0.002), but no significant difference was found between both pain subgroups or between the AEP subgroup and healthy controls. However, at minute 40, only the AEP subgroup significantly differed from healthy controls (p=0.025). The degree of RLLA exhibited by the pain subgroups increased significantly over time (FP; p<0.001, h^2=0.45; AEP; p=0.001, h^2=0.33). Specifically, the FP subgroup showed a significant increase in lower lumbar kyphosis from minute 20 to minute 60 (4.49°±6.31° vs. -7.55°±10.00°, p=0.038). In contrast, the AEP subgroup showed a significant increase in lower lumbar lordosis from baseline to minute 40 (2.06°±3.04° vs. 5.98°±0.88°, p=0.006), which was followed by a significant decreased at minute 50 (5.98°±0.88°, vs. 1.30°±1.41°, p<0.001) and minute 60 (5.98°±0.88°, vs. 0.09°±1.56°, p<0.001). However, healthy controls did not show any significant change in RLLA over time (p=0.288, h^2=0.12). Refer to **Figure 5.c.**

Discussion

Summary of the findings:

The present study aimed to investigate spine postural behaviors among two commonly studied MCI subgroups (FP and AEP) compared to heathy controls, and their role on pain development during a 1-hour of prolonged sitting. The results of this study showed that all study groups presented with significantly distinctive postural behaviors at the beginning and at the end of the sitting period. Only the MCI subgroups, however, showed significant deterioration in the lumbosacral kinematics and pain levels overtime. The direction of deterioration in lumbosacral kinematics over the 1-hour sitting period occurred in the direction of the motor control impairment (kyphosis for FP or lordosis for the AEP subgroup). Interestingly, both MCI subgroups reported a similarly significant increase in pain through mid-sitting. However, after mid-sitting, the AEP subgroup displayed a significantly reversed decrease in the lordotic posture which was accompanied by much less increase in pain level compared to the FP subgroup. The findings of this study suggest a possible association between the lumbosacral postures and pain development overtime.

FP subgroup:

In the present study, the FP subgroup exhibited an increased kyphotic presentation of the lower lumbosacral region over the entire 1-hour of sitting period as compared to the other groups. Interestingly, the observed differences in kinematics did not only appear after the onset of increased pain, instead, they

were initially present at baseline, which may further suggest an inherent postural behaviors in the FP subgroup that predisposed them to pain (15, 33). In addition, these behaviors continued to deteriorate in the direction of flexion throughout testing, which could imply an overtime loss of the motor control of the moving lower lumbosacral segments in the direction of pain provocation (9) contributing to the increased pain overtime. Furthermore, over the 1-hour sitting period, FP subgroup did not show any attempt to produce a positional alteration in order to reduce their pain, instead, they maintained a directional increase of the lower lumbosacral flexion. This might further support the presence of a “neutral spinal position deficit” in which they underestimated the neutral position of lower lumbar by adopting a kyphotic posture (34) throughout the sitting period resulting in pain provocation. Lastly, the FP subgroup spent the majority of their sitting, in general, at end-range flexion posture. Maintaining an end-range posture from the beginning through the end of sitting period, as shown clearly in the present study, was accompanied by a significant increase in pain overtime. Specifically, the pain increased to statistically significant level from the beginning of the sitting period after >20 minutes and remained significant for the rest of the sitting period. This could suggest that the exhibited flexion end-range behavior might have caused a progressive increase of the lower lumbar strain in the FP subgroup, disrupting the physiological distribution of spinal loading in lumbosacral structures, leading to the incremental increase in pain over the sitting period (15, 33).

Similar to these findings, previous studies reported a greater posterior sacral tilt (15, 16) and flexion of the lower lumbar angle (15) in the FP subgroup during a 5-second, 1-hour sitting (17), and field cycling (33). Similar to the findings of the present study, the cited studies attributed pain increase to the sustain extreme flexion posture in the FP subgroup (17, 20, 35) secondary to: a) inherent motor control impairments in the direction of flexion, b) proprioceptive alterations of spine structures (34), and c) restricted lumbosacral range of movement toward the opposite direction of the motor control deficits (15). Lastly, it is important to note that the present study determined the direction of the postural control impairment over a 1-hour sitting period and identified its influence in pain increase within the FP subgroup. This could further clarify the underlying mechanism of pain development and eventually assist in the development of customized chairs or biofeedback training approaches into clinical practice to address these postural faults adopted by this subgroup.

AEP subgroup:

In contrast, the AEP subgroup exhibited an increased lordotic posture of the lower lumbosacral region over the entire 1-hour of sitting period as compared to the FP and healthy controls. Similar to the FP subgroup, the observed differences in kinematics were present at baseline and evidently appeared after the onset of pain, which again may further support the presence of the inherent postural behaviors in the AEP subgroup (15, 33). In the same manner to the FP subgroup, the observed postural behaviors continued to deteriorate in the direction of extension but only throughout the early phase of sitting (<40 minutes), which may suggest an overtime loss of the motor control of the lower lumbosacral segments (9) contributing to the increased pain at the early phases of sitting. However, after 40 minutes of sitting, the AEP subgroup showed some positional alteration toward “neutral” which could be interpreted as an

adaptive approach to reduce/control their pain level. This finding might further support that the AEP subgroup possibly had a “neutral spinal position deficit” only at the early phase of sitting period, in which they underestimated the neutral position of lower lumbar by adopting a lordotic posture (34) resulting in pain provocation. However, less positional deficits were observed after 40 minutes of sitting as the AEP subgroup moved toward “neutral”. Lastly, the AEP subgroup spent most of their early sitting time at end-range extension. Sustaining an end-range postures from the beginning through the mid-point of sitting period was associated with a significant increase in pain. Specifically, the pain increased to statistically significant level from the beginning of the sitting period after >20 minutes through the end. Although, the pain after 40 minutes was significantly different from baseline, it was slightly lower compared to the FP subgroup. The initial lordotic behavior over the 1-hour sitting may contribute to the increased extension compressive force, developed by sustained lumbar extension and possible muscle fatigue, in posterior spinal structures resulting in development of pain (15). However, the later correction of the postural faults toward neutral might explain the noted reduction in pain level toward the end of the sitting period in this MCI subgroup.

Similar to these findings, previous studies reported a greater anterior sacral tilt (15, 16) and extension of the lower lumbar angle (15) in the AEP subgroup during 5-second sitting, 10-minute (20), and functional tasks (11). Although sitting in a standard chair might have promoted lower lumbar flexion in the AEP subgroup (20), ironically they assumed hyperextension postures away from the neutral spectrum resulting in pain increase in the first 40 minutes of sitting. However, toward the end of sitting period they assumed more of a neutral posture which was associated with relatively lesser back pain compared to the FP subgroup. The initial lordotic posture could be explained by reduced ability of the AEP subgroup to relax their paraspinal muscles which in return might have minimizing their ability to tilt their pelvis posteriorly (13, 20). Unfortunately, the lack of muscle activation data hindered the ability to confirm this notion. The latter “neutral posture” is in line with the previously reported findings by Curran et al. (2014) [20], in which the AEP subgroup reported greater back discomfort when they sat on a forward inclined seatpan, but the pain was lower while sitting on a flat seatpan chair. The findings from this study could imply that the positions of lumbosacral region in the AEP subgroup were maybe related to pain alterations.

Study Limitations

The levels of trunk muscles activation were not measured in the present study, which might have omitted their influence in spine postures, although previous studies found inconsistent differences in muscle activities among the MCI subgroups (34) or when they are compared to healthy controls (20). In addition, the sitting period was only monitored for an hour, which might not have provided a thorough understanding of how MCI subgroups operates during their daily office tasks that extends beyond an hour. However, due to a) the likelihood of experiencing LBP by these subgroups over a single hour, and b) the logistic of the testing, it was intended to limit the sitting period to an hour to avoid unacceptable pain aggravation. Furthermore, the association between pain levels and lumbosacral kinematics were not analyzed, however, the purpose of this study was to establish the differences among the MCI subgroups

in lumbosacral kinematics prior to the onset of pain increase and at the highest levels of pain over an hour of sitting, and thus the correlation analysis will be performed in depth in a future publication to understand the nature of this relationship. Also, sitting posture might not be challenging enough for the AEP subgroup to produce pain due to its flexed nature (15-17), however, in the present study the AEP subgroup reported an increase in pain level over the 1-hour sitting. This can be attributed to the static loading at the lumbosacral spine associated with the prolonged sitting period making it a provocative means to aggravate pain in both studied MCI subgroups. Although the FP and AEP disorders are sagittal plane motor control deficits, so the two-dimensional inclinometer would sufficiently capture the deviations from the sagittal plane, future studies are warranted to monitor regional and segmental spine postures in the three planes of movements overtime. Unfortunately, this was not available for the present study.

Clinical Implications

The findings of the present study highlight the postural behaviors that NSCLBP patients with MCI display while sitting for an extended period of time. Identifying these behaviors and their contributions to pain development might refine the application of the classification-based cognitive functional therapy (CB-CFT) (14) in FP and AEP subgroups. A postural biofeedback training to facilitate proper lumbosacral kinematics away from the end-range sitting postures, could be relevant in spine rehabilitation for these subgroups (14, 36). Also, incorporation the findings to intervention approaches for these subgroups might advance NSCLBP management. For example, ergonomic recommendations regarding the use of a lumbar roll for the FP subgroup and a declined seatpan for the AEP subgroup might assist in pain reduction among the MCI subgroups.

Conclusion

The results of this study showed that both MCI subgroups presented with distinctive underlying maladaptive postural patterns. However, the significant increase in pain over the 1-hour sitting might not be only attributed to the inherent maladaptive postures, also it may be related to the directional deterioration in lumbosacral postures overtime. Incorporating these findings into treatment strategies might assist in reducing sitting back pain among MCI subgroups.

List Of Abbreviations

Non-Specific Chronic Low Back Pain (NSCLBP)

Motor Control Impairment (MCI)

Flexion Pattern (FP)

Active Extension Pattern (AEP)

Sacral Tilt (ST)

Third Lumbar Vertebrae (L3)

Relative Lower Lumbar Angle (RLLA)

Low Back Pain (LBP)

Chronic LBP (CLBP)

Multidimensional Classification System (MDCS)

Loma Linda University health (LLUH)

Mansoor Alameri (MA)

Amjad Shallan (AS)

Body Mass Index (BMI)

Numeric Pain Rating Scale (NPRS)

Ronald Morris Disability Questionnaire (RMDQ)

Tampa Scale of Kinesophobia (TSK)

2-Dimensional (2D)

Standard Deviation (SD)

One-way Analysis of Variance (ANOVA)

Declarations

Ethical approval. Ethical approval was obtained from the Institutional Review Board at LLUH #5180306. All subjects read and signed a written informed consent prior to participation in the study.

Consent for publication. Clinical data are entirely unidentifiable within the manuscript. Thus, obtaining consent for publication was deemed unnecessary.

Availability of data and materials. The data that support the findings of this study are available from [LLUH] but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of [LLUH].

Competing interests. The authors declare that they have no competing interests.

Funding. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author's contributions.

MA contributed to the conception, participated in the design, managed the data collection, assisted in the statistical analysis, interpreted the data, and substantively revised the manuscript.

EL contributed to the conception, participated in the design, managed the data collection, interpreted the data, and revised the manuscript.

ND participated in the design, managed the data collection, revised the manuscript, and performed the statistical analysis.

RD participated in the design and revised the manuscript.

AS participated in the design, managed the data collection, and revised the manuscript.

HJ contributed to the conception, participated in the design, managed the data collection, assisted in the statistical analysis, interpreted the data, and substantively revised the manuscript.

All authors read and approved the final manuscript.

Acknowledgements. We would like to thank all participants who volunteered their time to advance scientific inquiry.

References

1. Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. **A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010**. The lancet. 2012 Dec 15;380(9859):2224-60.
2. Papageorgiou AC, Croft PR, Ferry S, Jayson M, Silman. **Estimating the prevalence of low back pain in the general population. Evidence from the South Manchester Back Pain Survey.** Spine. 1995 Sep;20(17):1889-94.
3. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, et al. **A systematic review of the global prevalence of low back pain.** Arthritis Rheum. 2012 Jun;64(6):2028-37.
4. Thomas E, Silman AJ, Croft PR, Papageorgiou AC, Jayson MI, Macfarlane GJ. **Predicting who develops chronic low back pain in primary care: a prospective study.** Bmj. 1999 Jun 19;318(7199):1662-7.
5. Hoy D, Brooks P, Blyth F, Buchbinder R. **The epidemiology of low back pain.** Best Pract Res Clin Rheumatol. 2010 Dec 1;24(6):769-81.

6. Hayden J, Dunn K, Van der Windt D, Shaw W. **What is the prognosis of back pain?.** Best Pract Res Clin Rheumatol. 2010 Apr 1;24(2):167-79.
7. Hayden JA, Tougas ME, Riley R, Iles R, Pincus T. I**ndividual recovery expectations and prognosis of outcomes in non-specific low back pain: prognostic factor exemplar review**. Cochrane Database Syst Rev. 2014(9).
8. Dillingham T. **Evaluation and management of low back pain: an overview.** State of the art reviews. 1995;9:559-74.
9. O'Sullivan P. **Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism.** Man Ther. 2005 Nov 1;10(4):242-55.
10. Leboeuf-Yde C, Lauritsen JM, Lauritzen T. **Why has the search for causes of low back pain largely been nonconclusive?** Spine. 1997 Apr 15;22(8):877-81.
11. Hemming R, Sheeran L, van Deursen R, Sparkes V. **Non-specific chronic low back pain: differences in spinal kinematics in subgroups during functional tasks.** Eur Spine J. 2018 Jan 1;27(1):163-70.
12. Hwang U-j, Kwon O-y, Jung S-h, Ahn S-h, Kim H-a. **Predictors of pain intensity and Oswestry Disability Index in prolonged standing service workers with nonspecific chronic low back pain subclassified as active extension pattern.** Musculoskelet Sci Pract. 2019 Apr 1;40:58-64.
13. Dankaerts W, O'sullivan P, Burnett A, Straker L. **Altered patterns of superficial trunk muscle activation during sitting in nonspecific chronic low back pain patients: importance of subclassification.** Spine. 2006 Aug 1;31(17):2017-23.
14. Vibe Fersum K, O'Sullivan P, Skouen J, Smith A, Kvåle A. **Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: A randomized controlled trial.** Eur J Pain. 2013 Jul;17(6):916-28.
15. Dankaerts W, O'sullivan P, Burnett A, Straker L. **Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified.** Spine. 2006 Mar 15;31(6):698-704.
16. Astfalck RG, O'sullivan PB, Straker LM, Smith AJ, Burnett A, Caneiro JP, et al. **Sitting postures and trunk muscle activity in adolescents with and without nonspecific chronic low back pain: an analysis based on subclassification.** Spine. 2010 Jun 15;35(14):1387-95.
17. O'Keeffe M, Dankaerts W, O'Sullivan P, O'Sullivan L, O'Sullivan. **Specific flexion-related low back pain and sitting: comparison of seated discomfort on two different chairs.** Ergonomics. 2013 Apr 1;56(4):650-8.
18. Sheeran L, Sparkes V, Caterson B, Busse-Morris M, van Deursen. **Spinal position sense and trunk muscle activity during sitting and standing in nonspecific chronic low back pain: classification analysis.** Spine. 2012 Apr 15;37(8):E486-95.
19. Deursen Lv, Patijn J, Durinck J, Brouwer R, Erven-Sommers Jv, Vortman B. **Sitting and low back pain: The positive effect of rotatory dynamic stimuli during prolonged sitting.** Eur Spine J. 1999 Jun 1;8(3):187-93.

20. Curran M, Dankaerts W, O'Sullivan P, O'Sullivan L, O'Sullivan K. **The effect of a backrest and seatpan inclination on sitting discomfort and trunk muscle activation in subjects with extension-related low back pain.** Ergonomics. 2014 May 4;57(5):733-43.
21. Andersson G. **Epidemiologic aspects on low-back pain in industry.** Spine. 1981;6(1):53-60.
22. Pynt J, Higgs J, Mackey M. **Seeking the optimal posture of the seated lumbar spine.** Physiother Theory Pract. 2001 Jan 1;17(1):5-21.
23. Schinkel-Ivy A, Nairn BC, Drake JD. **Investigation of trunk muscle co-contraction and its association with low back pain development during prolonged sitting.** J Electromyogr Kinesiol. 2013 Aug 1;23(4):778-86.
24. O'Sullivan PB. **Lumbar segmentalinstability': clinical presentation and specific stabilizing exercise management.** Man Ther. 2000 Feb 1;5(1):2-12.
25. Dankaerts W, O'sullivan P, Straker L, Burnett A, Skouen J. **The inter-examiner reliability of a classification method for non-specific chronic low back pain patients with motor control impairment.** Man Ther. 2006 Feb 1;11(1):28-39.
26. Dankaerts W, O'Sullivan P. **The validity of O'Sullivan's classification system (CS) for a sub-group of NS-CLBP with motor control impairment (MCI): overview of a series of studies and review of the literature.** Man Ther. 2011 Feb 1;16(1):9-14.
27. Hawker GA, Mian S, Kendzerska T, French M. **Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap).** Arthritis Care Res. 2011 Nov;63(S11):S240-52.
28. Rabey M, Smith A, Beales D, Slater H, O'sullivan P. **Differing psychologically derived clusters in people with chronic low back pain are associated with different multidimensional profiles.** Clin J Pain. 2016 Dec 1;32(12):1015-27.
29. Lentz TA, Beneciuk JM, Bialosky JE, Zeppieri Jr G, Dai Y, Wu SS, et al. **Development of a yellow flag assessment tool for orthopaedic physical therapists: results from the optimal screening for prediction of referral and outcome (OSPRO) cohort.** J Orthop Sports Phys Ther. 2016 May;46(5):327-43.
30. Kamil NSM, Dawal SZM. **Effect of postural angle on back muscle activities in aging female workers performing computer tasks.** J Phys Ther Sci. 2015;27(6):1967-70.
31. Mork PJ, Westgaard RH. **Back posture and low back muscle activity in female computer workers: a field study.** Clin Biomech 2009 Feb 1;24(2):169-75.
32. Nairn BC, Azar NR, Drake JD. **On-site observations of spine angle data during prolonged office sitting while performing computer-aided drafting work: a case study.** IIE Trans Occup [iso]. 2013 Jan 1;1(1):76-81.
33. Van Hoof W, Volkaerts K, O'Sullivan K, Verschueren S, Dankaerts W. **Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls–field study**

using a wireless posture monitoring system. Man Ther. 2012 Aug 1;17(4):312-7.

34. Sheeran L, Sparkes V, Caterson B, Busse-Morris M, van Deursen R. **Spinal position sense and trunk muscle activity during sitting and standing in nonspecific chronic low back pain: classification analysis.** Spine. 2012 Apr 15;37(8):E486-95.
35. O'Sullivan K, McCarthy R, White A, O'Sullivan L, Dankaerts W. **Lumbar posture and trunk muscle activation during a typing task when sitting on a novel dynamic ergonomic chair.** Ergonomics. 2012 Dec 1;55(12):1586-95.
36. Van Hoof W, Volkaerts K, O'Sullivan K, Verschueren S, Dankaerts W. **Cognitive functional therapy intervention including biofeedback for LBP during cycling: A Single Case Study.** Sport & Geneeskunde. 2011 Oct 1;44(4).

Tables

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• ≥ 3 months NSCLBP • ≥ 5 points scored on RMDQ score • Pain in the lower lumbosacral region • Absence of “red flags” (such as inflammatory diseases or causa equina) • Absence of dominant “yellow flags” (such as identification of beliefs, emotions, and behaviors that interact with the pain problem) • Clear mechanical basis of disorder • Associated impairments in the control of the motion segment(s) in the provocative movement direction (s) • Absence of impaired movement of the symptomatic segment in the painful direction of movement (based on clinical joint mobility examination) • Diagnosis of an FP or AEP disorder (both examining clinicians independently agreed upon the diagnosis)	• <5 points scored on RMDQ score • Signs of neurologic involvement, e.g., radicular pain, and more generalized pain • Evidence of specific diagnosis, e.g., spondylolisthesis, inflammatory disease, • Previous spine surgery • Pregnant at the time of the study or 6 months postpartum

Abbreviation:

NSCLBP, non-specific chronic low back pain; RMDQ, Ronald Morris Disability Questionnaire; LBP, low back pain; FP, flexion pattern; AEP, active extension pattern.

Table 2. Mean (SD) of Baseline Characteristics by Study Group (N = 30).

	FP (n-10)	AEP (n=10)	CG (n=10)	p-value
Male (n)	7	4	6	0.39
Age, y	27.8 (4.0)	27.9 (5.3)	27 (5.8)	0.91
Height, feet	5.8 (0.3)	5.3 (0.3)	5.2 (0.5)	0.06
Mass, lbs	157.5 (30.3)	154.4 (36.1)	143.8 (25.0)	0.58
BMI (kg/m^2)	24.8 (4.5)	25.0 (4.4)	25.2 (2.9)	0.98
NPRS (average/wk/100mm)	45.3 (14.1)	40.0 (19.2)	-	0.50
NPRS (average/24hr/100mm)	19.7 (13.8)	12.0 (10.9)	-	0.31
NPRS (average/Baseline)	17.8 (10.1)	7.9 (6.9)	-	0.02
Pain Duration, y	3.5 (5.3)	6.0 (5.6)	-	0.33
RMDI (%)	7.2 (2.2)	6.0 (1.5)	-	0.24
TSK (64 score)	14.2 (5.7)	22.8 (8.4)	-	0.06

Abbreviation: SD, Standard Deviation; FP, Flexion Pattern; AEP, Active Extension Pattern; CG, Control Group; BMI, Body Mass Index; NPRS, Numeric Pain Rating Scale; RMDI, Ronald Morris Disability Index; TSK, Tampa Scale of Kinesophobia

	FP (n=10)				AEP (n=10)				Healthy Controls (n=10)			
Time	**ST**	**L3**	**RLLA**	**NPRS**	**ST**	**L3**	**RLLA**	**NPRS**	**ST**	**L3**	**RLLA**	**NPRS**
0	-0.4 (2.0)	-3.1 (2.5)	-0.1 (2.6)	17.8 (10.1)	3.3 (2.9)	1.2 (1.6)	2.1 (3.0)	7.9 (6.9)	2.2 (3.9)	0.5 (2.5)	2.8 (4.4)	0.0 (0.0)
10	-0.7 (3.1)	-5.7 (1.5)	0.5 (5.1)	30.9 (16.7)	1.9 (5.0)	2.7 (1.8)	-0.7 (8.7)	21.1 (16.8)	0.9 (4.2)	-0.6 (2.6)	0.3 (5.0)	0.0 (0.0)
20	1.5 (2.8)	-5.3 (2.0)	4.5 (6.3)	37.3 (13.6)	4.3 (3.7)	2.5 (1.4)	3.6 (3.6)	23.6 (13.9)	0.7 (4.3)	-1.0 (3.5)	-0.3 (6.1)	0.0 (0.0)
30	0.3 (1.2)	-6.5 (2.1)	1.7 (8.6)	48.3 (4.7)	4.6 (2.6)	3.9 (1.9)	3.5 (5.9)	29.8 (18.9)	0.3 (4.4)	-1.0 (3.7)	-0.7 (6.6)	0.0 (0.0)
40	-1.5 (2.8)	-6.2 (1.8)	-0.7 (8.8)	55.9 (11.2)	6.0 (2.6)	1.9 (1.3)	6.0 (0.9)	27.9 (12.7)	0.3 (4.6)	-0.8 (4.5)	-0.5 (7.9)	0.0 (0.0)
50	-4.0 (2.9)	-4.2 (5.5)	-4.8 (11.1)	63.3 (9.8)	3.8 (2.2)	3.3 (2.7)	1.3 (1.4)	32.4 (2.1)	0.6 (3.7)	-0.6 (4.0)	0.3 (7.3)	0.0 (0.0)
60	-6.6 (3.0)	-6.8 (2.0)	-7.6 (10.0)	67.1 (9.0)	3.5 (2.0)	5.0 (2.9)	0.1 (1.6)	35.3 (23.7)	1.0 (3.0)	0.1 (4.2)	1.2 (5.5)	0.0 (0.0)
Within group p-value (h^2)*	<0.001 (0.57)	0.017 (0.24)	<0.001 (0.45)	<0.001 (0.80)	<0.001 (0.36)	<0.001 (0.55)	0.001 (0.33)	<0.001 (0.44)	0.153 (0.20)	0.294 (0.12)	0.057 (0.90)	-
Group x time (p-value, h^2)**	ST (0.001, 0.45)			L3 (<0.001, 0.34)			RLLA (<0.001, 0.36)			NPRS (<0.001, 0.47)		

Abbreviation: SD, Standard Deviation; FP, Flexion Pattern; AEP, Active Extension Pattern; ST, Sacral Tilt; L3, Lumbar 3 Spinous Process; RLLA, Relative Lower Lumbar Angle; NPRS, Numeric Pain Rating Scale; h^2, Partial Eta Squared

*One-Way Repeated Measures ANOVA, p£0.05

**Mixed Factorial ANOVA, p£0.05

Figures

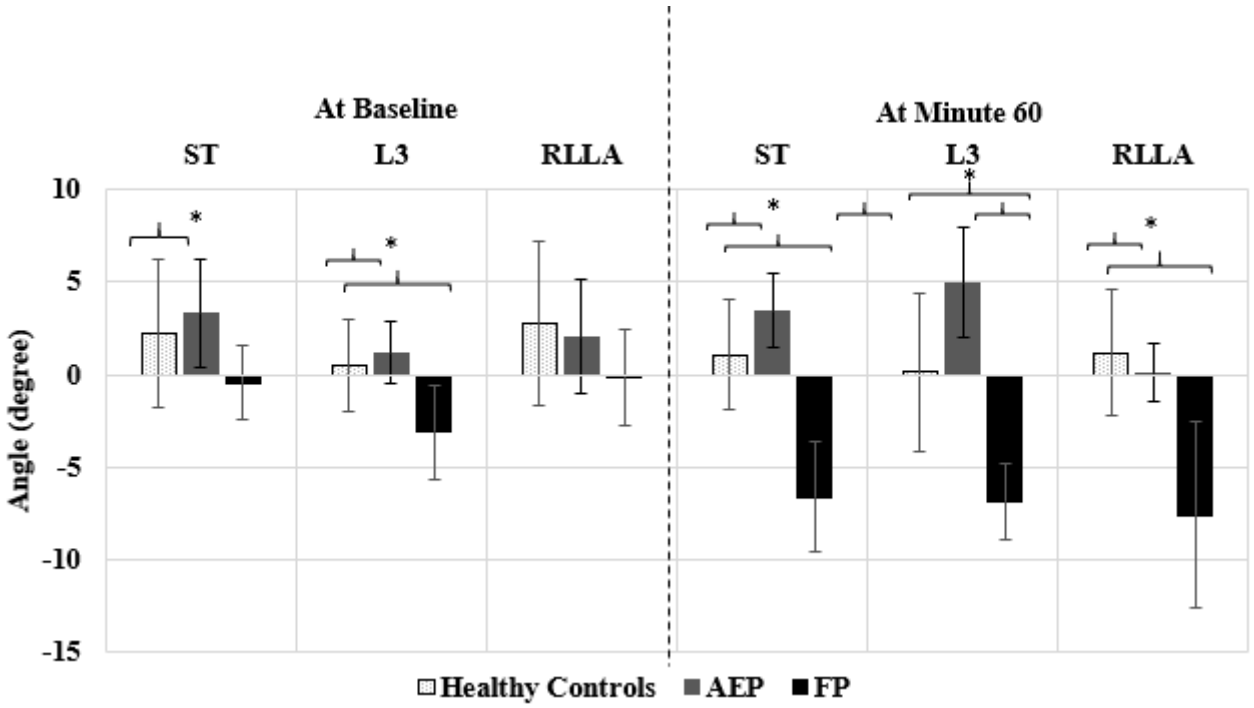


Figure 1

Mean (SD) of lumbosacral kinematics at baseline and minute 60 per group (N = 30). Abbreviation: FP, Flexion Pattern; AEP, Active Extension Pattern; ST, Sacral Tilt; L3, Lumbar 3 Spinous Process; RLLA, Relative Lower Lumbar Angle (+) angle indicates an anterior sacral tilt/ extension/ lordosis; (-) angle indicates a posterior sacral tilt/ flexion/ kyphosis *Significant difference (p□0.05)

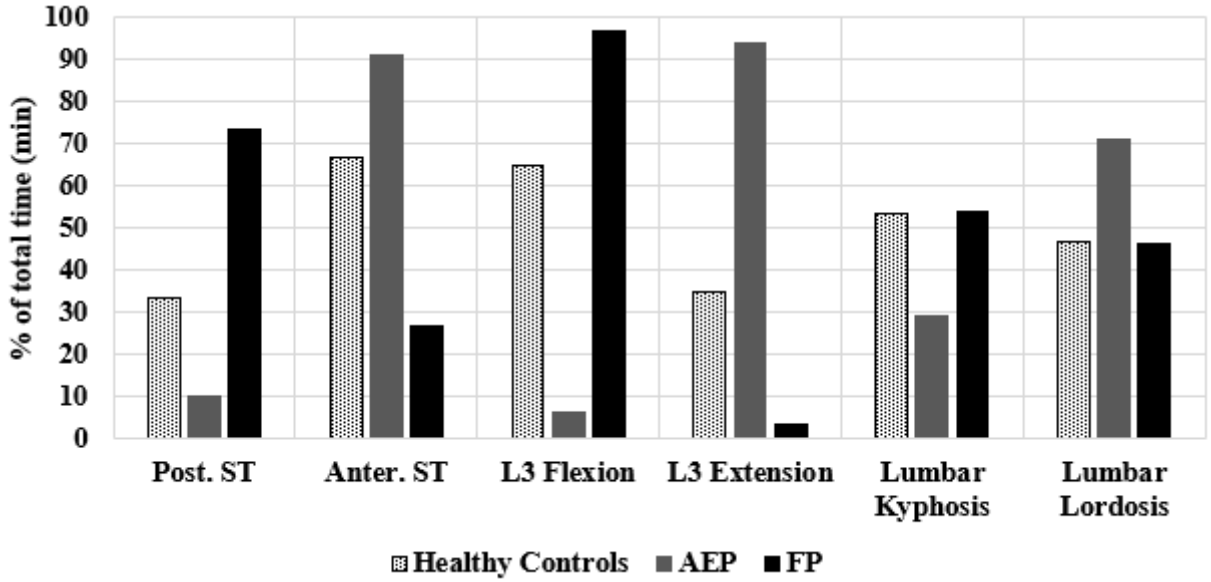


Figure 2

Percent (%) of the time spent in the lumbosacral angles per groups (N = 30). Abbreviation: Post., posterior; Anter., anterior; L3, position of the third lumbar spine vertebrae

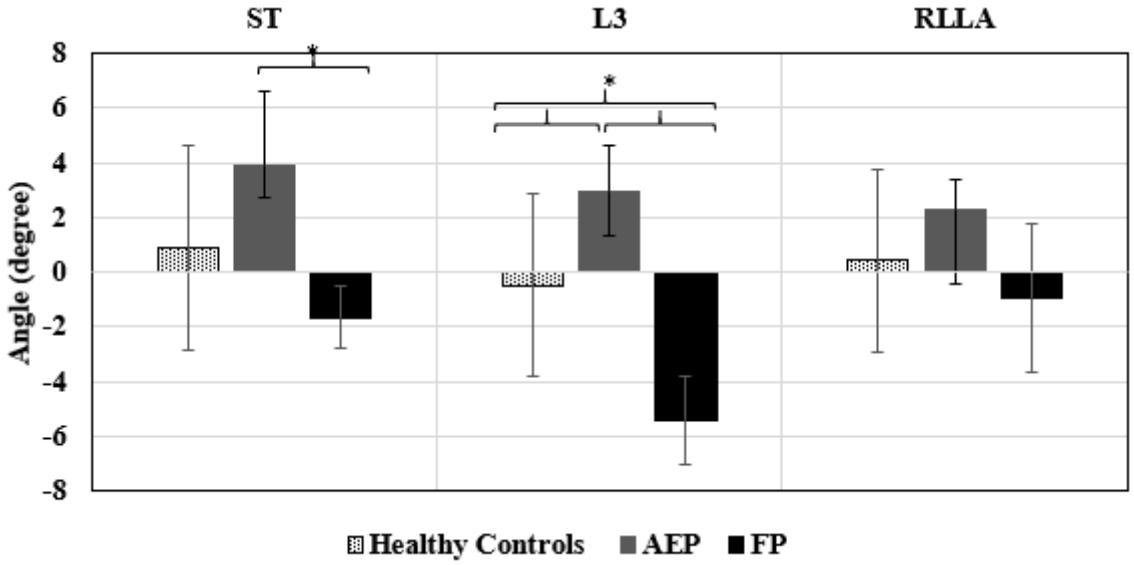


Figure 3

Mean (SD) of lumbosacral kinematics over the 1-hour of sitting per group (N = 30). Abbreviation: FP, Flexion Pattern; AEP, Active Extension Pattern; ST, Sacral Tilt; L3, Lumbar 3 Spinous Process; RLLA, Relative Lower Lumbar Angle (+) angle indicates an anterior sacral tilt/ extension/ lordosis; (-) angle indicates a posterior sacral tilt/ flexion/ kyphosis *Significant difference (p□0.05)

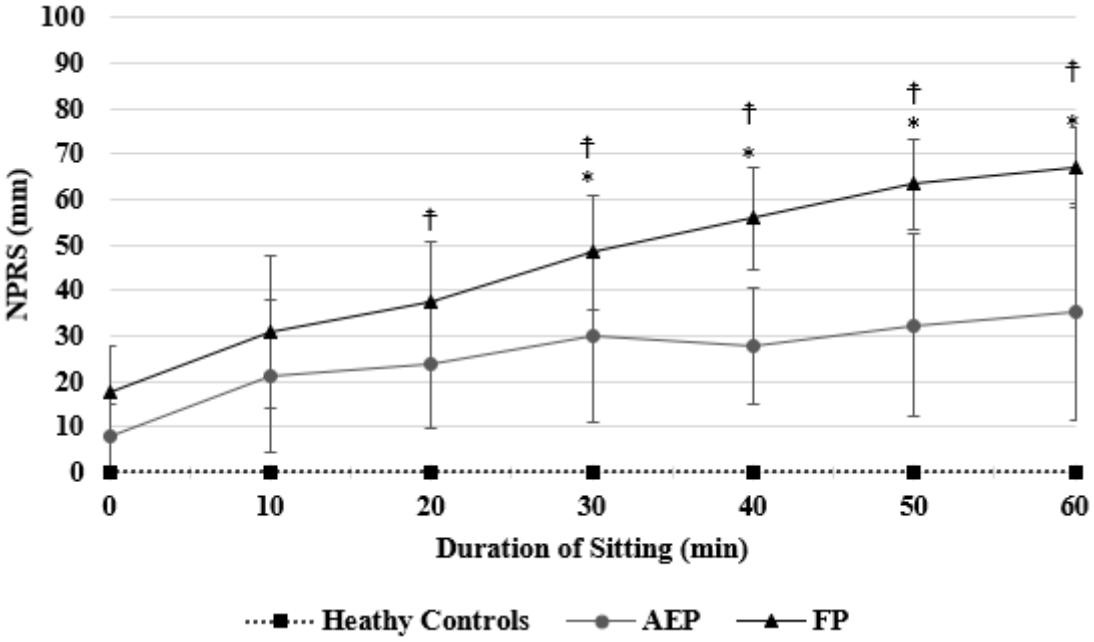
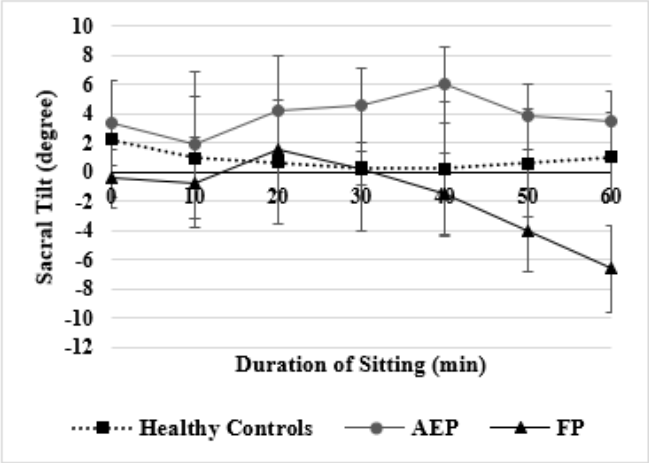
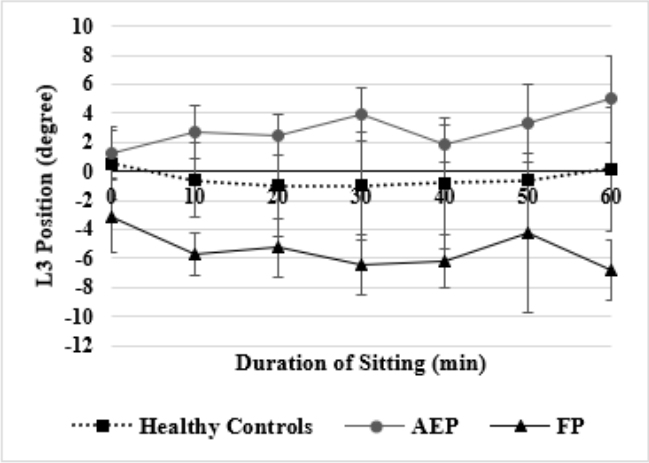


Figure 4

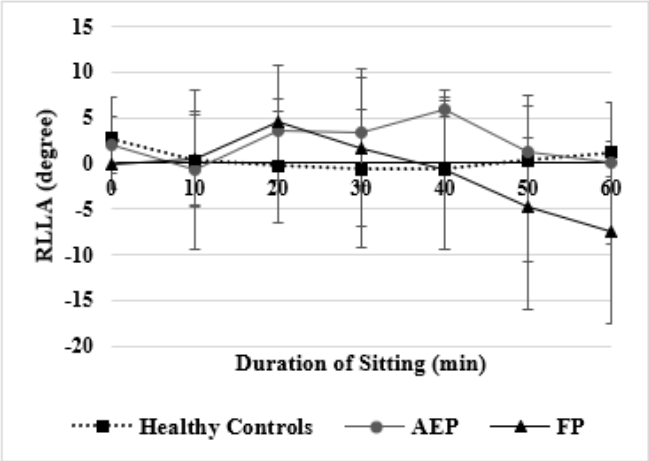
Mean (SD) of lumbosacral kinematics over the 1-hour of sitting per group (N = 30). Abbreviation: FP, Flexion Pattern; AEP, Active Extension Pattern; ST, Sacral Tilt; L3, Lumbar 3 Spinous Process; RLLA, Relative Lower Lumbar Angle (+) angle indicates an anterior sacral tilt/ extension/ lordosis; (-) angle indicates a posterior sacral tilt/ flexion/ kyphosis *Significant difference (p□0.05)



a.



b.



c.

Figure 5

The amount of change in lumbosacral kinematics; a. sacral tilt, b. Third Lumbar Vertebrae position, and c. Relative Lower Lumbar Angle over the 1-hour sitting (N = 30). Abbreviation: FP, Flexion Pattern; AEP, Active Extension Pattern; ST, Sacral Tilt; L3, Lumbar 3 Spinous Process; RLLA, Relative Lower Lumbar Angle For the sacral tilt: (+) angle indicates an anterior sacral tilt; (-) angle indicates a posterior sacral tilt For the L3

position: (+) angle indicates an extension; (-) angle indicates a flexion For the RLLA: (+) angle indicates a lordosis; (-) angle indicates a kyphosis