Ecological monitoring of lumbar spine posture and movement during daily activities in individuals with chronic low back pain: A case series

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Abstract

Ecological monitoring (EM) of the lumbar spine can be used to quantify frequency of movements and duration of postures throughout the day in real-life environments. The purpose of this study is to characterize lumbar posture and movement using EM in a case series of subjects with chronic low back pain (CLBP). Posture and movement for 6 people with CLBP were measured using mobile sensors during a clinical assessment (CA) and during two 8-hour EM sessions, including one weekday (WD) and one weekend day (WE). Each CA included measures of lumbar posture, maximum range of motion (ROM), and LBP symptoms. During EM, magnitude, frequency, and duration of postures and movements were measured. Posture and movement differed between the CA and EM, and between WD and WE sessions. Asymmetries in maximum ROM and frequency of lateral flexion were apparent during EM but not CA. Maximum ROMs were generally larger during CA, but 1/3 of subjects displayed larger maximum ROMs during EM. Subjects who reported pain during the CA differed in whether they favored or avoided the pain-provoking movement during EM. Future research using EM to measure lumbar spine behavior during daily activities is needed and should include both WD and WE sessions to capture variability in posture and movement behavior.

Background

Low back pain (LBP) affects up to 80% of people at some point in their lives and incidence of LBP reported among adults ranges from 10–15% annually (Andersson, 1999). Approximately 90% of people will recover from an episode of LBP within 12 weeks, but an average of 60% of people with LBP report recurrences, and an average of 62% of patients still experience LBP one year after the initial episode (Spitzer et al, 1987; Hestbaek, Leboeuf-Yde and Manniche, 2003). Chronic low back pain (CLBP) is defined as a back pain problem that has persisted for at least 3 months, and has resulted in pain on at least half the days in the past 6 months (Deyo et al, 2014). According to a U.S. National Health and Nutrition Examination Survey conducted in 2009–2010, the prevalence of CLBP was 13.1% (Shmagel, Foley and Ibrahim, 2016). Recurrence and chronicity of LBP can have a profound impact on a person's functioning, disability, work productivity, quality of life, and costs of care (Gore et al, 2012).

For many individuals with CLBP, no clear pathological cause of pain can be determined (Deyo et al, 2014; Hart, Deyo and Cherkin, 1995; Spitzer et al, 1987). The Kinesiopathologic Model (KPM) and the Physical Stress Theory (PST) provide frameworks for understanding possible causes of LBP in such cases. The KPM suggests that deviations of posture and movement precede and contribute to tissue injury and musculoskeletal pain (Sahrmann, Azevedo and Dillen, 2017). The PST provides further insight into how physical stresses associated with posture and movement may contribute to tissue injury and pain. According to this theory, a predictable and adaptive change in a biological tissue occurs in response to the relative level of stress applied; this level depends on magnitude, duration, and direction of forces (Mueller and Maluf, 2002). Considering these parameters when examining lumbar spine posture and movement would allow researchers to better characterize the amount of cumulative stress placed on the tissues of the low back. Based on the KPM and PST, evaluating posture and movement throughout daily activities would be useful for identifying the associations between LBP and the magnitude, duration, and direction of posture- and movement-related stresses.

The associations of LBP with posture and movement have been evaluated extensively using approaches ranging from simple clinical observation to highly technical 3D motion capture systems. Clinical observation provides visual information on overall spine movement during posture and movement tests (Van Dillen et al, 1998). A study by Biely, Silfies, Smith and Hicks (2014) assessed trunk movements to help identify aberrant movement patterns in a CLBP patient population. A problem with visual observation alone is that it cannot provide an objective measure of lumbar spine movement. In addition, these examinations were performed in a clinical environment, which does not capture nor replicate a person's movement during their daily activities.

Due to the limited objective information gathered from clinical observation, investigators have incorporated 3D motion capture systems to gather objective kinematic measures of lumbar spine movement during clinical examination tests in a laboratory setting (Van Dillen et al, 2003; Gombatto, Norton, Scholtes and Van Dillen, 2008). Lumbar spine kinematics have also been evaluated during various functional tasks in a laboratory setting using 3D motion capture systems and motion sensors in order to determine movement characteristics in individuals with LBP (Hernandez A, Gross K, Gombatto S, 2017; Mitchell et al, 2017; Gombatto et al, 2017). A limitation of many studies reporting on lumbar kinematics in individuals with LBP is that they have been conducted in a clinical or laboratory setting, and investigators have assumed that these findings reflect actual postures and movements that occur in daily life. This assumption may lead to errors in the understanding of the associations of LBP with posture and movement. Therefore, there is a need to objectively characterize posture and movement behavior during daily life.

Ecological monitoring (EM) of the lumbar spine employs portable motion sensors to monitor posture and movement behavior during daily activities in a person's natural environment. It is necessary to measure posture and movement behavior in real-life situations in order to quantify parameters of lumbar spine throughout the day, including magnitude of excursion, frequency of repetitive movements in various directions, and duration of prolonged postures. These parameters are needed to objectively characterize cumulative stress placed on the lumbar spine. Some investigators have used portable motion tracking systems to monitor activity levels of individuals with CLBP and non-specific LBP. Oliveira et al (2018) compared the effectiveness of two interventions on general physical activity levels using activity monitors. Another study by Kent, Laird and Haines (2015) employed biofeedback along with a specific lumbar spine motion tracking system in participants with sub-acute and chronic LBP in order to determine if modifying lumbar posture and movement with visual and auditory feedback can reduce activity limitations and pain. However, few investigators have used EM to characterize posture and movement behavior in people with CLBP using specific parameters including magnitude, frequency, duration, and direction of stresses applied to the low back during daily activities.

Thus, it remains unclear how closely posture and movement observed during EM reflect observations in a clinical setting, and how posture and movement behavior varies across different days of the week in this population.

The purpose of this study is to use a series of cases to characterize habitual posture and movement behavior in a population with CLBP during a clinical assessment (CA) and EM movement assessment, and hence provide more insight into the mechanical stresses placed upon the lumbar spine. In addition, this study will evaluate posture and movement behavior during the weekday (WD) and weekend (WE). Identifying these behaviors is critical for directing individualized movement retraining and patient education to reduce mechanical stresses on the lumbar spine, thereby decreasing pain, reducing recurrence, and improving function in people with CLBP.

Methods

This case series was part of a pilot study; testing and data collection took place at the Rehabilitation Biomechanics Laboratory (RBL) at San Diego State University (SDSU) in San Diego, California. Approval from the Institutional Review Board and consent from each participant were obtained prior to testing.

Participants

A convenience sample was recruited from the SDSU campus and San Diego community. Flyers describing the study and general eligibility criteria were posted on campus, at local fitness centers, and at nearby medical clinics. Telephone screening questionnaires were used to gather information on demographics, medical history, and LBP history to determine eligibility. Individuals of all ages and either sex were eligible for participation. In order to qualify for the study, individuals had to report a pain level of 3/10 or greater on the Numeric Pain Rating Scale (NPRS, 0–10) over the 7 days prior to screening (Childs, Riva and Fritz, 2005), as well as chronicity of LBP, which was defined based on the National Institute of Health (NIH) guidelines as LBP that has persisted for at least 3 months and has resulted in pain on at least half the days in the past 6 months, in a single episode or multiple episodes (Deyo et al, 2014). Individuals were excluded from participating if they had spinal surgery, spine tumor or infection, severe systemic disease, systemic neurological involvement, fibromyalgia, or chronic widespread pain. Pregnant women were also excluded. Included in this case series are 6 subjects with CLBP.

Procedures

Eligible subjects were scheduled for two testing sessions within a one-week period, including one weekday (WD) and one weekend day (WE). During the first session, subjects completed a series of self-report measures. Both testing sessions consisted of a clinical assessment (CA) of lumbar spine posture and movement that took place in a clinical examination room in the laboratory, followed immediately by an 8-hour session of ecological monitoring (EM) of lumbar spine posture and movement using portable motion sensors.

Self-report measures

Information on subject demographics, LBP history, medical and occupational history, functional limitation, and disability was collected using an online data capture software platform (REDCap Cloud, California) at the start of the first session. The Roland-Morris Disability Questionnaire (RMDQ) was used to measure functional limitation and disability associated with LBP (Chapman et al, 2011; Deyo et al, 2014). The RMDQ has been previously shown to have good internal consistency and responsiveness. Chronbach's alpha for the scale has been estimated as 0.93, 0.90 and 0.84, which is within the recommended range of 0.70–0.90 (Roland and Fairbank, 2000).

Posture and Movement Testing

For both testing sessions, two portable motion sensors (ViMove, DorsaVi, Inc, Melbourne, Australia) were applied to each subject's lower back and pelvis with adhesive applicators (Figure 1a). The ViMove system has demonstrated higher reliability in measuring lumbar spine sagittal and frontal plane movements than both the Modified Schober method and the Double Inclinometer method, two techniques historically used for assessing lumbar spine movement (Ronchi, Lech, Taylor, and Cosic, 2008). The ICC values for the accelerometers used in the ViMove sensors ranged from 0.859 - 0.954" (Ronchi, Lech, Taylor, and Cosic, 2008). The ViMove has also been found to demonstrate clinically acceptable values for concurrent validity of lumbar inclination with the Vicon motion capture system, including measurements of flexion (RMSE±SD = 1.82°±1.00), extension (RMSE±SD = 0.71°±0.34), right lateral flexion (RMSE±SD = 0.77°±0.24), and left lateral flexion (RMSE±SD = 0.98°±0.69) (Mjøsund et al, 2017).

Motion sensors were placed at the first lumbar vertebrae and the level of the posterior superior iliac spine by an examiner who is a physical therapist with 18 years of clinical experience and 16 years of movement analysis experience. Sensors were then secured with Tegaderm (3M, Inc.) overwrap in preparation for EM. Adhesives and Tegaderm were secured while the subject's spine was in a flexed position to allow for stretch during movements throughout the day.

After sensor placement, each subject was instructed to perform a variety of movements and assume several sitting and standing postures while data on lumbar spine position was collected using commercially available software (DorsaVi, Inc). Standard instructions were provided to each subject, and demonstrations were provided by the examiner as necessary. First, usual standing posture was assessed by recording the angle of lumbar lordosis while the subject stood in his/her usual posture. Each subject was then instructed to move into maximum ranges of forward flexion, extension, and lateral flexion to the left and right. For each of these movements, three consecutive trials were performed.

Lumbar spine posture was also recorded when the subject adopted the following postures in sitting: usual, slouched, and upright. Change in LBP symptoms on the 11-point NPRS (0-10) was recorded for each test. A change of 2 or more points on the NPRS has been shown to exceed the MDC in individuals with LBP (Childs, Piva, and Fritz, 2005).

EM sessions began immediately after the CA and lasted for 8 hours, during which the individual departed from the laboratory and conducted typical daily activities while wearing the sensors. During the EM sessions, individuals carried a wireless handheld device that recorded data from the sensors throughout the duration of the monitoring session (Figure 1b).

Posture and Movement Measurements

Measures derived from the CA included: maximum range of motion (ROM) for flexion, extension and left/right lateral flexion movements in standing (average of 3 trials), and reported change in LBP during movement on the NPRS. Any movement performed during the CA which increased a subject's NPRS was considered a pain-provoking movement (PPM).

Specific posture and movement measures derived from the 8-hour EM session were evaluated using the DorsaVi software, and included: maximum ROM into flexion, extension, and right/left lateral flexion; frequency of movement events into lumbar flexion, extension, and left/right lateral flexion; duration of the longest period of uninterrupted time in standing; and percentage of total sitting time spent in usual, slouched and upright postures, determined by individualized postures identified in the CA.

Events were registered by the DorsaVi software for movements greater than or equal to 20° of motion for flexion, and greater than or equal to 10° of motion for extension and right/left lateral flexion. For frequency of movement events into flexion, extension and right/left lateral flexion, subcategories including 'short-term events' and 'sustained events' were identified.

'Short-term events' were defined as instances of movement into a given direction for a duration of 1.5 to 30 seconds for flexion, and 1.5 to 15 seconds for extension and lateral flexion. 'Sustained events' were defined as instances of movement into a given direction of motion for a duration greater than 30 seconds for flexion, and greater than 15 seconds for extension or lateral flexion. These thresholds for ROM and duration that characterized events as short-term or sustained were predetermined by the DorsaVi, Inc software.

Both categories of events were considered relevant in analyzing potential contributing factors to LBP. Number of short-term events were considered to represent the construct of frequency of movement, while sustained events were considered to provide information on duration of postures. Total number of events was calculated by adding the total number of short-term and sustained events of flexion, extension, and lateral flexion.

Data Analysis

Data including demographic information, kinematic data collected during CA and EM sessions, and self-report measures were summarized using frequency counts or descriptive statistics, and qualitatively evaluated for each subject. Posture and movement patterns within a single subject as well as similarities and differences among subjects were examined in order to identify patterns.

First, we identified differences between posture and movement during the CA and EM sessions, general patterns of posture and movement behavior during EM, and differences between weekday and weekend EM sessions. Second, we assessed whether, during EM, subjects who reported increased pain during the CA tended to adopt or avoid pain-provoking postures and movements (PPMs).

Results

Participants

Six subjects with LBP were included in this case series, including 4 males and 2 females, ages 37-50 ($\bar{x}$=44.3 years, σ=4.6) with RMDQ scores ranging from 1-20 ($\bar{x}$=7, σ= 6.4, Table 1). Five of the six subjects wore the sensors for 8 hours during each WD and WE session. One subject (LBP4) had only one complete EM session; the data from the WD EM session was incompletely recorded

(5.4 hours) due to a technical error, and has been omitted from the results of this case series. No subjects reported any adverse effects of wearing the sensors or barriers to all-day wear.

Differences between the Clinical Assessment and Ecological Monitoring

During EM, 3 subjects displayed a difference in maximum range of lateral flexion movement of at least 5° between sides during EM that were not evident during the CA (Figure 2). Of these 3 subjects, 2 (LBP 1 and LBP 2) displayed no detectable lateral flexion in one direction during one EM session (Figure 2).

Subjects generally displayed greater maximum ROM during the CA than during EM, with 2 exceptions: LBP4 moved 6° further into left lateral flexion as well as 15° further into right lateral flexion (Figure 2) and LBP2 moved 8° further into flexion (Figure 3).

Posture and Movement Behavior during Ecological Monitoring

All subjects displayed at least a 2:1 ratio of movement frequency favoring one direction of lateral flexion (right or left) during at least one EM session; for the favored direction of lateral flexion, frequency of movement ranged from 1-28 events ($\bar{x}$=9.5 events, σ=8.5), while the direction of lateral flexion that was not favored ranged from 0-8 events ($\bar{x}$=3.3 events, σ=2.6, Figure 4). Absolute difference in movement frequency between sides ranged from 0-20 events ($\bar{x}$=6.2 events, σ=6.1).

Flexion was generally favored over extension during EM in terms of ROM and frequency (Figures 3, 5, 6). The average maximum ROM into flexion during an EM session was 44.9° (σ=9.2), versus the average maximum ROM into extension of 8° (σ=5.9). Five of the 6 subjects moved more frequently into flexion than extension by a ratio of at least 2:1 during both EM sessions (average number of short-term flexion events during one EM session=17.3, σ=9.3; average number of short-term extension events during one EM session=4.5, σ=8.3; Figure 5).

Frequency of flexion events for these 5 subjects ranged from 4-40 events ($\overline{x}$=16.4, σ=10.1), while frequency of extension events ranged from 0-3 events ($\overline{x}$=0.9 events, σ=1.1). All 5 subjects favoring flexion in terms of frequency displayed a total absence of extension events during one EM session (Figure 5).

One of the 6 subjects (LBP6), moved more frequently into extension than flexion during WE EM (28 extension events vs 22 flexion events) and displayed a greater overall frequency of extension events during both EM sessions when compared with other subjects (13 events during WD and 28 during WE compared to the overall average of 4.45 events per EM session, Figure 5).

Differences between Weekday and Weekend Ecological Monitoring Sessions

All subjects' lumbar spine posture and movement behavior differed between WD and WE sessions. For example, LBP1, LBP2 and LBP3 had no detectable extension ROM during one EM session, but displayed extension ROM more similar to other subjects during the other EM session (Figure 6, LBP4 excluded from count due to incomplete data). Similarly, LBP1 and LBP2 displayed no right lateral flexion ROM (0°) during one EM session but not the other (Figure 2).

With regard to frequency of movement, LBP3 displayed fewer short-term events into left lateral flexion during the WD session than the WE session (8 WD vs 21 WE left lateral flexion events, Figure 4). Total number of movement events (flexion, extension, and lateral flexion to both sides) also differed for many subjects between WD and WE sessions. For example, LBP2 moved more frequently on the WE (10 WD vs 35 WE total events), while LBP3 moved more frequently on the WD (56 WD vs 38 WE total events).

Differences between WD and WE sitting behaviors were also observed. For example, LBP5 spent 1.7 hours longer in a seated position on the weekend session compared with the weekday session (Figure 7). While LBP3 spent roughly the same amount of time sitting between WD and WE sessions (4.0 and 4.1 hours, respectively), the percentage of that time spent in a slouched position on the WE session (74%) was more than twice that of the WD session (36%) (Figure 7).

Reported Pain and Posture and Movement during Ecological Monitoring

All subjects reported increased NPRS scores with movement during the CA, with increase in scores of most pain-provoking movement ranging from 1-5 (median increase of 2 points, Table 2). Subjects who reported increased LBP with movements during the CA differed in whether they favored or avoided the painful movement during EM.

Half of the subjects, LBP1, LBP3 and LBP5 displayed a pattern of avoidance of pain-provoking movements. During the WE CA, LBP3 reported increased pain with extension. During the EM session that followed, the maximum ROM into extension displayed by LBP3 was 0°. Similarly, LBP1 reported increased pain with extension during the WD CA, and no extension events were detected during the WD EM session (Figure 8a). LBP1 also reported increased pain with right lateral flexion during the WE CA, and no right lateral flexion events were detected during the WE EM session (Figure 4). During the WE CA, LBP5 reported a decrease in LBP symptoms with seated positions, and then spent 6 of the 8 hours in sitting during the EM session that followed – the greatest cumulative duration spent in a seated position captured during an EM session (Figure 7).

Contrarily, LBP2, LBP4, and LBP6 displayed a pattern of favoring pain-provoking movements. LBP4 reported increased symptoms with right lateral flexion during the WD CA. However, during the WD EM session that followed, the subject displayed 26° of maximum lateral flexion to the right (a relatively high value compared to other subjects for whom the maximum ROM into left/right lateral flexion during an EM session was: $\bar{x}$ =13.09°, σ =5.11) and 15° to the left (a relatively typical value) (Figure 2).

LBP2 reported increased pain with right lateral flexion during the WE CA, but displayed right lateral flexion twice as often as left lateral flexion during the WE EM session (4 events into left lateral flexion, 8 into right lateral flexion). During the WE CA, LBP6 reported increased LBP with left lateral flexion, then displayed a greater frequency of left lateral flexion than the right during WE EM, and 4 sustained periods of left lateral flexion, which is the greatest number of sustained lateral flexion events in a single direction displayed by any subject in the case series (Figures 8b, 9).

Discussion

Several general themes related to posture and movement behavior emerged from this case series. During EM, most subjects displayed both greater magnitude and frequency of flexion when compared with extension, and all displayed asymmetry in terms of magnitude and/or frequency of lateral flexion. Asymmetries in maximum lateral flexion ROM which were exposed during EM were not apparent during CA. A limited number of subjects displayed greater maximum ROM into flexion and lateral flexion in EM than in CA.

Differences in posture and movement were identified between CA and EM and between WD and WE sessions. Total time spent sitting, and relative durations of slouched versus upright seated postures varied between WD and WE sessions across all subjects. Subjects with LBP who reported increased LBP with specific movements during the CA differed in whether they favored or avoided PPMs during EM.

These findings are unique to our study, as few studies present specific findings on posture and movement behavior in subjects with LBP based on data collected in an ecological setting. One study utilized activity monitoring as an objective ecological measure of gross activity levels, and found no significant differences in overall activity between people with and without LBP, but did not analyze any posture or movement variables (Griffin, Harmon and Kennedy, 2012).

In a pilot clinical trial, Kent, Laird and Haines evaluated the effectiveness of the ViMove sensor system to provide real time postural biofeedback for subjects with LBP in an ecological setting (2015). Although the biofeedback component was reported to be effective in altering posture in subjects with LBP, the authors did not report objective information regarding specific posture and movement behaviors in these subjects. Further, this study did not compare posture and movement behaviors during EM to those gathered during CA.

Another pilot trial conducted by Dekker-van Weering, Vollenbroek-Hutten and Hermens evaluated the effects of activity-based biofeedback for individuals with CLBP in an ecological setting (2015). Although activity-based biofeedback treatments in this small study appeared beneficial in decreasing pain for subjects with CLBP, lumbar spine posture and movement was neither evaluated, nor targeted with the intervention.

While there are currently a limited number of studies focused on differences in lumbar spine kinematics in subjects with CLBP in an ecological setting, many studies have investigated these differences in a clinical setting. A recent systematic review highlighted several characteristics of lumbar spine kinematics unique to subjects with LBP, including reduced lumbar ROM, slower movements, reduced proprioception, greater variability in ROM in flexion, lateral flexion, and rotation across subjects, and greater variability in speed of movements across subjects when compared with subjects without CLBP (Laird, Gilbert, Kent and Keating, 2014).

Despite these clinical findings, little work has been done to determine whether the same posture and movement behaviors are observed in an ecological setting. When evaluating individuals with LBP, physical therapists typically conduct patient assessments in a clinical setting. Assessing maximum lumbar ROM is often considered a key part of such assessments (Laird, Gilbert, Kent, and Keating, 2014). However, recent findings suggest significant variability in maximum ROM between repetitions during a clinical examination (Laird, Kent and Keating, 2016).

In our study, one third of the cases evaluated displayed greater ROM during EM than when asked to perform maximum ROM in the clinic, also suggesting that true maximums are not consistently attained in a CA. Further, while no asymmetries in maximum lateral flexion ROM were evident during CA, notable asymmetries in both maximum lateral flexion ROM and lateral flexion movement frequencies were apparent in the data obtained through EM, indicating that CA alone may not be representative of functional lumbar spine posture and movement behavior during daily activities.

Furthermore, there is currently little evidence investigating differences between posture and movement between weekdays and weekend days. Across all subjects, we found differences in magnitude and frequency of movements between WD and WE. Several subjects also displayed notable differences in time spent in various seated postures between WD and WE sessions. The variability in posture and movement behavior between WD and WE EM sessions for all subjects suggests that both sessions should be included in future studies and clinical assessments in order to capture work- and leisure-related variations in ecological posture and movement behaviors.

Our results showed variability in subjects' posture and movement behavior during EM for movements that were provocative of pain during CA. Some subjects were less inclined to move in directions which provoked pain, while others favored PPMs throughout the day. Of those subjects who favored PPMs, each did so by increasing one or more parameters of physical stress, including magnitude of the PPM as reported by maximum ROM (LBP 4), frequency of PPM as reported by total number of events (LBP2), or a combination of frequency and duration of the painful movement (LBP6).

These preliminary findings may provide a framework for identifying subgroups of subjects with CLBP who avoid or favor movements, in order to better understand the interplay between various parameters of physical stress and pain, and to ultimately guide interventions directed at retraining posture and movement, reducing pain, and improving function.

Results from this study demonstrate the feasibility of collecting information about daily posture and movements that are sensitive to the unique patterns of behavior exhibited by individuals with CLBP across the week. However, several limitations should be considered when interpreting the results of this case series. First, the small number of subjects included in a case series design (n=6) reduces the generalizability of the observed posture and movement behaviors for the general population of people with CLBP. Moreover, because only 2 females were included in this case series, posture and movement behaviors of females may not be adequately represented.

Additionally, although several different parameters of physical stress, including direction, magnitude, frequency, and duration were characterized when evaluating posture and movement behavior with EM, velocity of movement was not considered and should be taken into account in future studies. Spinal rotational stresses were not analyzed in this study, due primarily to measurement limitations of the portable motion tracking devices in the axial plane. Finally, cause and effect relationships between posture, movement, and CLBP cannot be established based on the case series study design. Future prospective research employing EM in a larger sample including controls with no LBP is warranted to identify statistical associations between patterns of posture and movement behavior throughout the day and LBP. Future studies may also examine the effectiveness of interventions that are directed at modifying pain-provoking posture and movement behaviors.

Conclusion

The results of this case series describe objective indicators of physical stress placed on the lumbar spine during daily activities in people with CLBP, and exemplify the heterogeneous nature of lumbar spine posture and movement in this population. Patterns of lumbar spine posture and movement and pain behaviors which could not be identified using CA alone were captured during EM. These results suggest that EM may provide a useful tool to identify posture and movement behavior of individuals with CLBP to better understand how specific parameters of physical stress, including magnitude, frequency, duration, and direction, may be related to LBP, and to ultimately guide and monitor the efficacy of interventions directed at preventing and alleviating the effects of CLBP.

Tables and Figures

Table 1: Subject Characteristics

Participant #	Sex	Age yrs	# Weeks Since Onset	Avg. Pain Last 7 Days	BMI kg/m^2	Occupation	RMDQ (0-24)
LBP1	M	50	35	4/10	27.54	Professor	4
LBP2	M	37	70	3/10	23.08	Professor	2
LBP3	F	50	52	3/10	20.31	Physical Therapist	6
LBP4	M	42	208	7/10	23.88	Unemployed	20
LBP5	F	45	156	7/10	20.24	Realtor	9
LBP6	M	42	52	4/10	29.56	Video Editor	1

Abbreviations: LBP, Low Back Pain; CON, Control BMI, Body Mass Index; RMDQ, Roland Morris Disability Questionnaire

Table 2: Most Pain-Provoking Movement during Clinical Assessment

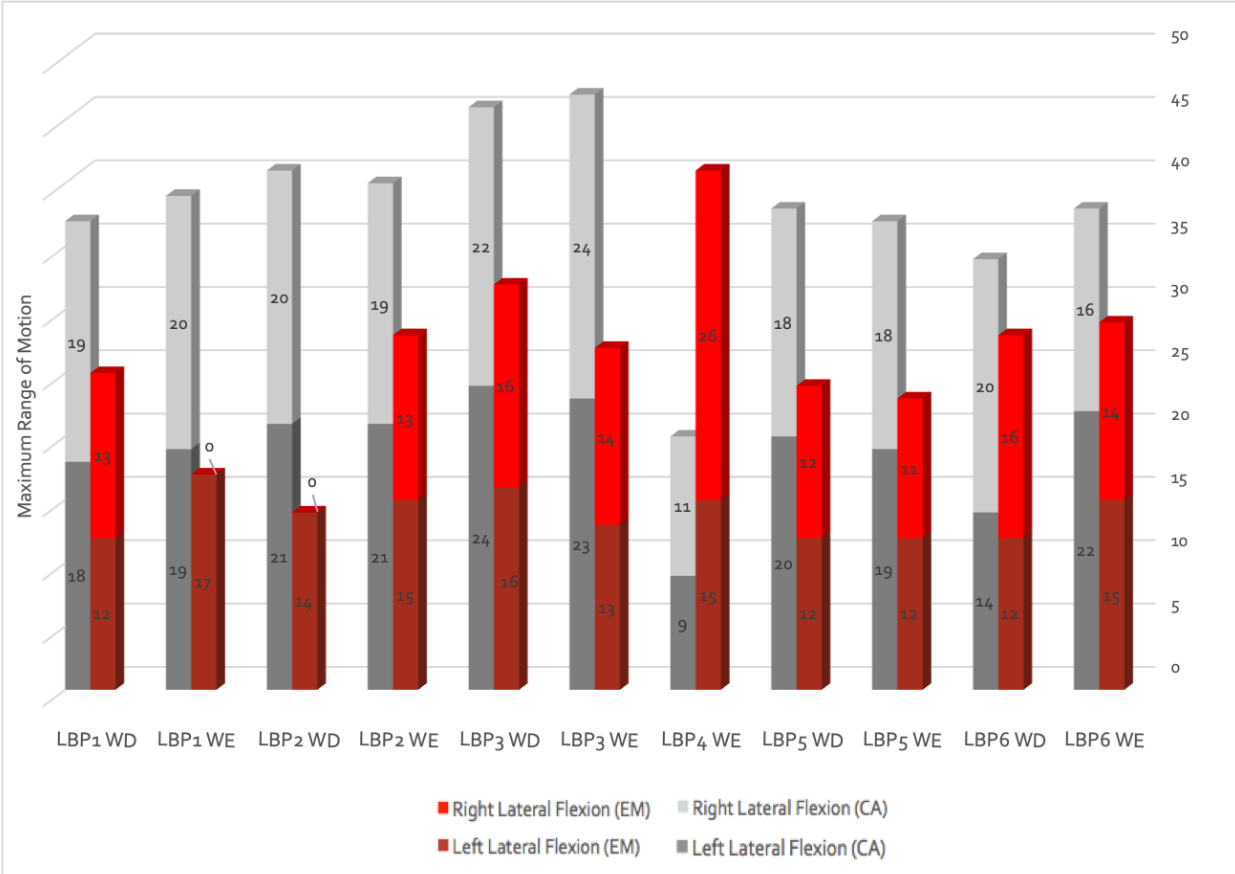
Participant #	WD PPM	WD NPRS Increase	WE PPM	WE NPRS Increase
LBP1	Extension	3	Right Lateral Flexion	1
LBP2	N/A	N/A	Right Lateral Flexion	N/A
LBP3	Extension	5	Extension	4

LBP4	Right Lateral Flexion	N/A	Standing Anterior-Posterior Pelvic Tilt	2.5
LBP5	Extension	2	Left Lateral Flexion	2
LBP6	Left Lateral Flexion	1.5	Slouched Sitting	2

Abbreviations: WD, Weekday; WE, Weekend; PPM, Most Pain-Provoking Movement

Figure 1a. **(left)** DorsaVi portable motion sensors attached with adhesive strips to designated landmarks on the lumbar spine and pelvis. **Figure 1b.** **(right)** Wireless handheld device that records motion sensor data, and is carried by participants during the 8-hour ecological monitoring session.

Figure 2. Maximum range of motion into left and right lateral flexion during clinical assessment (gray) and ecological monitoring (red) on weekday and weekend sessions.



Maximum Range of Motion
0
5
10
15
20
25
30
35
40
45
50
LBP1 WD
LBP1 WE
LBP2 WD
LBP2 WE
LBP3 WD
LBP3 WE
LBP4 WE
LBP5 WD
LBP5 WE
LBP6 WD
LBP6 WE
Right Lateral Flexion (EM)
Right Lateral Flexion (CA)
Left Lateral Flexion (EM)
Left Lateral Flexion (CA)

Figure 3. Maximum range of motion into flexion during clinical assessment (gray) and ecological monitoring (red) on weekday and weekend sessions.

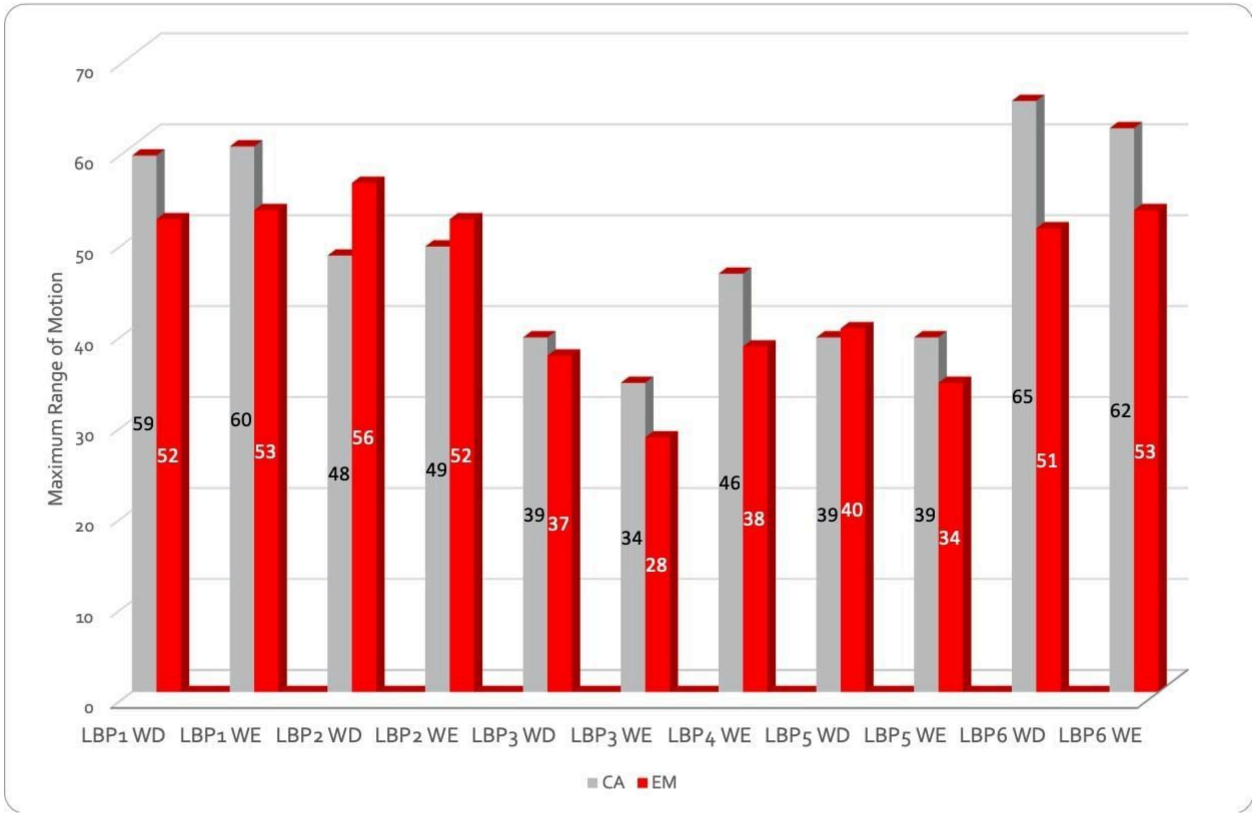
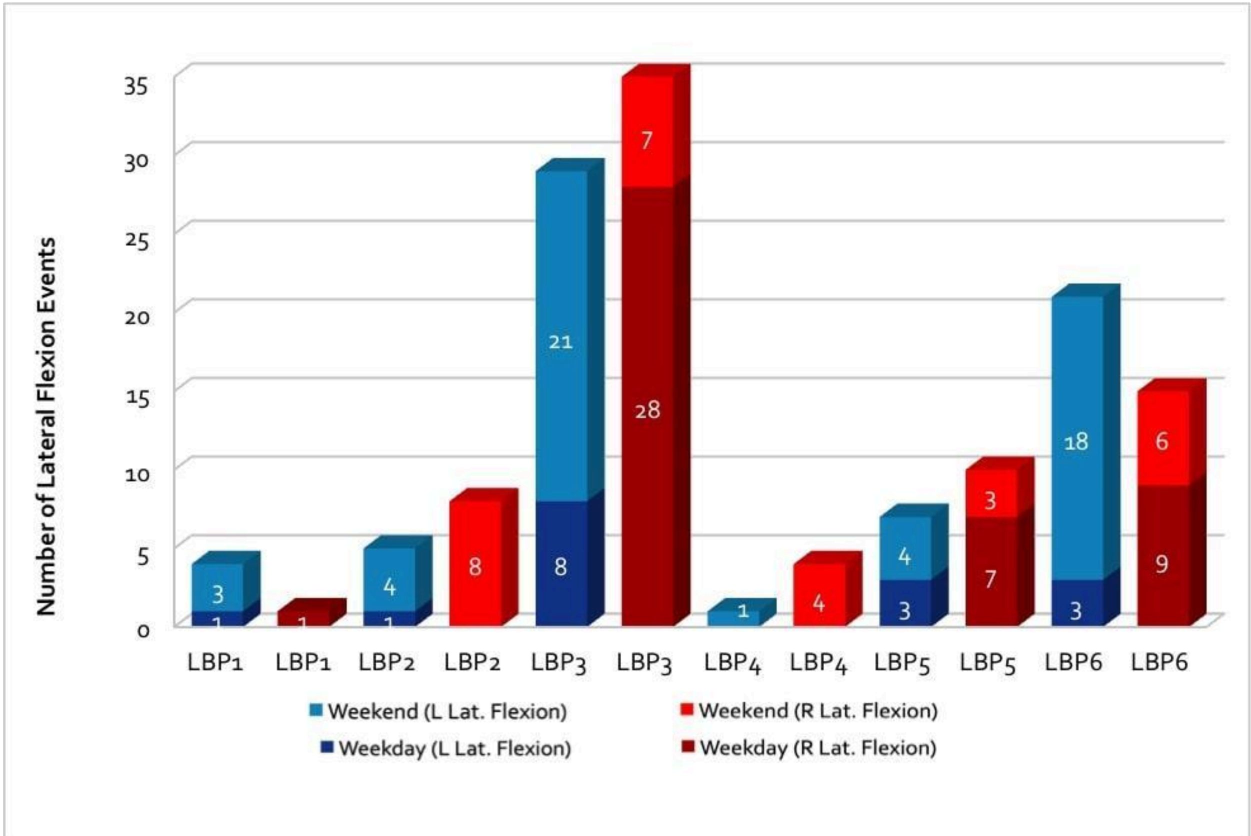
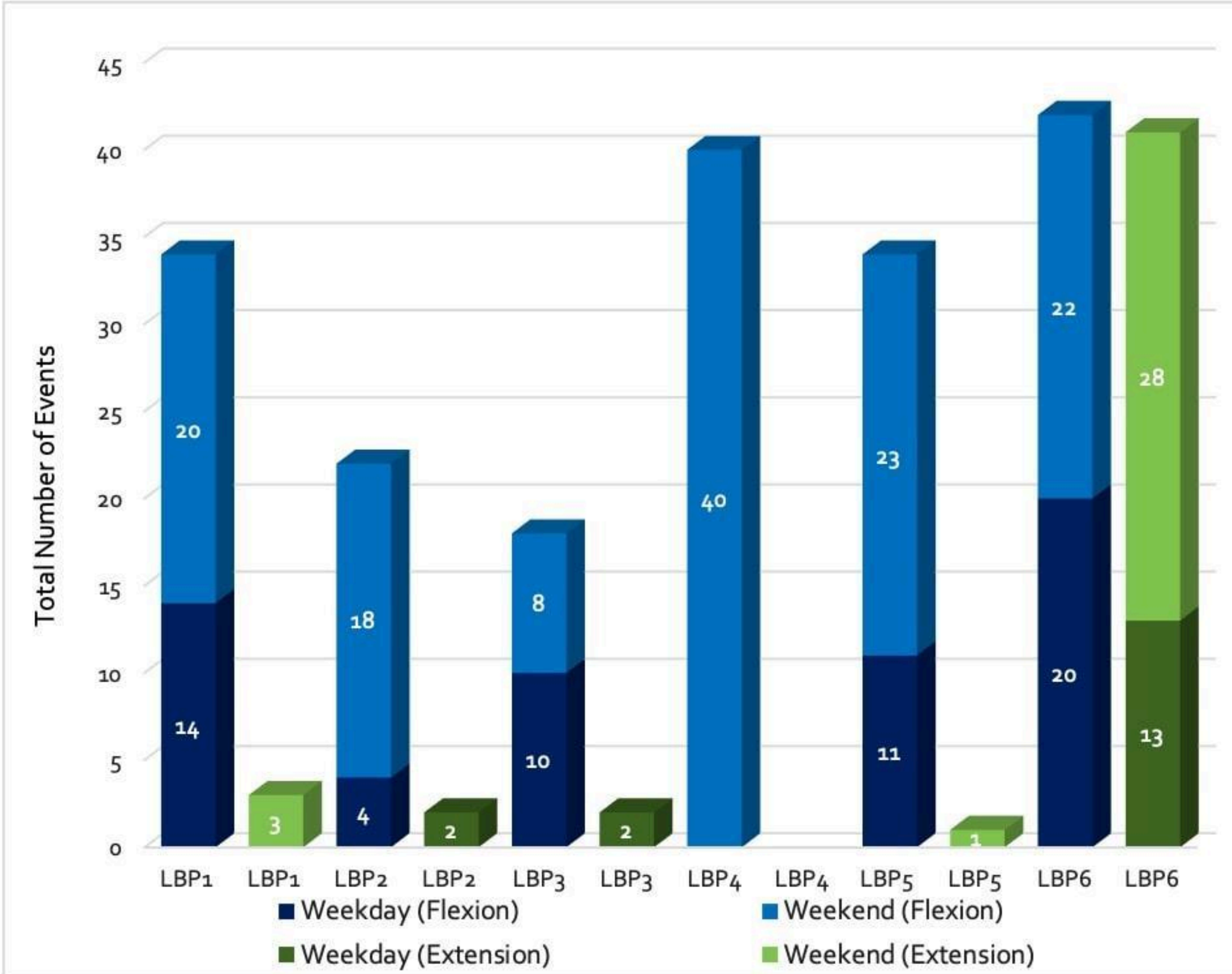


Figure 4. Frequency of short-term events into left (blue) and right (red) lateral flexion during ecological monitoring on weekday (dark) and weekend (light) sessions.



<u>Figure 5.</u> Total number of short-term flexion (blue) and extension (green) events during ecological monitoring on weekday (dark) and weekend (light) sessions.



45
40
35
30
25
20
15
10
5
0
Total Number of Events
20
14
3
18
4
2
8
10
2
40
23
11
1
22
20
28
13
LBP1
LBP1
LBP2
LBP2
LBP3
LBP3
LBP4
LBP4
LBP5
LBP5
LBP6
LBP6
Weekday (Flexion)
Weekend (Flexion)
Weekday (Extension)
Weekend (Extension)

Figure 6. Maximum range of motion into extension during clinical assessment (gray) and ecological (red) on weekday (dark) and weekend (light) sessions.

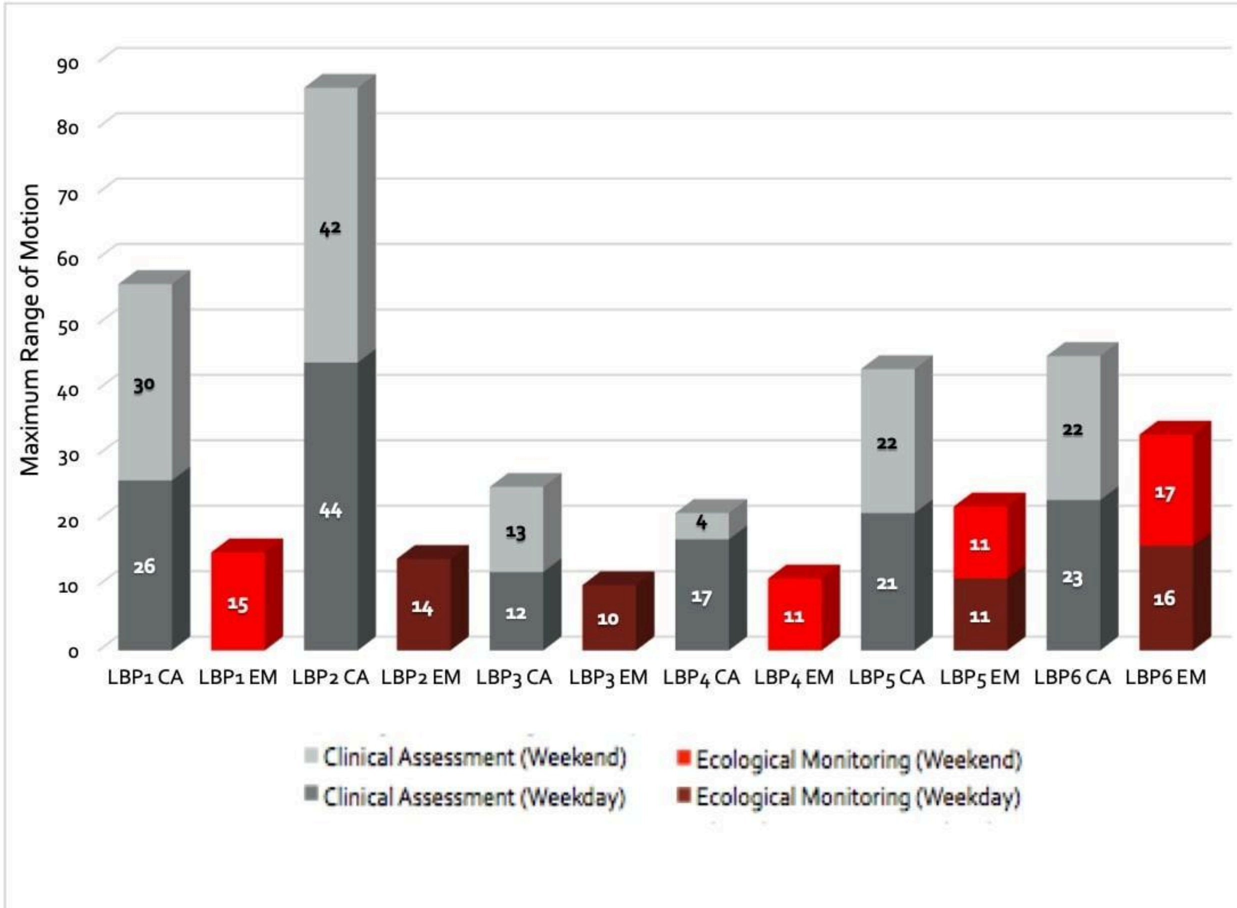
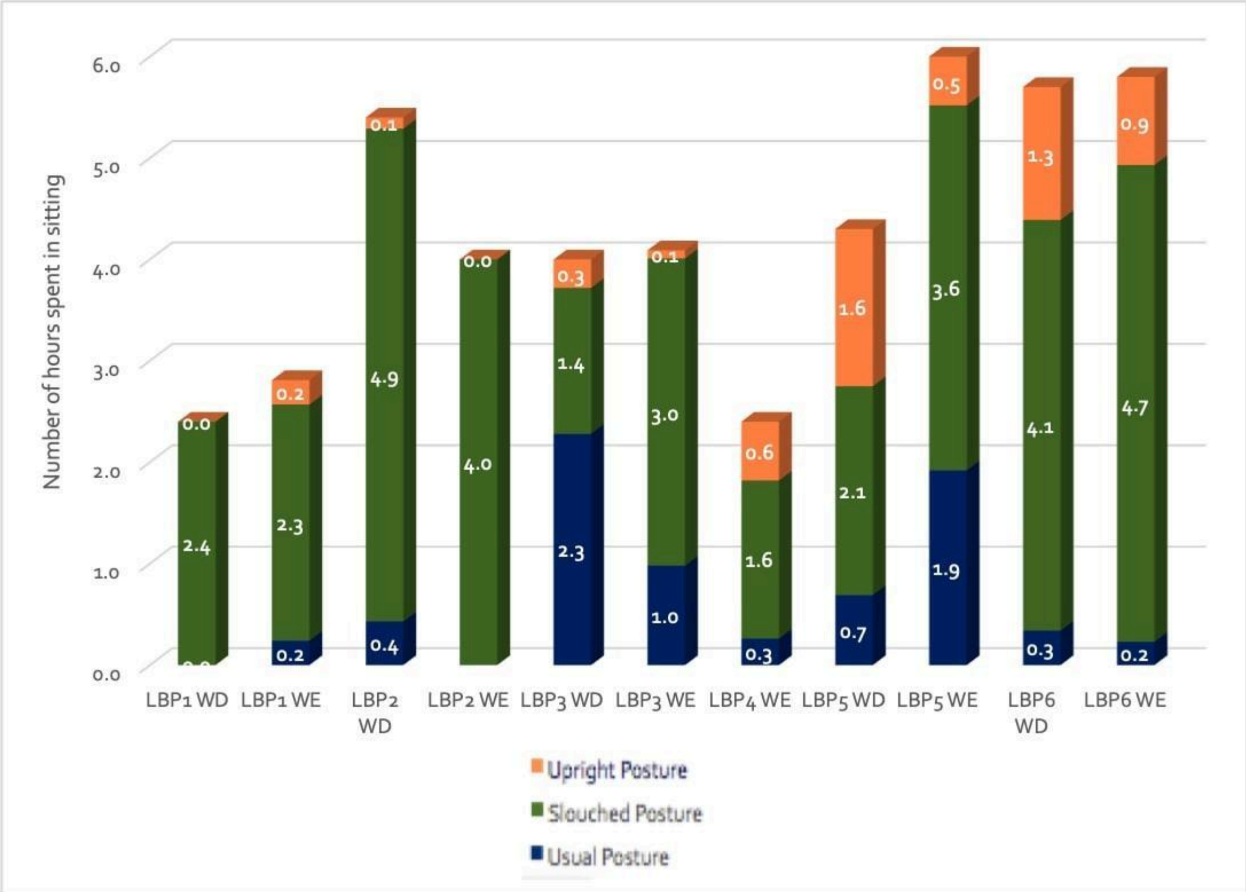
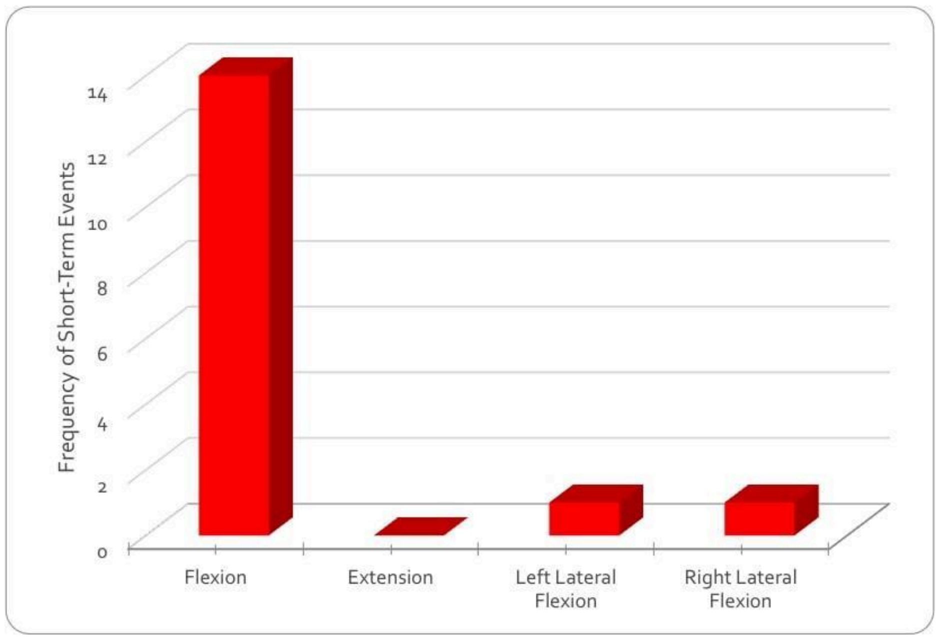


Figure 7. Amount of time (in hours) spent sitting in usual (blue), slouched (green), and upright (orange) posture during ecological monitoring on weekday and weekend sessions.

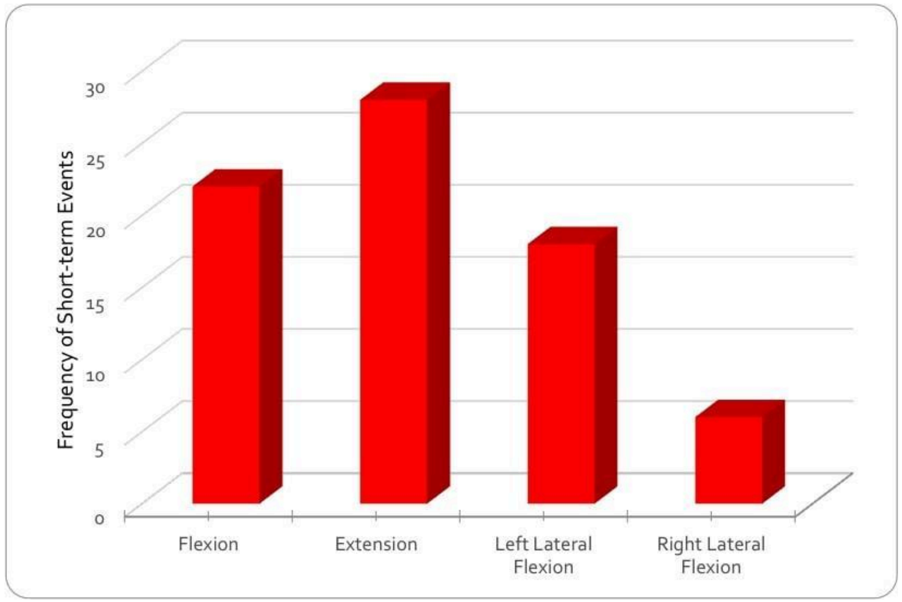


Number of hours spent in sitting
6.0
5.0
4.0
3.0
2.0
1.0
0.0
LBP1 WD
LBP1 WE
LBP2 WD
LBP2 WE
LBP3 WD
LBP3 WE
LBP4 WE
LBP5 WD
LBP5 WE
LBP6 WD
LBP6 WE
Upright Posture
Slouched Posture
Usual Posture

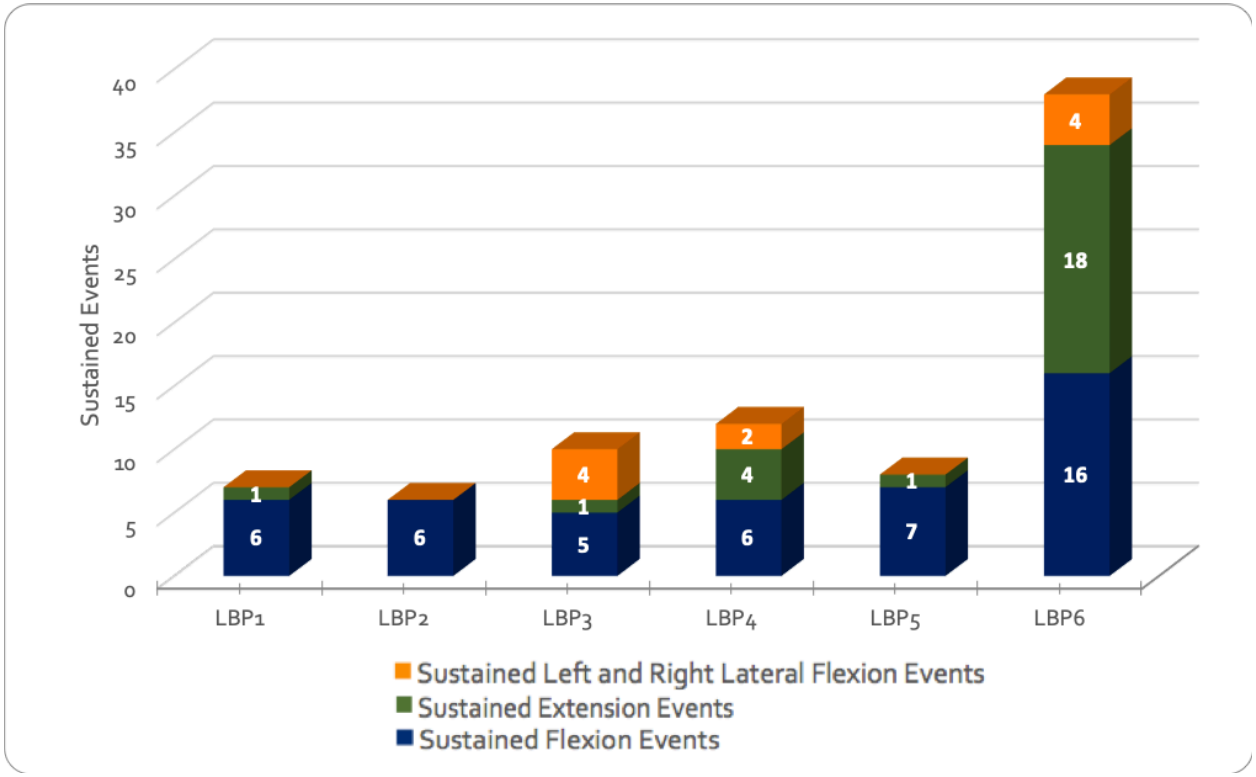
<u>Figure 8a.</u> **Avoidance** of a pain-provoking movement. Frequency of short-term events for LBP1 during the weekday ecological monitoring session; during the clinical assessment on this day, LBP1 reported **increased pain with extension.**



<u>Figure 8b.</u> Favoring of a pain-provoking movement. Frequency of short-term events for LBP6 during the weekend ecological monitoring session; during the clinical assessment on this day, LBP6 reported **increased pain with left lateral flexion.**



<u>Figure 9.</u> Total number of sustained flexion (blue), extension (green), and left/right lateral flexion (orange) events during both weekday and weekend ecological monitoring sessions combined.



Sustained Events
40
35
30
25
20
15
10
5
0
LBP1
LBP2
LBP3
LBP4
LBP5
LBP6
6
1
6
5
1
4
6
4
2
7
1
16
18
4
Sustained Left and Right Lateral Flexion Events
Sustained Extension Events
Sustained Flexion Events

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