2020

Work Related Diurnal Changes in Trunk Mechanical Behavior

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Digital Object Identifier: https://doi.org/10.13023/etd.2020.366

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WORK RELATED DIURNAL CHANGES IN TRUNK MECHANICAL BEHAVIOR

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering in the College of Engineering at the University

By

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2020

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ABSTRACT OF THESIS

WORK RELATED DIURNAL CHANGES IN TRUNK MECHANICAL BEHAVIOR

The objectives of this study were to analyze effects of day-long exposure to LBP risk factors on lumbo-pelvic coordination (LPC) in nursing occupations and to verify if physical activity level affects diurnal work-related changes in LPC. Thirty-three nurses were recruited into three groups based on workplace physical demands and each completed two data collection sessions, one before and one after their 8-12 hour work shift. Participants completed several stationary trunk forward-bending/backward-return exercises at self-selected “fast” and “slow” rotational speeds, and while holding a 15 lbs. load. Kinematic data collected during these exercises were then used to characterize the timing and magnitude aspects of LPC during each exercise. We did not find any work-related changes in our measures of LPC, however, significant differences among groups were seen in thoracic rotation for all exercises ($F>13.39$, $p<.03$) and pelvic rotation during the slow exercise ($F=3.678$, $p=.037$). Considering earlier reports of changes in LPC following a short period of exposure to a single LBP risk factor, our results suggest that such changes when exposed to multiple risk factors and over the course of work day do not accumulate and likely recover by the end of work day.

KEYWORDS: low back pain, lumbo-pelvic coordination, diurnal changes, nursing, LBP risk factors

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8/5/2020

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ACKNOWLEDGMENTS
There are many people who have supported me during my time as a graduate student at the University of Kentucky. I would like to thank my advisor, Dr. Bazrgari, for challenging me to always go a step further in data collection and analysis, and for pushing me to think critically about problems that I face. Your guidance throughout the entire my time at UK has been tremendous. I would also like to thank Clare Tyler for her assistance and companionship throughout the often-tiring process of collecting data as well as navigating graduate school. In addition, I would like to thank Dr. Sawaki for offering her lab space and tireless recruiting efforts, both of which were integral for the completion of this study.

I would also like to thank my father, mother, brother, and sisters for providing constant support, encouragement, and confidence in my abilities throughout my graduate school experience and every single day of my life.

Without the help from those I have mentioned, as well as many others, I would not be in the position I am in today, and I am very grateful.

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Chapter 1-Introduction

1.1-Low Back Pain

Back pain in the United States has been a prevalent issue. In 1999, there were a reported 44 million adults claiming to have a disability, of which 6.8 million were categorized as back problems or back pain (2001, Anonymous 2001). Incidence of low back pain (LBP) has increased and nearly 80% of the population in the US will deal specifically with LBP at some point in their life (Freburger, Holmes et al. 2009). Back pain is responsible for the loss of 149 million workdays, resulting in lost productive time as well as reduced performance while at work (Guo, Tanaka et al. 1999, Stewart, Ricci et al. 2003). This can be especially impactful in jobs that require physical tasks such as lifting or transferring any type of weight. Back pain experienced in the workplace can be attributed to high loading tasks that implement lifting, bending, and twisting, as well as tasks that implement sustained low load postures like sitting or standing for long periods of time (O'Sullivan 2005). While many cases of LBP are resolved within 4 weeks, a small percentage develop into chronic LBP, directly contributing to the loss of workdays, low productivity, and morbidity (O'Sullivan 2005, Ramdas and Jella 2018).

Incidence of LBP resulting from occupational activities continues to be a widespread problem. Because of the high risk and resulting loss of labor and work efficiency, LBP has been researched extensively to provide preventative measures and rehabilitation strategies. Researching biomechanical characteristics of movement is important in understanding the development of back pain. This is because the usefulness of clinical tests for diagnosing LBP has yet to be deemed accurate or informative, often misdiagnosing cases because of the unknown etiology of LBP (Hancock, Maher et al. 2007, Allegri, Montella et al. 2016). Assessment of lumbopelvic coordination (LPC) focuses on the timing and magnitude of thoracic spine and pelvic movement. Timing refers to the order in which the pelvis and lumbar back contribute to trunk movement and magnitude refers to how much the pelvis and lumbar back contribute to trunk movements. Workplace factors, including fatigue, age of workers, and lifting loads, have been investigated to show the effect on LPC. These studies have found timing and magnitude aspects of LPC similar to someone with LPB following exposure to workplace factors (Lee and Wong 2002, Hu and Ning 2015, Hu and Ning 2015, Pries, Dreischarf et al. 2015, Shojaei, Vazirian et al. 2016, Shojaei, Vazirian et al. 2017). Timing and magnitude metrics of LPC assessed on studies can be used to pinpoint musculoskeletal functional disability, especially in the assessment, diagnosis, and rehabilitation of LBP. The timing characteristics of lumbopelvic coordination can be attributed to neural and musculoskeletal determining factors (Harris-Hayes, Sahrmann et al. 2009). Magnitude values from assessed LPC are related to the loading of the tissues during movement (Harris-Hayes, Sahrmann et al. 2009). These lumbopelvic movement patterns can be identified and classified as normal or abnormal regarding presence of LBP characteristics (Granata and Sanford 2000). A brief review of methods used to characterize LPC as well as applications of measures of LPC concerned with LBP are included in the sections that follow.

1.2-Characterization of LPC

LPC has been investigated through previous studies during various daily physical activities, including walking and running, lifting loads, and reaching tasks (Granata and Sanford 2000, Thomas and Gibson 2007, Seay, Van Emmerik et al. 2011, Galgon and Shewokis 2016, Zehr 2017). In addition to investigating LPC during physical activities that one typically performs throughout the day, previous research has also investigated LPC through forward bending and backward return motions. Forward bending and backward return is also identified as a risk factor for LBP and is a means for assessing LPC in the sagittal plane (Granata and Sanford 2000, Lee and Wong 2002, Vazirian, Shojaei et al. 2017). Typically, in this task, the subject starts in a standing position and bends at the waist to maximum forward flexion while keeping the knees straight and returns to the original standing position (**Fig. 1**). Rotations of pelvis, lumbar, and thoracic spine with respect to original upright standing posture are measured using different methods depending on the motion measurement system used. We have been using Inertial Measurement Units (IMUs) in our lab for the motion measurements. Separate IMUs were typically attached on the back of subject to measure pelvic and thoracic rotations while lumbar rotation is calculated as the difference between thoracic and pelvic rotations (**Fig. 2**; please see Methods for details).

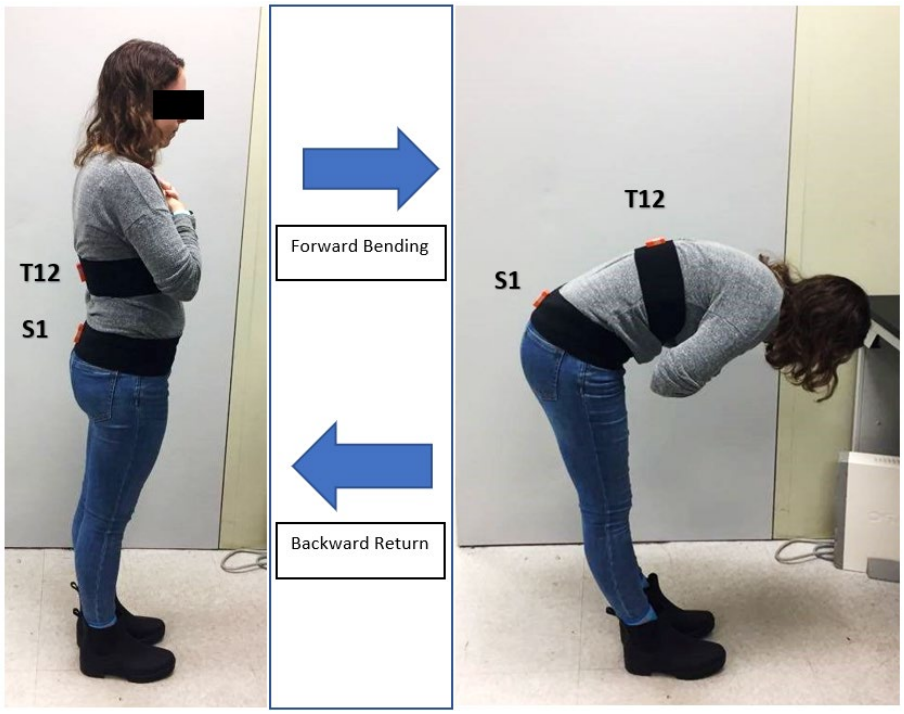

Figure 1: Trunk forward bending and backward return. This task is typically used for the assessment of lumbo-pelvic coordination

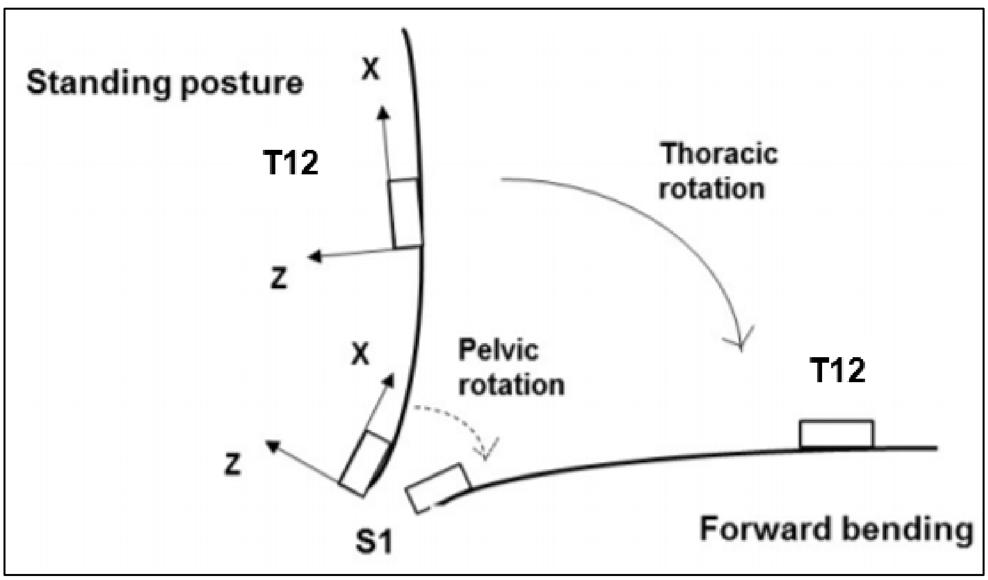

Figure 2: Measuring rotations of thorax and pelvis using Inertial Measurement Units. Units are attached on the back the T12 and the S1 spinal level. Lumbar rotation in this method is calculated at each instance of the time as the difference between measured thoracic and pelvic rotations. Adopted from (Shojaei 2018)

1.2.1-Magnitude Aspect of LPC

The magnitude aspect of LPC can be characterized several ways. The methods used in several studies as well as this study characterize magnitude of LPC through thoracic, pelvic, and lumbar rotations. Additionally, lumbar and thoracic movement is evaluated as a ratio at the time of maximum thoracic rotation, known as the lumbo-thoracic ratio (LTR). Magnitude of segment contribution has been presented by other studies qualitatively using curves that represent range of motion. Examples, such as **Figure 3**, show curves for lumbar angle and hip angle during forward bending. The higher of the two curves represents more dominant contribution to movement at a given instant of time (Tojima, Ogata et al. 2016, Vazirian, Van Dillen et al. 2016, Vazirian, Shojaei et al. 2017). The curves in this figure represent the lumbar angle and the hip angle, which differ from the lumbar angle and pelvic angle used in this study. This presents a different approach to characterizing the magnitude aspect of LPC.

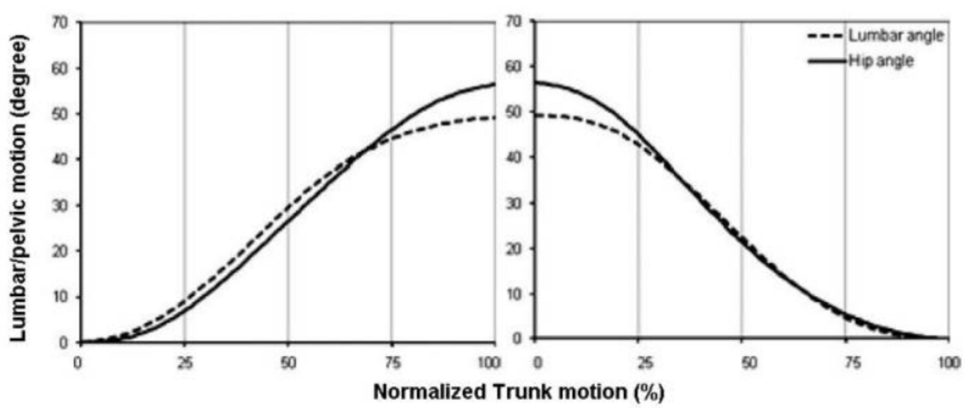

Figure 3: Qualitative comparison of normalized trunk motion. Plot shows lumbar and pelvic contribution to forward bending and backward return motion. Adopted from (Vazirian et al., 2016a)

1.2.2- Timing Aspect of LPC

The timing aspect of LPC has been evaluated in several different ways as well. One method widely implemented is the calculation of the continuous relative phase (CRP) for analysis of the coordination of segments during movement (Lamb and Stöckl 2014, Ebrahimi, Kamali et al. 2018). This method uses phase portraits to quantify the coordination between segments as a function of time in order to understand the relationship of the segments during movement (Lamb and Stöckl 2014). A phase portrait is a plot of a measured signal versus its velocity, or first derivative. Calculation of CRP is commonly used in sports and health science because of its ability to describe the coordination of two segments in a dynamic environment

(Lamb and Stöckl 2014). Thus, Lamb and Stöckl indicate that the segment and joint angle of interest (and corresponding first derivative) should be used for phase portraits in cases of LPC analysis. Several studies have also utilized mean absolute relative phase (MARP) and deviation phase (DP), two additional parameters that characterize the timing of LPC that can be derived from CRP (Stergiou, Jensen et al. 2001, Galgon and Shewokis 2016, Vazirian, Van Dillen et al. 2016, Ebrahimi, Kamali et al. 2018). MARP and DP represent the synchrony between two segments during repeated movements. MARP measures the pattern of coordination during movement and DP measures the stability of the movement in the coordination pattern described by MARP values. When segments move together more synchronously, they are represented with a MARP value closer to zero, indicating more in phase movement between segments. Values closer to π indicate segments that show more out of phase movement. Similarly, DP values closer to zero indicate increased stability whereas decreased stability is associated with higher DP values (Galgon and Shewokis 2016).

1.3-Applications of LPC in Research

LPC has been researched both in healthy subjects and individuals with current LBP or a history of LBP. Studies involving healthy individuals were mainly concerned with the effects of exposure to known risk factors for LPB on LPC whereas studies involving individuals with LBP were mainly concerned about characterization of potential abnormalities in their LPC. A brief review of this research is presented in the following two sections.

1.3.1- LPC of Individuals with Current or a Recent History of LBP

Several studies have investigated LPC differences in individuals with and without symptoms of LBP. A study by Esola, et al. found that LBP patients had a forward bending pattern with a smaller lumbar-to-pelvic ratio during the middle portion of the motion (Esola, McClure et al. 1996). Seraj, et al. found differences in the angles of the pelvis during forward bending when comparing healthy controls and LBP patients. Both Seraj et al. and Esola et al. found a decreased lumbar-to-pelvic and lumbar-hip ratio in the middle of the forward bending motion (Shahbazi Moheb Seraj, Sarrafzadeh et al. 2018). Several other studies had similar findings regarding the increased pelvic contribution in the end range of motion while lumbar contribution was decreased at the beginning and middle of the motion, as well as the decreased total range of motion when comparing LBP patients to healthy controls (Ahern, Follick et al. 1988, O'Sullivan 2005, Tafazzol, Arjmand et al. 2014, Shojaei, Vazirian et al. 2017, Vazirian, Shojaei et al. 2017). Studies investigating the timing of LPC found more in-phase movements and less variability of movements of segments in LBP patients compared to healthy subjects during walking and running as well as forward bending and lifting activities (Seay, Van Emmerik et al. 2011, Zehr 2017, Ebrahimi, Kamali et al. 2018). These reported abnormalities of LPC in patients with LBP raise the question of whether such abnormal LPC has a causal role in LBP occurrence or they were adopted by patients as a result of LBP. Regardless of whether such LPC abnormalities are causes or consequences of LBP, they appear to persist beyond LBP alleviation. Shojaei et al. identified abnormal LPC patterns in non-chronic LBP patients and suggested they were an adaptation to reduce deformation of tissues during movement to avoid pain (Shojaei 2018). In a different longitudinal study, Shojaei et al. investigated LPC in LBP patients over the course of 6 months. It was found that although symptoms of pain improved over the course of the study, abnormal LPC patterns persisted (Shojaei, Salt et al. 2020). The persistence of LPC abnormalities beyond symptom recovery may in part have a role in LBP recurrence, though such a postulation requires further research in future.

1.3.2- LPC of Healthy Individuals

Research has shown that injury can occur from both repeated loading during lifting or bending tasks as well as from sustained loads that occur from sitting for long periods of time (McGill 1997). The accumulation of loads on the spine that occur at an occupation can cause fatigue and increase risk of injury (Norman, Wells et al. 1998). Research has highlighted the changes in magnitude of lumbar range of motion and synchrony of lumbar-pelvic motion occur as a result of increased spinal loading, speed and muscle fatigue. These include changes to lumbar rotation, and decreased variability following exposure to activities such as lifting a load or performing a series of repeated, fast paced forward bending exercises (Asgari, Sanjari et al. 2015, Hu and Ning 2015, Hu and Ning 2015, Makhoul, Sinden et al. 2017). Van Hoof, et al. compared cyclists with and without LBP showing that both groups spent time in their end-range of lumbar flexion during the 2 hour bike ride. However, LBP patients had greater lumbar flexion compared to healthy individuals and spent significantly more time in the lumbar end-range of motion (Van Hoof, Volkaerts et al. 2012). Similarly, research investigating the results of prolonged sitting found increased lumbar flexion following 1 hour of seated deskwork in healthy subjects (Howarth, Glisic et al. 2013). Additional research based on magnitude aspects of LPC measured from healthy individuals has shown that muscle fatigue results in greater lumbar contribution during motion in healthy individuals (Hu and Ning 2015, Vazirian, Van Dillen et al. 2016). However, when comparing effects of age during lifting and forward bending exercises, it was found that older individuals show characteristics similar to LBP individuals for both timing and magnitude characteristics which include reduced lumbar rotation and decreased variability (Shojaei, Vazirian et al. 2016, Vazirian, Shojaei et al. 2017).

1.4- Research Gap

Changes in LPC in healthy subjects are often directly compared to LBP patients within a study. Studies that compare LPC before and after exercises may see more drastic differences in LBP individuals, however healthy individuals often follow the same trend in coordination patterns, but less extreme. The similarities that exist in the LPC changes seen in LBP and healthy individuals can be used to support the hypothesis of the causal role of abnormal LPC in LBP occurrence and development to chronic LBP.

Each of the earlier studies that identified changes in timing and magnitude of LPC only exposed subjects to a single factor (e.g., prolonged sitting, repeated lifting, or fatigue) to invoke changes. Many studies observe subjects perform forward bending and backward return exercises during a single testing session, when in real life, subjects are exposed to many different factors over the duration of an entire day. These studies do not reflect the actual duration of a work shift, which is much longer and includes a wide range of risk factors. It is therefore not clear whether day-long work activities that involve a longer duration of exposure to one or more of the known LBP risk factors will invoke changes similar to studies that have investigated the same risk factors for a shorter duration.

Some studies have analyzed the effects of work-shifts in nurses (Ovayolu, Ovayolu et al. 2014, Samaei, Mostafaee et al. 2017) and other healthcare occupations, however they are typically cross sectional studies that asses pain based on a visual analog scale and through the use of questionnaires. Very few studies quantify pre-work and post-work changes based on measured data. Given this research gap regarding the characterization and quantification of LPC measures before and after performing activities and over the course of entire work shift, there exists a need for further investigation. These identified risks show the need for research in advancing our understanding of LBP in order to develop prevention methods. Further research can aid in the development of preventative measures such as educational programs for exercise and proper lifting.

1.5-Goal of Study

To address the above noted research gap, the goal of this study was set to quantify the diurnal work-related changes in LPC. Specifically, work-related changes were investigated in nurses by characterizing timing and magnitude of LPC before and after an 8-12 hour work-shift. Healthcare occupations, specifically nurses, have been identified as a group with a high risk for LBP due to the working hours and physical labor involved with a work shift (Tosunoz and Oztunc 2017).

Previous findings state that individuals with LBP often have reduced lumbar contribution and increased pelvic rotation during forward bending and backward return tasks. Additionally, it has been shown that LBP patients have a more in-phase and less variable LPC during trunk movement. Therefore, we adopted the conceptual model denoted in **Fig. 4** to relate exposure to work-related risk factors for LBP to occurrence of LBP via changes in LPC. Accordingly, it was hypothesized that magnitude and timing of LPC following a work shift will exhibit behavior similar to that of a person suffering from LBP. These characteristics include decreased lumbar contribution in the middle of the forward bending motion, decreased total lumbar range of motion during activities, and more synchronous and less variability in movements. Moreover, it was hypothesized that work-related changes in LPC of nurses would be greater with increased level of physical activity. In other words, larger work-related changes in LPC of nurses experiencing more active days are expected compared to those working less active days. If successful, the role of such hypothesized work-related changes in LPC in LBP occurrence among nurses can be investigated in future longitudinal studies.

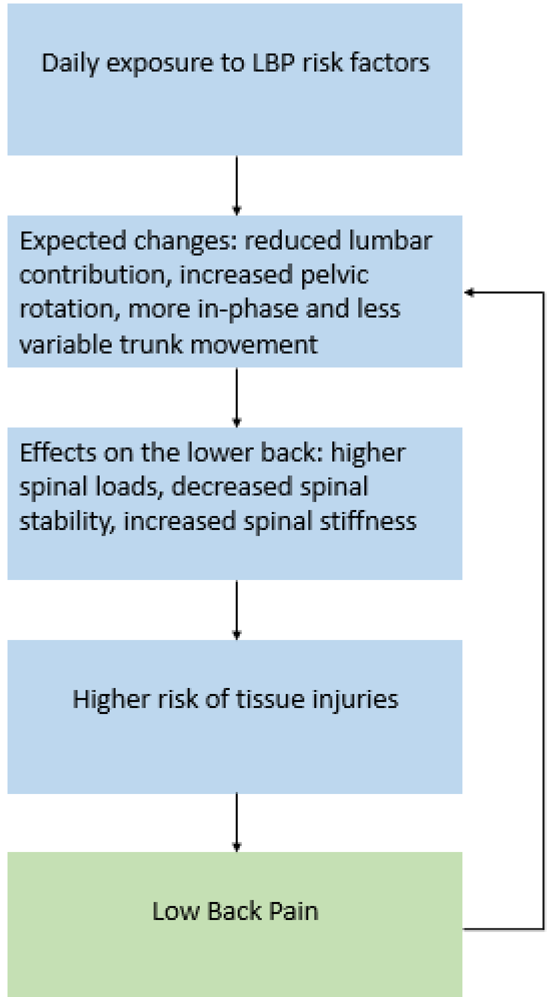

Figure 4: Conceptual model

CHAPTER 2-Methods

2.1-Study Design and Participants

The study design was a repeated measures study to evaluate how the workday of a nurse affects LPC. Participants were recruited in three groups based on their workplace location and activities. Each participant completed two 30-minute data collection sessions consisting of different paced forward bending exercises and lifting a weight from the ground. The first session took place immediately before the start of a work shift and the second session took place immediately following a work shift.

2.2-Study Subjects

The groups included 12 nurses from the University of Kentucky (UK) healthcare system who performed physically demanding tasks throughout their shift, 12 nurses from UK healthcare who performed primarily sedentary tasks throughout their shift, and 9 nurses from a local rehabilitation hospital (i.e., Cardinal Hill Rehabilitation Hospital; CH) who also performed physically demanding activities during their work shift.

2.2.1- Inclusion Criteria

Interested nurses completed a provisional eligibility screening via email to assure they met the criteria advertised on the study flyers. The provisional eligibility criteria required that subjects were between 20-60 years of age, worked 8-12 hour shifts as a nurse at a University of Kentucky (UK) or Cardinal Hill Rehabilitation Hospital (CH), and did not suffer from back pain requiring absence from work in the last year. Participants who met the provisional eligibility criteria were then scheduled for a further screening and data collection session. Prior to data collection and secondary screening, informed consent was obtained from participants using University of Kentucky Institutional Review Board approved processes.

2.2.2- Exclusion Criteria

Participants were excluded if they had a history of a major spinal surgery. Additional questions related to past history medical history, including whether the subject had previous musculoskeletal problems, neuromuscular diseases, joint (hip) replacements, pregnancy in the past year, history of falls, any problems that would limit participant's ability to walk or bend joints, or any other disorders, illnesses or injuries that would interfere with the study. Investigators used their judgement for inclusion of participants who reported a history of any of the listed circumstances. In addition to screening questions, participants also answered questions about their habitual physical activities. Questions were related to nature of the activities they performed while at work as well as activities they did in their leisure. The frequency of activities was ranked on a scale of never, seldom, sometimes, often, or always and assigned a numerical value of 1, 2, 3, 4, and 5, respectively. This screening form/questionnaire can be found in the **Appendix**.

2.3- Subject Recruitment

UK nurses who performed physically demanding activities were recruited from units such as the emergency department and the cardiovascular intensive care unit where tasks included lifting and transferring of patients, walking or standing most of the shift, and pushing patients in wheelchairs. UK nurses who performed primarily inactive tasks, or "sedentary" nurses were recruited from case management and central monitoring departments and spent at least half of their shift sitting down. CH nurses performed physically demanding tasks similar to UK physically demanding nurses in addition to helping patients with limited mobility who require substantial physical support to complete their activities of daily living. Two groups of UK nurses were recruited to understand the influence of the level of occupational physical activity on work-related changes in LPC. The distinction between these activity levels was made based on the departments that the nurses worked in and was confirmed with each nurse prior to enrollment. CH nurses were also included to see how the physically demanding tasks specific to a rehabilitation hospital setting would differ from those seen at UK hospital.

Nurses that participated in data collection included Licensed Practical Nurses, Registered Nurses, Certified Nursing Assistants, Nursing/Patient Care Technicians, and Certified Medical Assistants among other types of nurses. Subjects were recruited using materials generated by CCTS. These advertising materials were posted on monitors throughout the hospital, distributed as flyers, and links to the study were posted on the CCTS website. Additionally, managers of different nursing units throughout the hospital were contacted and those who showed interest forwarded these advertising materials to their employees.

Table 1: Descriptive statistics of groups compared using a 1-way ANOVA. The physically demanding group was younger compared to the sedentary group (Physically Demanding: 30.58 (10.25) vs Sedentary: 46.75 (9.47)). CH nurses had a greater body mass than both groups of UK nurses (CH: 86.74 (27.78) vs Sedentary: 67.58 (13.56) and Physically Demanding: 68.30 (10.74)).

Participant Demographics					
	UK Sedentary	UK Physically Demanding	Cardinal Hill	F-values	p-values
	Mean (SD)	Mean (SD)	Mean (SD)		
Age (years)	46.75 (9.47)	30.58 (10.25)	37.78 (12.22)	7.073	**0.003**
Height (cm)	163.46 (3.87)	166.79 (9.56)	169.40 (8.12)	1.647	0.210
Body Mass (kg)	67.58 (13.56)	68.30 (10.74)	86.74 (27.78)	3.672	**0.037**

2.4-Equipment and Calibration

Kinematic and kinetic data were collected using inertial measurement units (IMU's) (Xsens Technologies, Enschede, Netherlands) and a force plate (AMTI, Watertown, MA), respectively. IMU's were attached via Velcro straps to participant's T12 and S1 vertebrae, for measurement of the thoracic and pelvis rotations, respectively. IMU's were also placed laterally on participant's shank (right above the ankle joint) and thigh (right above the knee joint) for collection of data during the manual material handling exercise. The position of IMU's was measured and recorded during the first session for accurate replacement at the same spots during the second session.

After the Velcro straps were placed on the subject in the appropriate location, IMUs were calibrated using MT Manager (Xsens Technologies, Enschede, Netherlands). During the calibration process, sensors were placed on the force plate and moved to the appropriate locations on the subject. The calibration process changes the sensors from tracking motion in a global coordinate system based on the coordinates of the force plate, to a local coordinate system based on their initial locations on the subject. This local coordinate system provides the absolute change in angle, setting the initial orientation of the sensors as the upright, standing position of the subject. This initial position is considered zero.

2.5-Experimental Procedures

Following calibration, participants were then instructed to stand on the force plate and perform the following tasks in a randomized order using a random number generator: trunk forward bending and backward returns with slow and fast self-selected paces. Participants then performed a manual material handling task (MMH) while lifting and lowering a 15 lb. load from the ground. To perform the slow forward bending and backward return task, participants stood in an upright position with their hands across their chest. The researcher then counted to five and the subject bent to maximum forward flexion at a slow, “self-selected” pace while keeping their knees straight. Subjects held this position while the researcher counted to five, before returning to a standing position. The fast forward bends followed a procedure similar to the slow exercises, except they were performed at a self-selected fast pace with no pause when the participant reached the full forward flexion posture. During MMH, participants stood in an upright position, bent forward to reach the weight that was positioned on the ground, lifted the weight from the ground to chest height, returned it back to the ground at a marked location 10 cm in front of the force plate, and then returned to an upright standing position (see **Figure 5**). Three repetitions of each task were performed.

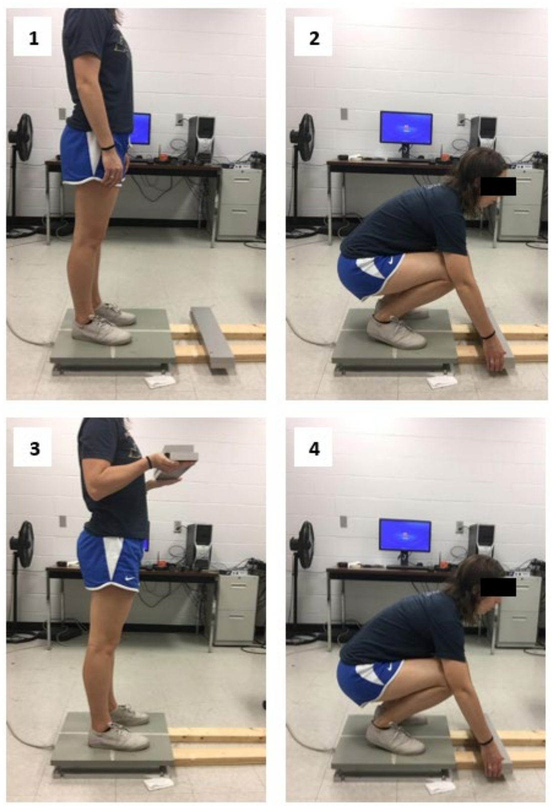

Figure 5: Example of MMH task

2.6-Data Collection and Processing

Kinematic data were collected using MT Manager and analyzed using Matlab (MathWorks, MA, USA). Three-dimensional orientation data from the IMU's were sampled at a rate of 60 Hz and filtered using a Kalman filter specifically developed to capture human motion and minimize noise from Xsens IMUs. Custom Matlab scripts were used to extract rotation matrices from the IMUs. These matrices were used to obtain rotation of the thorax and pelvis with respect to the upright standing posture from the IMUs attached in the back of the participants at the T10 and S1 spinal levels, respectively. Lumbar rotation, represented as joint movement between the pelvis and thorax, was calculated by subtracting pelvis rotation values from thoracic rotation values at each time instant of the task. The lumbo-thoracic ratio was then calculated as follows:

$$LTR = \frac{Lumbar\ rotation}{Thorax\ rotation} * 100 \qquad (1)$$

Rotations of thorax, pelvis, and lumbar spine along with the value of LTR, all calculated at the time of maximum thoracic rotations, were considered measures of the magnitude aspect of LPC. Furthermore, MARP and DP were calculated from the CRP to characterize the timing aspect of LPC and to find how "in sync" the segments were during movement. To find CRP, thorax and pelvis rotational values were first normalized using Equation 2 so that values of thoracic and pelvic rotation changed between -1 and 1 and centered around 0. This technique separates the forward bending movement from the backward return movement, giving the two motions equal positive and negative values.

$$Normalization = \frac{x(t) - \min(x(t)) - (\max(x(t)) - \min(x(t)))}{2} \qquad (2)$$

Wherein x(t) denotes rotation of thorax (or pelvis) during the task. Phase angle of thorax (or pelvis), $\varphi(t)$, during the task was then calculated as follows:

$$\xi(t) = x(t) + iH(t) \qquad (3)$$

$$\varphi(t_i) = \tan^{-1}\left(\frac{H(t_i)}{x(t_i)}\right) \qquad (4)$$

Wherein H(t) denotes the imaginary part of the Hilbert transformation that results from the transformation of the real signal into an analytic signal. From the complex signal, phase angle at a given instant of time can be calculated as shown in equation 4.

CRP was then calculated by subtracting the thorax and pelvis phase angles.

$$CRP(t_i) = \varphi_{Thorax}(t_i) - \varphi_{Pelvis}(t_i) \quad (5)$$

The CRP values were first rectified and then their average and standard deviation across the three repetitions of the task for each percentile of the task were calculated. Finally, the average of the above calculated means and standard deviation were calculated to represent MARP (equation 6) and DP (equation 7), respectively.

$$MARP = \sum_{i=1}^{100} \frac{|CRP|_i}{100} \quad (6)$$

$$DP = \sum_{i=1}^{100} \frac{SD_i}{100} \quad (7)$$

$$|CRP| = Mean\ of\ the\ absolute\ value\ of\ CRP\ across\ 3\ motions\ at\ each\ percentile$$

$$\overline{SD} = Standard\ deviation\ of\ CRP\ across\ 3\ motions\ at\ each\ percentile$$

Prior to MARP and DP calculations, each exercise was separated into a forward bending (FB) motion and a backward return (BR) motion. This was done to see if segments differed in coordination and stability during the forward bending versus the backward return movements.

2.7-Statistical Analysis

Repeated measures analysis of variance (ANOVA) tests were conducted to investigate diurnal changes in measures of timing and magnitude aspects of LPC as well as their differences among the nurse groups. The dependent variables obtained from forward bending and backward return tests (both slow and fast paces) were measured for thoracic, pelvic, and lumbar rotations along with the LTR, MARP, and DP. The dependent variables obtained from the MMH tests were measures for thoracic, pelvic and lumbar rotations along with the LTR that were obtained from the bending phase of the MMH with and without load in hand. All thoracic, pelvic, and lumbar rotations were measured in degrees as the angle from the upright, standing position to maximum forward flexion. The independent variables included the nursing group as the between subjects factor with three levels (UK physically demanding nurse, UK sedentary nurse, CH nurse) and time as the within subject factor with two levels (pre shift, post shift). Statistical analysis was conducted using SPSS (IBM SPSS Statistics 26, Armonk, NY, USA). A 95% confidence interval was used and reported p-values less than 0.05 indicated a statistically significant difference among the groups and were further analyzed using a Tukey post hoc testing procedures.

Following initial statistical analysis, an analysis of covariance (ANCOVA) test was performed. This was done using data collected during the screening process regarding habitual physical activities (see **Appendix**). Answers to the screening questions were assigned a numerical value and Akaike's Information Criterion (AIC) was calculated using Excel (Microsoft, WA, USA) to find the best fit statistical model when adding habitual physical activities as covariates. Based on results, it was found that the frequency of walking at work (walking), feeling tired after work (tired), playing sports during leisure time (sports), and cycling during leisure time (cycling) were the best fit covariates for the statistical model. A repeated measures ANCOVA was performed for each covariate using the same dependent variables, between subjects factors, within subjects factors, and confidence interval as the initial statistical analysis.

CHAPTER 3- Results

3.1-Summary of Statistics

Summary of statistical results as well as mean values of outcome measures at pre-shift and post-shift are presented in **Tables 2-9**. Statistically significant results are highlighted in the cell by bold font and gold background. Dependent variables labeled with an asterisk (*) indicate that data were transformed using a logarithm with the base 10 for normality and homogeneity purposes of values, as necessitated to comply with the assumptions of ANOVA.

3.2- Slow Forward Bending and Backward Return

Pelvic rotation was greater in UK physically demanding nurses compared to CH nurses (Physically Demanding: 52.74˚ (20.45˚) vs CH: 32.03˚ (19.07˚)). Thoracic rotation was greater in all UK nurses compared to CH nurses (Sedentary: 99.57˚ (19.46˚) and Physically Demanding: 107.66˚ (12.11˚) vs CH: 77.01˚ (6.63˚)) (**Figure 6** and **Figure 7**). No other differences were seen when comparing pre-shift and post-shift values or other timing and magnitude aspects among groups.

Table 2: Summary of statistical results for within groups and differences among groups in measures of magnitude (i.e., pelvic, thoracic, and lumbar rotation and lumbo-thoracic ratio: LTR) and timing (i.e., mean absolute relative phase MARP and deviation phase: DP) aspects of lumbo-pelvic coordination during slow bending and backward return. MARP and DP during forward bending (FR) and backward return (BR) were calculated separately.

Slow Forward Bend								
	Magnitude							
	Pelvis*		Thorax*		Lumbar		LTR	
	F	p	F	p	F	p	F	p
Time	0.015	0.905	0.278	0.602	0.445	0.510	0.048	0.827
Group	3.678	**0.037**	12.966	**<0.001**	0.991	0.383	0.548	0.584
Time*Group	0.707	0.501	0.009	0.991	0.756	0.478	0.708	0.500
	Timing							
	MARP FB		DP FB		MARP BR*		DP BR*	
	F	p	F	p	F	p	F	p
Time	0.242	0.626	0.208	0.652	5.006	0.033	4.232	0.048
Group	0.586	0.563	0.471	0.629	1.026	0.371	0.975	0.389
Time*Group	0.840	0.442	0.437	0.650	1.400	0.262	0.977	0.388

Table 3: Summary of mean (standard deviation) values of each group for pre-shift and post-shift data collection sessions for the slow exercise. MARP and DP refer to mean absolute relative phase and deviation phase, respectively.

Slow Exercise				
	Pre-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Average of Groups**
Maximum Pelvic Rotation* (Degrees)	**46.76 (28.96)**	**52.74 (20.45)**	**32.03 (19.07)**	44.92 (24.37)
Maximum Thoracic Rotation* (Degrees)	**99.57 (19.46)**	**107.66 (12.11)**	**77.01 (6.63)**	96.36 (18.67)
Maxium Lumbar Rotation (Degrees)	52.80 (23.13)	54.98 (19.68)	45.02 (13.83)	51.47 (19.54)
Lumbothoracic Ratio (%)	54.38 (22.38)	51.24 (17.49)	59.78 (21.02)	54.71 (19.99)
MARP Forward Bend (Radians)	0.13 (0.11)	0.12 (0.07)	0.09 (0.05)	0.12 (0.08)
DP Forward Bend (Radians)	0.13 (0.10)	0.12 (0.06)	0.09 (0.05)	0.11 (0.07)
MARP Backward Return* (Radians)	0.11 (0.08)	0.09 (0.05)	0.16 (0.17)	0.11 (0.11)
DP Backward Return* (Radians)	0.11 (0.07)	0.09 (0.06)	0.16 (0.15)	0.12 (0.09)
	Post-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Average of Groups**
Maximum Pelvic Rotation* (Degrees)	**41.52 (21.94)**	**54.47 (24.56)**	**33.35 (18.66)**	44.00 (23.13)
Maximum Thoracic Rotation* (Degrees)	**100.35 (20.78)**	**108.85 (13.16)**	**78.02 (9.41)**	97.35 (19.70)
Maxium Lumbar Rotation (Degrees)	58.88 (20.44)	54.36 (23.76)	44.75 (17.12)	53.38 (21.06)
Lumbothoracic Ratio (%)	58.98 (17.49)	50.12 (21.25)	57.94 (21.34)	55.47 (19.78)
MARP Forward Bend (Radians)	0.13 (0.12)	0.10 (0.07)	0.10 (0.04)	0.11 (0.08)
DP Forward Bend (Radians)	0.11 (0.09)	0.10 (0.09)	0.10 (0.05)	0.11 (0.08)
MARP Backward Return* (Radians)	0.12 (0.10)	0.07 (0.05)	0.06 (0.04)	0.08 (0.07)
DP Backward Return* (Radians)	0.12 (0.09)	0.07 (0.06)	0.07 (0.05)	0.09 (0.07)

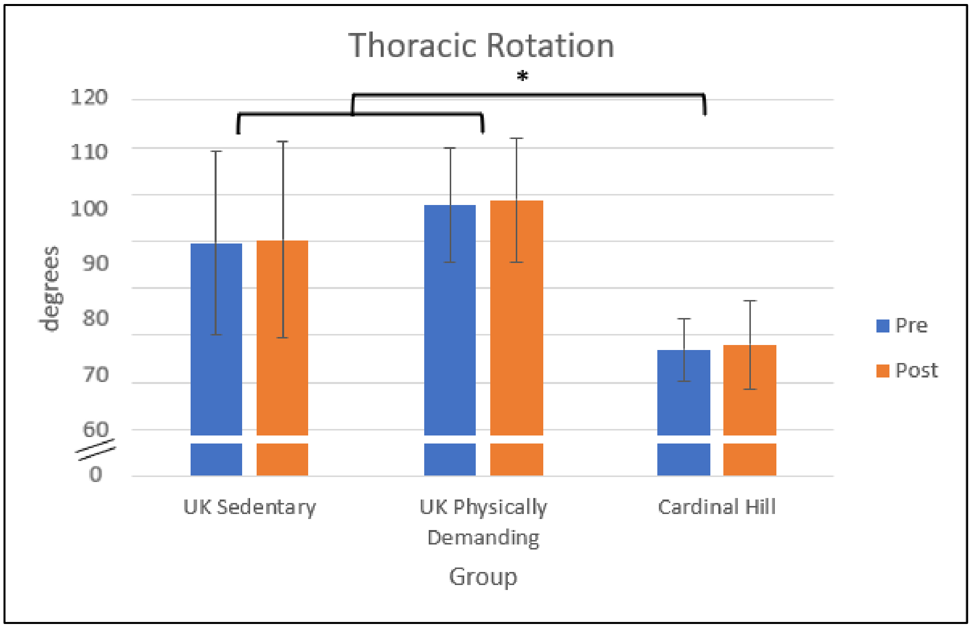

Figure 6: Differences among groups in thoracic rotation during the slow exercise. Error bars indicate standard deviations.

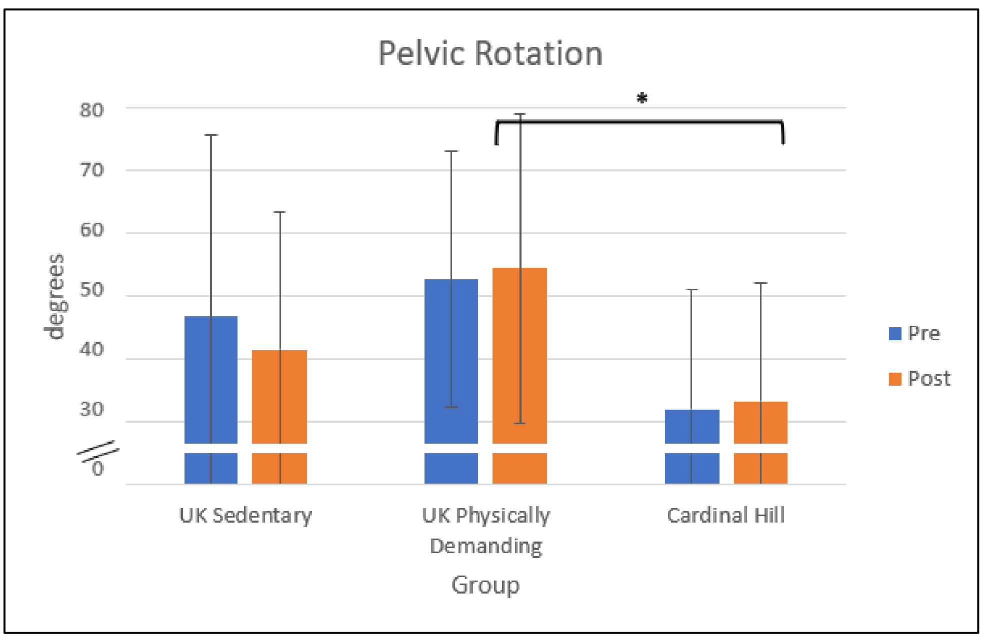

Figure 7: Differences among groups in pelvic rotation during the slow exercise. Error bars indicate standard deviations

3.3-Fast Forward Bending and Backward Return

Thoracic rotation was greater in all UK nurses compared to CH nurses (Sedentary: 108.31˚ (19.07˚) and Physically Demanding: 118.28˚ (12.75˚) vs CH: 84.86˚ (8.23˚)) (**Figure 8**). No other differences were seen when comparing pre-shift and post-shift values or other timing and magnitude aspects among groups.

Table 4: Summary of statistical results for within and among group differences in measures of magnitude (i.e., pelvic, thoracic, and lumbar rotation and lumbo-thoracic ratio: LTR) and timing (i.e., mean absolute relative phase MARP and deviation phase: DP) aspects of lumbo-pelvic coordination during slow forward bending and backward return. MARP and DP during forward bending (FR) and backward return (BR) were calculated separately

Fast Forward Bend								
Magnitude								
	Pelvis*		Thorax*		Lumbar		LTR	
	F	p	F	p	F	p	F	p
Time	2.539	0.122	2.535	0.122	0.444	0.510	1.563	0.221
Group	3.001	0.065	13.394	**<0.001**	0.977	0.388	0.786	0.465
Time*Group	0.613	0.548	0.435	0.651	1.373	0.269	1.489	0.242
Timing								
	MARP FB*		DP FB*		MARP BR*		DP BR*	
	F	p	F	p	F	p	F	p
Time	0.016	0.902	0.004	0.950	0.004	0.952	0.009	0.924
Group	1.796	0.183	2.211	0.127	0.171	0.844	0.131	0.878
Time*Group	0.003	0.997	0.001	0.999	1.426	0.256	1.438	0.253

Table 5: Mean (standard deviation) values of dependent variables for each group from pre-shift and post-shift data collection sessions for the fast exercise. MARP and DP refer to mean absolute relative phase and deviation phase, respectively.

Fast Exercise				
	Pre-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Average of Groups**
Maximum Pelvic Rotation* (Degrees)	53.71 (30.64)	62.66 (20.86)	37.92 (18.14)	52.66 (25.56)
Maximum Thoracic Rotation* (Degrees)	**108.31 (19.07)**	**118.28 (12.75)**	**84.86 (8.23)**	105.54 (19.54)
Maxium Lumbar Rotation (Degrees)	54.71 (25.05)	55.85 (21.19)	47.09 (15.75)	53.05 (21.12)
Lumbothoracic Ratio (%)	51.47 (23.39)	47.17 (17.23)	56.03 (18.77)	51.15 (19.77)
MARP Forward Bend* (Radians)	0.17 (0.14)	0.12 (0.08)	0.17 (0.09)	0.15 (0.09)
DP Forward Bend* (Radians)	0.12 (0.08)	0.09 (0.06)	0.13 (0.06)	0.11 (0.07)
MARP Backward Return* (Radians)	0.16 (0.17)	0.15 (0.06)	0.22 (0.26)	0.17 (0.17)
DP Backward Return* (Radians)	0.10 (0.11)	0.10 (0.04)	0.15 (0.16)	0.12 (0.11)
	Post-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Average of Groups**
Maximum Pelvic Rotation* (Degrees)	47.12 (23.59)	58.84 (26.51)	36.81 (14.89)	48.57 (23.82)
Maximum Thoracic Rotation* (Degrees)	**98.96 (25.83)**	**115.61 (16.52)**	**80.14 (10.67)**	99.88 (23.55)
Maxium Lumbar Rotation (Degrees)	60.30 (21.44)	57.05 (23.49)	44.34 (18.46)	54.77 (21.84)
Lumbothoracic Ratio (%)	67.79 (40.61)	49.85 (20.61)	54.03 (21.13)	57.51 (29.83)
MARP Forward Bend* (Radians)	0.15 (0.09)	0.12 (0.08)	0.18 (0.12)	0.15 (0.10)
DP Forward Bend* (Radians)	0.11 (0.06)	0.09 (0.07)	0.14 (0.08)	0.11 (0.07)
MARP Backward Return* (Radians)	0.16 (0.11)	0.12 (0.10)	0.25 (0.29)	0.17 (0.18)
DP Backward Return* (Radians)	0.11 (0.07)	0.09 (0.07)	0.16 (0.17)	0.11 (0.11)

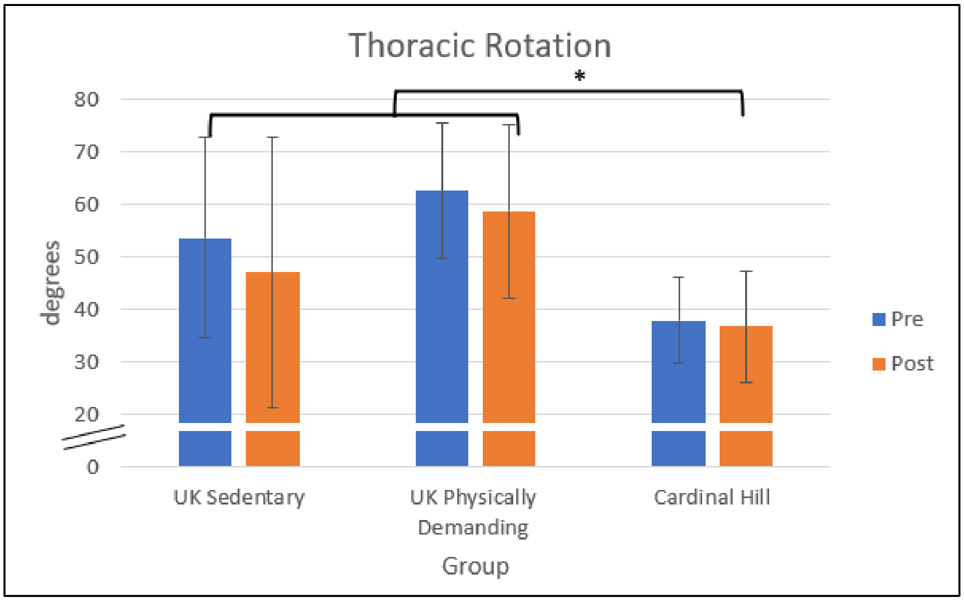

Figure 8: Differences among groups in thoracic rotation during the fast exercise. Error bars indicate standard deviations.

3.4- Manual Material Handling

Thoracic rotation during MMH with load was greater in UK physically demanding nurses compared to CH nurses (Physically Demanding: 91.53˚ (19.30˚) vs CH: 75.91˚ (13.49˚)) (**Figure 9**). Thoracic rotation during MMH without load was greater in all UK nurses compared to CH nurses (Sedentary: 86.58˚ (11.80˚) and Physically Demanding: 93.07˚ (15.66˚) vs CH: 75.23˚ (12.95˚)) (**Figure 10**). No other differences were seen when comparing pre-shift and post-shift values or other timing and magnitude aspects among groups.

Table 6: Summary of statistical results for within and among group differences in measures of magnitude (i.e., pelvic, thoracic, and lumbar rotation and lumbo-thoracic ratio: LTR)

Manual Material Handling with Load								
Magnitude								
	Pelvis*		Thorax*		Lumbar		LTR	
	F	p	F	p	F	p	F	p
Time	1.261	0.271	2.394	0.133	0.575	0.455	0.105	0.748
Group	1.969	0.158	4.067	**0.028**	0.237	0.790	0.329	0.723
Time*Group	1.191	0.319	1.434	0.255	2.042	0.149	0.095	0.909
Manual Material Handling without Load								
Magnitude								
	Pelvis*		Thorax*		Lumbar		LTR	
	F	p	F	p	F	p	F	p
Time	2.910	0.099	1.581	0.219	0.395	0.535	0.133	0.719
Group	1.857	0.175	6.802	**0.004**	0.295	0.747	0.478	0.625
Time*Group	1.921	0.165	1.522	0.236	2.558	0.095	0.566	0.574

Table 7: Mean (standard deviation) values in degrees of dependent variables for each group from pre-shift and post-shift data collection sessions for MMH with and without load

Manual Material Handling with Load				
	Pre-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Average of Groups**
Maximum Pelvic Rotation* (Degrees)	24.70 (18.25)	34.77 (30.11)	18.06 (20.65)	26.55 (24.08)
Maximum Thoracic Rotation* (Degrees)	**83.36 (12.33)**	**91.53 (19.30)**	**75.91 (13.49)**	**84.30 (16.30)**
Maxium Lumbar Rotation (Degrees)	67.40 (24.92)	65.88 (27.47)	65.37 (20.90)	66.29 (24.14)
Lumbothoracic Ratio (%)	80.62 (27.75)	75.60 (34.33)	88.33 (30.18)	80.90 (30.39)
	Post-Shift			
	UK Sedentary	**UK Physically Demanding**	**Cardinal Hill**	**Total**
Maximum Pelvic Rotation* (Degrees)	25.18 (21.22)	41.47 (37.24)	18.11 (18.64)	29.21 (28.57)
Maximum Thoracic Rotation* (Degrees)	**90.00 (11.94)**	**96.60 (26.10)**	**75.35 (15.46)**	**88.41 (20.42)**
Maxium Lumbar Rotation (Degrees)	73.89 (29.22)	64.62 (26.72)	64.38 (21.88)	67.93 (26.07)
Lumbothoracic Ratio (%)	81.14 (30.51)	73.57 (37.59)	87.61 (30.43)	80.15 (32.71)
Manual Material Handling without Load				
	Pre-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Total**
Maximum Pelvic Rotation* (Degrees)	27.18 (20.10)	35.97 (28.07)	18.93 (20.46)	28.13 (23.70)
Maximum Thoracic Rotation* (Degrees)	**86.58 (11.80)**	**93.07 (15.66)**	**75.23 (12.95)**	**85.84 (15.02)**
Maxium Lumbar Rotation (Degrees)	64.72 (24.78)	65.79 (27.72)	59.99 (17.27)	63.91 (23.70)
Lumbothoracic Ratio (%)	73.80 (25.84)	73.20 (32.92)	85.69 (32.94)	76.63 (30.04)
	Post-Shift			
	Sedentary	**Physically Demanding**	**Cardinal Hill**	**Total**
Maximum Pelvic Rotation* (Degrees)	26.23 (19.91)	44.36 (35.73)	19.27 (17.96)	30.92 (27.75)
Maximum Thoracic Rotation* (Degrees)	**90.71 (10.91)**	**99.71 (24.51)**	**73.86 (15.31)**	**89.39 (20.36)**
Maxium Lumbar Rotation (Degrees)	71.25 (29.20)	64.33 (28.37)	58.21 (18.27)	65.21 (26.15)
Lumbothoracic Ratio (%)	75.79 (27.71)	69.98 (36.33)	84.57 (31.95)	75.81 (31.81)

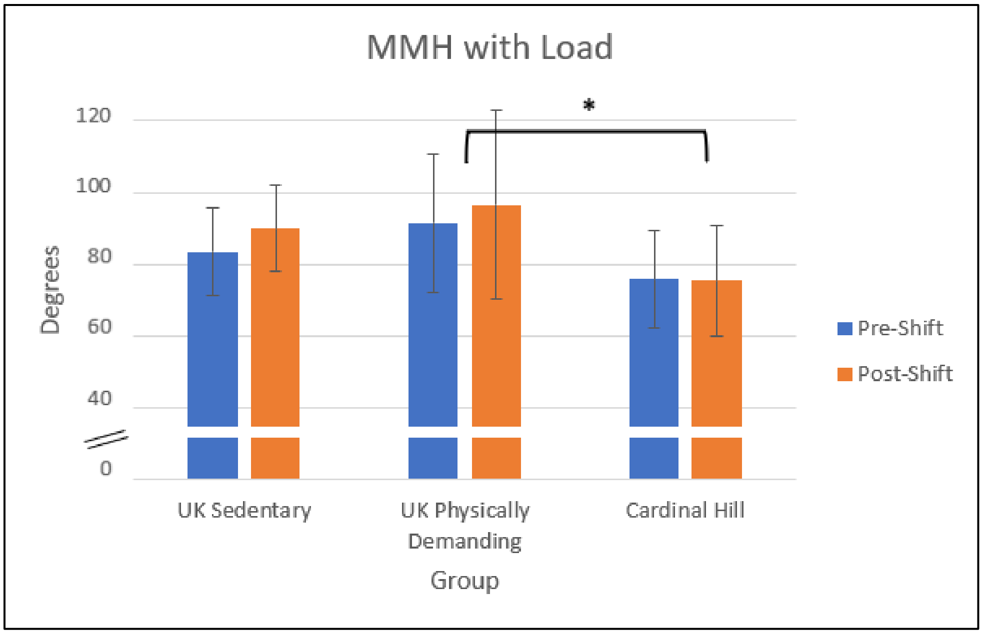

Figure 9: Differences among groups in thoracic rotation during MMH with load. Error bars indicate standard deviations.

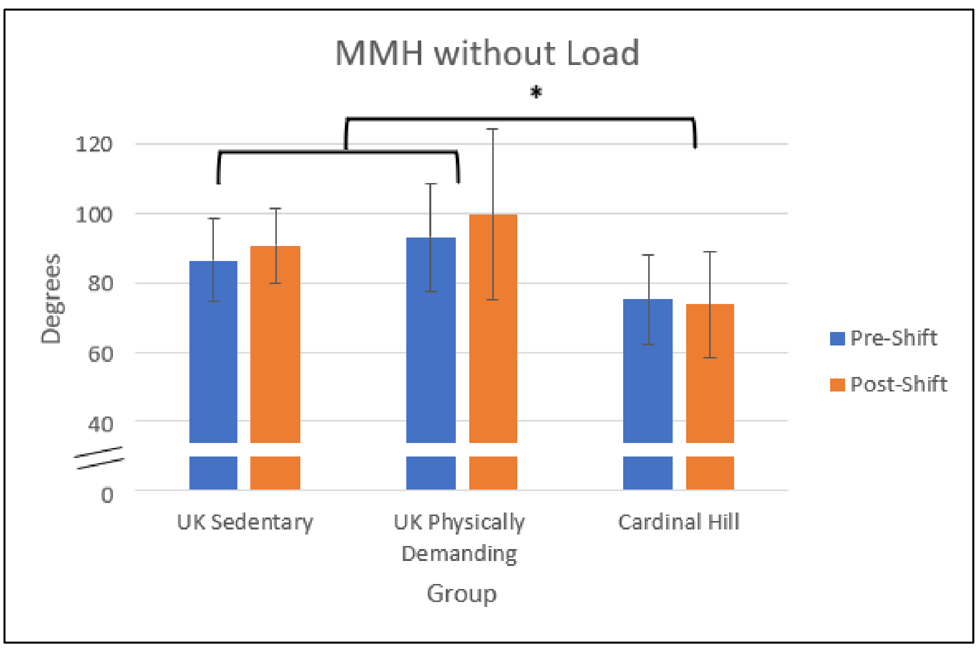

Figure 10: Differences among groups in thoracic rotation during MMH without load. Error bars indicate standard deviations.

3.6- Addition of Covariates

The addition of covariates to the statistical model, identified from the screening questions and AIC analysis, did not provide any differences between pre-shift and post-shift values. These covariates included the frequency of walking at work, feeling tired after work, playing sports during leisure time, and cycling during leisure time. Compared to the original statistical model, additional differences among groups were seen in the fast exercise. The use of walking as a covariate showed a difference among groups in pelvic rotation in addition to the differences in thoracic rotation originally seen. The UK sedentary group saw greater pelvic rotation compared to CH nurses. Differences in thoracic rotation were the same as the original model in which both groups of UK nurses saw greater rotation compared to CH nurses.

Table 8: Summary of statistical results using frequency of walking at work as a covariate for within and among group differences in measures of magnitude (i.e., pelvic, thoracic, and lumbar rotation and lumbo-thoracic ratio: LTR)

Fast Forward Bend								
Magnitude								
	Pelvis		Thorax		Lumbar		LTR	
	F	p	F	p	F	p	F	p
Time	0.001	0.981	0.000	0.989	0.065	0.800	0.216	0.645
Group	4.436	**0.021**	16.417	**0.000**	0.747	0.483	0.350	0.707
Time*Group	0.597	0.557	0.268	0.767	0.641	0.534	0.430	0.655
Time*Walking	0.027	0.870	0.031	0.862	0.032	0.860	0.102	0.752
Timing								
	MARP FB		DP FB		MARP BR		DP BR	
	F	p	F	p	F	p	F	p
Time	2.655	0.114	3.440	0.074	0.389	0.538	0.457	0.504
Group	1.896	0.168	1.944	0.161	0.180	0.837	0.139	0.870
Time*Group	0.747	0.483	1.017	0.374	1.513	0.237	1.562	0.227
Time*Walking	2.643	0.115	3.460	0.073	0.404	0.530	0.479	0.494

Chapter 4- Discussion

4.1- Role of LPC in LBP

The high prevalence of LBP in healthcare occupations, specifically in nurses, can be attributed to the high exposure to known LBP risk factors throughout the duration of an 8-12 hour shift. Previous studies have performed the characterization and quantification of LPC through exposure to a single LBP risk factor within a laboratory setting, but exploration of the exposure of subjects to several risk factors over the course of an entire shift is necessary to understand the full extent of the impact of workplace factors on LPC and risk of LBP due to biomechanical factors. The primary goal of this study was to verify if exposure to LBP risk factors affects LPC in nurses as a result of an 8-12 hour work shift. It was hypothesized that magnitude and timing of LPC following a work shift will exhibit behavior similar to that of a person suffering from LBP, including decreased total lumbar range of motion during activities, and more synchronous and less variability in movements. The secondary goal of this study was to verify if the level of physical activity affects changes in LPC. It was hypothesized that nurses working more active days would experience larger work-related changes in LPC than those working less active shifts. Results of this study did not fully support the hypotheses. No changes between pre-shift and post-shift measures were seen in any of the exercises. Changes among groups were seen in pelvic rotation during the slow exercise and in thoracic rotation during all exercises. No changes in lumbar rotation, LTR or timing aspects were seen.

4.2- Diurnal Changes in LPC

The first goal of this study was to verify the effects of a day-long exposure to LBP risk factors on LPC that are present in a nursing occupation. It was hypothesized that magnitude and timing of LPC following a work shift will exhibit behavior similar to that of a person suffering from LBP, consistent with findings from previous studies. Other studies have investigated LPC through evaluation of forward bending and backward return exercises using similar data collection and analysis techniques. Hu and Ning investigated the effects of MMH on the timing characteristics of LPC. The current study employed the same techniques as the Hu and Ning study regarding trunk motion, instrumentation, and analysis in order to investigate differences before and after lifting exercises and the corresponding effects on coordination following muscle fatigue (Hu and Ning 2015). Also investigating pre-exercise and post-exercise differences, Van Hoof, et. al measured magnitude aspects of LPC during prolonged lumbar flexion using a strain gauge technology which continuously measured changes over the course of a 2 hour cycling ride (Van Hoof, Volkaerts et al. 2012). The findings from this study as well as many others indicate that changes in timing and magnitude of LPC occur when comparing values before and after performing exercises or prolonged positions. Characteristics after prolonged sitting showed increased lumbar flexion, resulting from flexion relaxation (Howarth, Glisic et al. 2013). Other studies involving measurement before and after active movements found decreased lumbar contribution in the middle of the forward bending motion, decreased total lumbar range of motion during activities, and more synchronous and less variable in movements.

In the current study, however, no pre-shift vs post-shift differences were seen despite the exposure of all subjects to a wide range of risk factors. One suggestion for the interpretation of these results is that the effect of multiple risk factors canceled each other out. Additionally, even though subjects returned for post-shift data collection immediately after their shift ended, the commute from the hospital to the laboratory where data collection occurred could have provided enough recovery for abnormal LPC characteristics to recover.

4.3- Changes Among Groups in LPC

The second goal of this study was to verify if the level of physical activity affects diurnal work-related changes in LPC. It was hypothesized that work-related changes in LPC of nurses would be larger with greater levels of physical activity, meaning that nurses working more active days were expected to experience larger work-related changes in LPC than those working less active shifts. Several studies have investigated differences in LPC between groups, finding significant differences in timing and magnitude and providing basis for the current study. Vazirian, et. al investigated age-related differences in LPC using forward bending/backward return exercises. In this study, timing aspects were investigated using MARP and DP values following the calculation of CRP (Vazirian, Shojaei et al. 2017). Shojaei, et. al also used the same data collection and analysis techniques for investigation of the timing of LPC between groups of healthy and LBP individuals (Shojaei, Vazirian et al. 2017). LPC seen in older versus younger individuals was comparable to LPC in LBP individuals. These timing characteristics from these two studies include more in-phase and less variable movement based on MARP and DP calculations. Additionally, Shojaei, et al. found decreased lumbar contribution in LBP patients compared to healthy individuals.

In the current study, there was significantly larger pelvic rotation during the slow exercise in UK physically demanding nurses compared to CH nurses (52.74˚ (20.45˚) vs 32.03˚

(19.07˚)). Additionally, thoracic rotation was larger in both UK sedentary and physically demanding nurses compared to CH nurses for the slow exercise (99.57˚ (19.46˚) and 107.66˚ (12.11˚) vs 77.01˚ (6.63˚)) and fast exercise (108.31˚ (19.07˚) and 118.28˚ (12.75˚) vs 84.86˚ (8.23˚)). Thoracic rotation during MMH with load was greater in UK physically demanding nurses compared to CH nurses (91.53˚ (19.30˚) vs 75.91˚ (13.49˚)). Thoracic rotation in MMH without load was greater in all UK nurses compared to CH nurses (86.58˚ (11.80˚) and 93.07˚ (15.66˚) vs 75.23˚ (12.95˚)). Since there were no diurnal changes observed in this study, it was not possible to the asses how the level of physical activity affected diurnal work-related changes in LPC. The differences among groups observed in thoracic and pelvic rotations might be due to the accumulation of diurnal changes related to the occupational risk factors experienced over time. It is likely that these diurnal changes were undetectable by our measures of LPC. These changes could be from the frequency of exposure to occupational risk factors as well as how strenuous the tasks are.

4.4- Covariate Addition

Covariates are added to statistical models as predictive variables that are related to the dependent variable (Salkind, Sage et al. 2010). According to the AIC analysis, the frequency of walking at work (walking), feeling tired after work (tired), playing sports during leisure time (sports), and cycling during leisure time (cycling) were variables that made the best fit model for covariate analysis. It was expected that the addition of walking would show differences in the results because the main criteria categorizing a nurse as physically demanding or sedentary was how much time was spent seated. Therefore, it was rationalized that if the frequency of walking at work was greater, more differences among groups would be seen in the model. The frequency of feeling tired after work can often also be linked to how active a person was at work, and the greater frequency that one was tired after work was thought to influence differences among groups as well. The addition of playing sports and cycling during leisure time were indicative of how active participants were while not at work. These were used to measure general physical fitness, which could play a role in the ability for participants to carry out physical tasks more easily at work. The more active a person is during their leisure time could indicate greater muscle development compared to someone who is relatively inactive during their leisure time. Muscle activity and coordination play an important role in spinal stability and more developed muscles in the lumbar region helps spinal stability and provides efficiency during movement (Bruno 2014).

The addition of covariates in the statistical model only found differences among groups in pelvic rotation during the fast exercise as well as the differences in thoracic rotation seen in the original model. The sedentary group saw greater pelvic rotation compared to CH nurses. Both groups of UK nurses saw greater rotation compared to CH nurses during thoracic rotation. The lack of pre-shift and post-shift differences is likely due to the reasons explained for the original model. The differences among groups seen in pelvic rotation based on frequency of walking is likely because amount of walking was the main deciding factor in categorizing nurses into groups. The lack of differences seen in other magnitude and timing aspects is likely because diurnal changes were undetectable by our measures of LPC, as mentioned above.

4.5- Limitations

Limitations of this study exist that should be taken into account when observing results and planning follow-up work. First, the activity level of a subject outside of work could affect their performance during these exercises. Data regarding habitual physical activities was recorded and these variables were incorporated as covariates in the statistical model. However, the addition of covariates only found further differences in pelvic rotation during the fast exercise. A questionnaire that incorporates more questions about physical activity could be beneficial in understanding the overall fitness and activity of individuals. The International Physical Activity Questionnaire (IPAQ) asks questions about the different types of physical activity and their intensity performed over the last 7 days. Questions about frequency of both moderate and vigorous physical activities are covered under categories related to occupation, transportation, housework, recreation, and time spent sitting (Booth 2000). The IPAQ would supplement the current questionnaire to provide a more detailed understanding of a participant's physical condition. Next, this study recruited both day shift workers and night shift workers. Nurses who work the night shift do not typically maintain the same schedule for the days they work and the days they do not work, so their routines differed regularly on whether they were up and active during the day or active all night. Five of the 12 physically demanding nurses and four of the 9 CH nurses worked night shifts, which could have influenced the results. Another consideration is that the level of active nurses varied from unit to unit. While nurses considered "physically demanding" spent the majority of their shift on their feet, some nursing units such as the emergency department perform a lot more strenuous lifts, transfers, and fast pace movements than a nurse who worked on a less active unit such as in the Children's Hospital. Finally, the sample size could have an influence on the results as well.

4.6- Conclusions

This study did not confirm the hypotheses that work-related changes in magnitude and timing of LPC would show characteristics of LBP patients and that such changes in LPC of nurses would be greater with greater level of physical activity. To our best knowledge, there are no other studies investigating changes in LPC after a full day of exposure to LBP risk factors in a non-laboratory setting. Although nurses are exposed to a wide range of known risk factors for LBP throughout their work shift, changes in different aspects of LPC due to such exposures appear to cancel each other out. In addition, we did not observe work-related changes in LPC, however the differences among groups in LPC may be an indication of cumulative changes in LPC that were not detectable by our approach.

Because of the high incidence of LBP seen in the nursing profession, our results could not establish evidence in support of a causal role for abnormal LPC in LBP experience among nurses. However, the limitations of our study that likely affected our ability in establishing such evidences should not be overlooked. Improvements for the current study include recruiting a larger, more homogenous subject population to mitigate any “within-group” dissimilarities that occur in occupational activities performed by nurses.

4.7- Future work

The limitation of the present study likely had a role in our inability to prove our hypotheses. Therefore, future studies can be designed to address such limitations. Specifically, recruiting a more homogenous group of nurses can be done by recruiting all “physically demanding” or “sedentary” nurses from the same nursing unit to ensure that all participants in a certain group perform the most similar types of tasks. Recruiting only day shift workers would help with homogeneity as well. Next, a power test for each exercise should be performed to ensure appropriate sample size. Future studies investigating the same or similar timing and magnitude characteristics would benefit from a larger sample size, providing the possibility of seeing more significant results.

Appendix

PARTICIPANT INFORMATION AND SCREENING FORM

(Form-M)

Project Title:

Work related diurnal changes in trunk mechanical behavior

Investigators:

Matt Ballard, Department of Biomedical Engineering, UK
Maeve McDonald, Department of Biomedical Engineering, UK
Clare Tyler, Department of Biomedical Engineering, UK
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Participant #: __________ (filled out by the experimenter) **Date:** __________

Part I – Verification of Advertised Criteria

Age group: 21-60 Other

During the past 12 months, have you had any episode of back pain that resulted in visiting a doctor or missing a work day? Yes No

Are you a nurse? Yes No

Does your job require you to sit most of the day? Yes No

***** This section to be completed via email. Invite participant for visit only if the underlined answers given.**

Part II – Personal Information

Name: (last) _________________________, (first)_____________________________

Phone: ___________________________ Email:________________________________

Address:

____

____

Age: _____________

Gender (please circle): Male Female

Race (please circle):

Caucasian African-American Asian Native American/Alaskan

Native Hawaiian/Pacific Islander Other: _________________________

Nursing Unit: ________________ Number of years at current occupation: ____________

Part III – Medical History Relevant to the Project

Have you had any history of the following? If yes, please explain:

1. Musculoskeletal problem
    a. Upper or lower back
    b. Shoulder and upper extremity
    c. Lower extremity
2. Neuromuscular disease
3. Spinal surgery
4. Joint (hip) replacement
5. Pregnancy during the past year
6. Fall
7. Problem caused by arthritis, muscle problem, broken bone, etc. that limits your ability to walk or bend your joints
8. Any other disorders, illnesses or injuries that you feel might interfere with this study

Part IV – Habitual Physical Activities

Choose the answer which best meets your conditions

1. Level of physical activity in your work: low moderate high
2. Frequency of sitting at work: never seldom sometimes often always
3. Frequency of standing at work: never seldom sometimes often always
4. Frequency of walking at work: never seldom sometimes often always
5. Frequency of heavy lifting at work: never seldom sometimes often always
6. Frequency of feeling tired after work: never seldom sometimes often always
7. Frequency of sweating at work: never seldom sometimes often always
8. In comparison with others close to your age is your work physically:
   Much heavier Heavier As heavy Lighter Much lighter
9. Do you play sports: Yes No
   If yes:
   a. Which sport do you play most frequently?
   b. How many hours per week do you play?
   c. Which days of the week do you play?
   d. How many months per year do you play?
   If you play a second sport:
   e. Which sport do you play?
   f. How many hours per week do you play?
   g. Which days of the week do you play?
   h. How many months per year do you play?
10. In comparison with others, your physical activity during leisure time is:
    Much more More The same Less Much less
11. Frequency of seating during leisure: never seldom sometimes often always
12. During leisure do you play sports never seldom sometimes often always
13. During leisure do you watch TV never seldom sometimes often always
14. During leisure do you walk never seldom sometimes often always
15. During leisure do you cycle never seldom sometimes often always
16. How many minutes per day do you walk and/or cycle to and from work, school and shopping?
    <5 5 – 15 15 – 30 30 – 45 >45

References

(2001). "Prevalence of Disabilities and Associated Health Conditions Among Adults—United States, 1999." JAMA **285**(12): 1571-1000.
Ahern, D. K., M. J. Follick, J. R. Council, N. Laser-Wolston and H. Litchman (1988). "Comparison of lumbar paravertebral EMG patterns in chronic low back pain patients and non-patient controls." Pain **34**(2): 153-160.
Allegri, M., S. Montella, F. Salici, A. Valente, M. Marchesini, C. Compagnone, M. Baciarello, M. E. Manferdini and G. Fanelli (2016). "Mechanisms of low back pain: a guide for diagnosis and therapy." F1000Research **5**: F1000 Faculty Rev-1530.
Anonymous (2001). "Prevalence of Disabilities and Associated Health Conditions Among Adults—United States, 1999." JAMA **285**(12): 1571-1000.
Asgari, M., M. A. Sanjari, H. R. Mokhtarinia, S. Moeini Sedeh, K. Khalaf and M. Parnianpour (2015). "The effects of movement speed on kinematic variability and dynamic stability of the trunk in healthy individuals and low back pain patients." Clinical Biomechanics **30**(7): 682-688.
Booth, M. (2000). "Assessment of Physical Activity: An International Perspective." Research Quarterly for Exercise and Sport **71**(2): 114-120.
Bruno, P. (2014). "The use of "stabilization exercises" to affect neuromuscular control in the lumbopelvic region: a narrative review." The Journal of the Canadian Chiropractic Association **58**(2): 119-130.
Ebrahimi, S., F. Kamali, M. Razeghi and S. A. Haghpanah (2018). "Correlation between Trunk-Pelvis Inter-Segmental Coordination Parameters during Walking and Disability Level in Chronic Low Back Pain Patients." Journal of biomedical physics & engineering **8**(2): 193-202.
Esola, M. A., P. McClure, G. Fitzgerald and S. Siegler (1996). "Analysis of lumbar spine and hip motion during forward bending in subjects with and without a history of low back pain." Spine **21**(1): 71-78.
Freburger, J. K., G. M. Holmes, R. P. Agans, A. M. Jackman, J. D. Darter, A. S. Wallace, L. D. Castel, W. D. Kalsbeek and T. S. Carey (2009). "The Rising Prevalence of Chronic Low Back Pain." Archives of Internal Medicine **169**(3): 251-258.
Galgon, A. K. and P. A. Shewokis (2016). "Using Mean Absolute Relative Phase, Deviation Phase and Point-Estimation Relative Phase to Measure Postural Coordination in a Serial Reaching Task." J Sports Sci Med **15**(1): 131-141.
Granata, P. K. and H. A. Sanford (2000). "Lumbar–Pelvic Coordination Is Influenced by Lifting Task Parameters." Spine **25**(11): 1413-1418.
Guo, H. R., S. Tanaka, W. Halperin and L. Cameron (1999). "Back Pain Prevalence in US Industry and Estimates of Lost Workdays." American Journal of Public Health **89**(7): 1029-1035.
Hancock, M. J., C. G. Maher, J. Latimer, M. F. Spindler, J. H. McAuley, M. Laslett and N. Bogduk (2007). "Systematic review of tests to identify the disc, SIJ or facet joint as the source of low back pain." European Spine Journal **16**(10): 1539-1550.
Harris-Hayes, M., S. A. Sahrmann and L. R. Van Dillen (2009). "Relationship between the hip and low back pain in athletes who participate in rotation-related sports." Journal of sport rehabilitation **18**(1): 60-75.
Howarth, S. J., D. Glisic, J. G. B. Lee and T. A. C. Beach (2013). "Does prolonged seated deskwork alter the lumbar flexion relaxation phenomenon?" Journal of Electromyography and Kinesiology **23**(3): 587-593.
Hu, B. and X. Ning (2015). "The Changes of Trunk Motion Rhythm and Spinal Loading During Trunk Flexion and Extension Motions Caused by Lumbar Muscle Fatigue." Annals of Biomedical Engineering **43**(9): 2112-2119.

Hu, B. and X. Ning (2015). "The influence of lumbar extensor muscle fatigue on lumbar–pelvic coordination during weightlifting." Ergonomics **58**: 1-24.
Lamb, P. F. and M. Stöckl (2014). "On the use of continuous relative phase: Review of current approaches and outline for a new standard." Clinical Biomechanics **29**(5): 484-493.
Lee, R. Y. W. and T. K. T. Wong (2002). "Relationship between the movements of the lumbar spine and hip." Human Movement Science **21**(4): 481-494.
Makhoul, P. J., K. E. Sinden, R. S. Macphee and S. L. Fischer (2017). "Relative Contribution of Lower Body Work as a Biomechanical Determinant of Spine Sparing Technique During Common Paramedic Lifting Tasks." Journal of applied biomechanics **33**(2): 137-143.
McGill, S. M. (1997). "The biomechanics of low back injury: Implications on current practice in industry and the clinic." Journal of Biomechanics **30**(5): 465-475.
Norman, R., R. Wells, P. Neumann, J. Frank, H. Shannon, M. Kerr, D. E. Beaton, C. Bombardier, S. Ferrier, S. Hogg-Johnson, M. Mondloch, P. Peloso, J. Smith, S. A. Stansfeld, V. Tarasuk, D. M. Andrews, M. Dobbyn, M. A. Edmonstone, J. P. Ingelman and B. Jeans (1998). "A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry." Clinical Biomechanics **13**(8): 561-573.
O'Sullivan, P. (2005). Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism, Elsevier. **10:** 242-255.
Ovayolu, O., N. Ovayolu, M. Genc and N. Col-Araz (2014). "Frequency and severity of low back pain in nurses working in intensive care units and influential factors." Pakistan journal of medical sciences **30**(1): 70-76.
Pries, E., M. Dreischarf, M. Bashkuev, M. Putzier and H. Schmidt (2015). "The effects of age and gender on the lumbopelvic rhythm in the sagittal plane in 309 subjects." Journal of Biomechanics **48**(12): 3080-3087.
Ramdas, J. and V. Jella (2018). Prevalence and risk factors of low back pain, International Journal of Advances in Medicine. **5:** 1120-1123.
Salkind, N. J., P. Sage and e. Sage (2010). Encyclopedia of research design. Los Angeles, [Calif.] ; London

Thousand Oaks, Calif., Los Angeles, Calif. ; London : SAGE.
Samaei, S. E., M. Mostafaee, H. Jafarpoor and M. B. Hosseinabadi (2017). "Effects of patient-handling and individual factors on the prevalence of low back pain among nursing personnel." Work **56**: 551-561.
Seay, F. J., A. R. E. Van Emmerik and A. J. Hamill (2011). "Influence of Low Back Pain Status on Pelvis-Trunk Coordination During Walking and Running." Spine **36**(16): E1070-E1079.
Shahbazi Moheb Seraj, M., J. Sarrafzadeh, N. Maroufi, I. Ebrahimi Takamjani, A. Ahmadi and H. Negahban (2018). "The Ratio of Lumbar to Hip Motion during the Trunk Flexion in Patients with Mechanical Chronic Low Back Pain According to O'Sullivan Classification System: A Cross-sectional Study." The archives of bone and joint surgery **6**(6): 560-569.
Shojaei, I. (2018). Lower back biomechanics at non-chronic stage of low back pain, Thesis (Ph. D.)--University of Kentucky, 2018.
Shojaei, I., E. G. Salt and B. Bazrgari (2020). "A prospective study of lumbo-pelvic coordination in patients with non-chronic low back pain." Journal of Biomechanics **102**.
Shojaei, I., M. Vazirian, E. Croft, M. A. Nussbaum and B. Bazrgari (2016). "Age related differences in mechanical demands imposed on the lower back by manual material handling tasks." Journal of Biomechanics **49**(6): 896-903.

Shojaei, I., M. Vazirian, E. G. Salt, L. R. Van Dillen and B. Bazrgari (2017). "Timing and magnitude of lumbar spine contribution to trunk forward bending and backward return in patients with acute low back pain." Journal of Biomechanics **53**(C): 71-77.
Stergiou, N., J. L. Jensen, B. T. Bates, S. D. Scholten and G. Tzetzis (2001). "A dynamical systems investigation of lower extremity coordination during running over obstacles." Clinical Biomechanics **16**(3): 213-221.
Stewart, W., J. Ricci, E. Chee, D. Morganstein and R. Lipton (2003). "Lost productive time and cost due to common pain conditions in the US workforce." Jama-Journal Of The American Medical Association **290**(18): 2443-2454.
Tafazzol, A., N. Arjmand, A. Shirazi-Adl and M. Parnianpour (2014). "Lumbopelvic rhythm during forward and backward sagittal trunk rotations: Combined in vivo measurement with inertial tracking device and biomechanical modeling." Clinical Biomechanics **29**(1): 7-13.
Thomas, J. S. and G. E. Gibson (2007). "Coordination and timing of spine and hip joints during full body reaching tasks." Human Movement Science **26**(1): 124-140.
Tojima, M., N. Ogata, Y. Nakahara and N. Haga (2016). "Three-Dimensional Motion Analysis of Lumbopelvic Rhythm During Trunk Extension." Journal of human kinetics **50**: 53-62.
Tosunoz, I. K. and G. Oztunc (2017). Low Back Pain in Nurses, International Journal of Caring Sciences. **10:** 1728-1732.
Van Hoof, W., K. Volkaerts, K. O'Sullivan, S. Verschueren and W. Dankaerts (2012). "Comparing lower lumbar kinematics in cyclists with low back pain (flexion pattern) versus asymptomatic controls – field study using a wireless posture monitoring system." Manual Therapy **17**(4): 312-317.
Vazirian, M., I. Shojaei and B. Bazrgari (2017). "Age-related differences in the timing aspect of lumbopelvic rhythm during trunk motion in the sagittal plane." Human Movement Science **51**: 1-8.
Vazirian, M., L. Van Dillen and B. Bazrgari (2016). "Lumbopelvic rhythm during trunk motion in the sagittal plane: A review of the kinematic measurement methods and characterization approaches." Physical therapy and rehabilitation **3**: 5.
Zehr, J. D. (2017). Using Relative Phase Analyses and Vector Coding to Quantify Pelvis-Thorax Coordination During Lifting—A Methodological Investigation M.Sc., University of Toronto (Canada).

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