2021

WORK-RELATED CHANGES IN THE TRUNK STIFFNESS OF NURSING PERSONNEL

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Digital Object Identifier: https://doi.org/10.13023/etd.2021.137

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WORK-RELATED CHANGES IN THE TRUNK STIFFNESS OF NURSING PERSONNEL

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 of Kentucky

By

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ABSTRACT OF THESIS

WORK-RELATED CHANGES IN THE TRUNK STIFFNESS OF NURSING PERSONNEL

Low back pain (LBP) is a significant issue related to spinal stability and, therefore, to trunk stiffness. Due to the nature of their work, nursing personnel are exposed to potential risk factors for LBP, such as lifting and trunk flexion, which have been reported in the literature to lead to decreases in trunk stiffness. Consequently, the purpose of this study was to investigate potential occupational effects on the trunk stiffness in nursing personnel. Twenty-four nursing personnel participated in this study and completed two sessions (pre-shift and post-shift) during which two passive flexion tests (with and without an ~7.5-lb load) were conducted to characterize their trunk stiffness in upright standing. Overall, no work-related changes in trunk stiffness were found in this study. However, trunk stiffness was higher for the loading condition with the load being held in the subjects' hands than for the condition without this load (p=0.002). Finding no work-related changes in trunk stiffness may have resulted from the heterogeneity of the recruited sample of nursing personnel and the potential recovery of trunk stiffness before their post-shift data collection sessions. Future studies should try to reduce participant heterogeneity and perform data collection closer to where the participants work.

KEYWORDS: Trunk Stiffness, Work-Related, Nursing Personnel, Low Back Pain

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ACKNOWLEDGMENTS

I would like to thank Dr. Babak Bazrgari for his indispensable help during the processes of collecting and analyzing data and for his very helpful, constructive feedback during the thesis-writing process. I greatly appreciate the time he has taken to help me along my journey as a Master's student, especially with answering my many questions.

I would also like to thank Maeve McDonald for her friendship over these past few years and for her immense help with data collection. Without her help, data collection would not have occurred as smoothly.

I would like to thank Matt Ballard, Iman Shojaei, and Aviv Brokman for their help with questions I had concerning data collection, data analysis, or statistical analysis.

I would also like to acknowledge the friends and acquaintances I have made over my years at the University of Kentucky.

Last, but not least, I would like to thank my family for always being there for me and for supporting me throughout all of my years of education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Low back pain (LBP) is a health condition that involves missing work (U.S. Bureau of Labor Statistics, 2019) and large expenses (Dieleman et al., 2016). It is suggested to be related to spinal stability (Reeves et al., 2019) with LBP potentially leading to instability or instability potentially leading to LBP (Gardner-Morse et al., 1995). Additionally, trunk stiffness is required for spinal stability (Bergmark, 1989) such that instability could arise from too little stiffness (McGill et al., 2003). Despite these associations, information regarding occupational effects on trunk stiffness appears to be limited.

Thus, the objective of this study was to ascertain the effects of occupational activities on trunk stiffness, specifically in nursing personnel. Trunk stiffness has been reported to decrease following exposure to potential LBP risk factors (e.g., lifting (Pope et al., 2002) or work-related trunk flexion (Hoogendoorn et al., 2000)) (Hendershot et al., 2011; Toosizadeh et al., 2013). Since nursing personnel are exposed to various occupational risk factors for LBP, including the lifting and transportation of patients (Jang et al., 2007) and prolonged standing (Mendelek et al., 2011), it was hypothesized that the trunk stiffness of nursing personnel would decrease over the course of their work shifts. It was further hypothesized that nursing personnel with more physically demanding job activity levels would show a greater decrease than those with more sedentary job activity levels.

This thesis is organized into six chapters, including this chapter. The following chapters include a literature review about work-related/time-related changes in trunk stiffness and/or other relevant measures (Chapter 2); the methods used in this thesis to characterize work-related changes in the trunk stiffness of nursing personnel (Chapter 3); the results of this thesis concerning the effects of work-related activities, physical activity, and loading condition on trunk stiffness (Chapter 4); a discussion of the results of and limitations in this thesis (Chapter 5); and recommendations for future studies (Chapter 6).

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Low back pain (LBP) is considerably problematic to human health. LBP has been reported to be an issue behind missing work in private industry such that for the issues of the lumbar back that involved missing work, 21.20% were related to pain and soreness in 2018 (U.S. Bureau of Labor Statistics, 2019). Additionally, in 2013, LBP was one of two contributing factors that collectively resulted in personal spending of $87.6 billion for health-related purposes, ranking them among the top three healthcare-related expenditures for that year in the U.S. (Dieleman et al., 2016). Public spending for these two factors was $0.14 billion in the U.S. in 2013 (Dieleman et al., 2016).

LBP and stability (or lack thereof) of the spine appear to exhibit a relationship (Reeves et al., 2019); however, the nature of this relationship is not consistently depicted in the literature. For example, it has been suggested that spinal instability may stem from tissue damage (McGill et al., 2003) or that back-related issues (potentially LBP) may produce this instability (Gardner-Morse et al., 1995). However, it also has been suggested that instability may be the culprit behind back pain (Gardner-Morse et al., 1995) and certain issues related to pain or strained tissues (van Dieën et al., 2003). There also exists an idea about the possibility of a lack of a well-defined relationship between LBP and spinal stability (Reeves et al., 2007).

Stability relates to the state of a system's equilibrium (Bergmark, 1989; Reeves et al., 2007) and its resilience against perturbations (Bergmark, 1989; Reeves et al., 2019; Reeves et al., 2007). A system with a stable equilibrium state will return to its initial equilibrium state after a perturbation, if it deviated in any way due to this perturbation, while a system with an unstable equilibrium state will not (Reeves et al., 2019; Reeves et al., 2007). Furthermore, as regards biomechanics, spinal stability relates to how the spine moves when a perturbation occurs and whether it remains within its physiological range (Reeves et al., 2007). Therefore, spinal mechanical stability is directly influenced by the stiffness of the spine and lower back such that a minimum level of trunk stiffness is required for the spine to be stable (Bergmark, 1989). Trunk muscles and spinal tissues provide such a required stiffness for the spine and, therefore, play an important role in maintaining spinal stability (Reeves et al., 2019). While both trunk muscles and spinal tissues provide passive stiffness for spinal stability (Bergmark, 1989; Gardner-Morse et al., 1995; Reeves et al., 2019), muscles can also provide active stiffness relating to their activation (Gardner-Morse et al., 1995). It is important that the stiffness not be considerably more or less than what is needed so that certain issues can be avoided (McGill et al., 2003). These issues include immobility, which could result from exhibiting a superfluous amount of stiffness, and instability, which could result from exhibiting a scant amount of stiffness (McGill et al., 2003).

Due to the importance of LBP and its links to missing work and spinal stability, which is associated with the stiffness of the spine and lower back (referred to as trunk stiffness hereafter), it would be beneficial to understand the effects of work-related factors and non-work-related factors on trunk stiffness. Therefore, the objective of this review is to provide a narrative summary of earlier research that has reported the effects of work-related and non-work-related factors on trunk stiffness and/or other measures that are relevant to trunk stiffness (e.g., range of motion of the trunk).

2.2 Methods

While conducting research for this literature review, certain keyword phrases were input to several databases (*InfoKat Discovery* through the University of Kentucky, *PubMed*, and *ScienceDirect*). These phrases consisted of different combinations of the keywords presented in Table 1.

Table 1. Keyword groups that were used when researching articles.

Group 1	Group 2	Group 3	Group 4
lower back	stiffness	occupational	changes
trunk	flexibility	work-related	alterations
lumbar	compliance	diurnal	variations
vertebral column	range of motion	circadian	
spine			

Abstracts of articles that were found were assessed to determine their relevance. This relevance was based on whether the article discussed an *in vivo* human study that recounted changes in trunk stiffness or that discussed related measures. Moreover, additional articles were found by looking into the references of the identified articles.

2.3 Results

A total of 21 articles met our review criteria. Fifteen of these articles discussed different forms of trunk stiffness (e.g., effective, intrinsic, [average] bending, rotational stiffness) or other stiffness measures of the lumbar spine (Beach et al., 2005; Brown and McGill, 2009; Cholewicki et al., 2000; Drake and Callaghan, 2008; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Parkinson et al., 2004; Shojaei et al., 2016; Shojaei et al., 2018; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). Among the reviewed articles, twelve (Table 2) discussed time-related changes in a measure of trunk stiffness (e.g., intrinsic stiffness) or range of motion of the lumbar spine or trunk (Adams et al., 1987; Beach et al., 2005; Callaghan and McGill, 2001; Drake and Callaghan, 2008; Dunk and Callaghan, 2010; Ensink et al., 1996; Fathallah et al., 1995; Hendershot et al., 2011; Kastelic et al., 2018; Miller et al., 2013; Parkinson et al., 2004; Toosizadeh et al., 2013). Most of the articles included in this review mentioned certain limitations in their studies; however, for the articles whose results were not included, their limitations did not appear to render the articles unusable.

Table 2. The studies that were reviewed that discussed relevant time-related changes.

Study	Sample Size	Description of Sample	Male	Female	Research Set-Up	Description of Task/Condition	Results: Range of Motion-Related	Results: Stiffness-Related
Adams et al. (1987)	21	*Number*	11	10	2 sessions: early morning, late afternoon; electronic inclinometers: L1 spinous process, S1 spinous process	forward bending: sitting, straightened legs	increase (early morning to late afternoon)	---
		Age (years)	32.7	20.6				
		Status	healthy					
Beach et al. (2005)	12	*Number*	6	6	3 sessions: before 2 hours of sitting, after each hour; frictionless surface; floating cradle	sitting over a 2-hour period; passive flexion: lying down	---	increase (from before two hours of sitting to after sitting for one hour), no change (from after sitting for one hour to after sitting for two hours) - for one stiffness zone
		Age (years)	24.5	23.3				
		Height (cm)	177	162				
		Body Mass (kg)	76.8	58.6				
		Status	healthy					
Callaghan and McGill (2001)	8	*Number*	8	---	4 measurements: before 3 minutes of standing, after this 3 minutes of standing/before 2 hours of sitting, after 2 hours of sitting/before another 3 minutes of standing, and after the second 3 minutes of standing; 3SPACE ISOTRAK (sacrum, T12/L1 level)	3 minutes of standing (twice); 2 hours of sitting	increase (no statistical significance)	---
		Age (years)	22.4	---				
		Height (cm)	174.7	---				
		Body Mass (kg)	74.4	---				
		Status	healthy	---				

Table 2. (continued)

Drake and Callaghan (2008)	10	*Number*	10	---	2 sessions: 8 a.m., 3 p.m.; cradle (for kneeling); frictionless surface	kneeling; axial twisting; 7 postures	---	no diurnal variations
		Age (years)	23.3	---				
		Height (cm)	179	---				
		Body Mass (kg)	75.6	---				
		Status	healthy	---				
Dunk and Callaghan (2010)	32	*Number*	8	8	2 measurements: pre-sitting, post-sitting; accelerometers: L1 spinous process, S2 level	sitting - 90 minutes; upright standing followed by bending to touch toes	decrease (post-sitting)	---
		Age (years)	24.0	25.9				
		Height (cm)	180	167				
		Body Mass (kg)	74.0	64.4				
		Status	healthy					
		Number	8	8				
		Age (years)	22.8	27.0				
		Height (cm)	178	170				
		Body Mass (kg)	81.3	70.7				
		Status	sitting-induced LBP					
Ensink et al. (1996)	29	*Number*	---	---	3 sessions: 8-9 a.m., 12-1 p.m., 4-5 p.m.; inclinometers: T12 spinous process, S1 spinous process	maximum extension, maximum flexion: no knee-bending	increase (between 8-9 a.m. and 4-5 p.m.)	---
		Age (years)	18-60					
		Height (cm)	173.0					
		Body Mass (kg)	77.2					
		Status	patients - "chronic low back pain or leg pain"					

Table 2. (continued)

Fathallah et al. (1995)	21	*Number*	21	---	3 sessions: morning, afternoon, evening; monitor system and harness (thorax, pelvis); potentiometers	slow-paced movements: initial posture to “maximum range of motion” then back to the initial posture; 3 planes	increase (morning to afternoon to evening) - sagittal plane (not statistically significant)	---
		Age (years)	25.03	---				
		Height (cm)	179.70	---				
		Body Mass (kg)	77.80	---				
		Status	"screened with regard to any history of back disorders"	---				
Hendershot et al. (2011)	12	*Number*	6	6	frame; harness (chest); leg rotation; 2 or 16 minutes at leg rotation angle; perturbations (T8 spinal level)	upright upper body; leg rotation	---	decrease (after 2 minutes of maximum flexion), decrease (after 16 minutes of maximum flexion)
		Age (years)	23	22				
		Height (cm)	180.3	166.1				
		Body Mass (kg)	75.3	60.1				
		Status	healthy					
Kastelic et al. (2018)	17	*Number*	9 (office workers)	8 (office workers)	2 sessions: before the subject worked, after the subject worked; inertial measurement units: S1, L1	subjects started upright, flexed, and then ended upright	no changes (from before to after a work shift of their subjects)	---
		Age (years)	42.2					
		Height (cm)	176					
		Body Mass (kg)	76.5					
		Status	healthy					

Table 2. (continued)

Miller et al. (2013)	17	*Number*	8 (triathlon club members)	---	two time periods (post-triathlon): 1-2 days, 4-5 days; frame; harness near T8 spinal level; perturbations (T8 spinal level)	upright trunk; sitting (90°) on a platform	---	decrease for the control group, no changes for the exercise-induced LBP group (between 1- to 2-day mark and 4- to 5-day mark for both)
		Age (years)	20.7	---				
		Height (cm)	183	---				
		Body Mass (kg)	72.9	---				
		Status	"recurrent, acute eiLBP"	---				
		Number	9 (triathlon club members)	---				
		Age (years)	20.4	---				
		Height (cm)	179	---				
		Body Mass (kg)	70.8	---				
		Status	healthy	---				
Parkinson et al. (2004)	8	*Number*	8	---	4 sessions: before any lifting, after each of the three periods of lifting; frictionless table; moveable cradle	lifting and carrying an object a specified distance, then replacing it on the ground	---	changes between the periods of lifting (not significantly affected by the lifting)
		Age (years)	24.6	---				
		Height (cm)	183	---				
		Body Mass (kg)	84.6	---				
		Status	healthy	---				
Toosizadeh et al. (2013)	12	*Number*	6	6	2 measurements: pre-lifting and post-lifting; perturbations (T8 spinal level); 3 angles; 2 rates for lifting	"repetitive dynamic lifting" - 40 minutes	---	decrease (over 40 minutes when all of the conditions were considered together)
		Age (years)	22	24				
		Height (cm)	182.1	165.2				
		Body Mass (kg)	75.9	59.1				
		Status	healthy					

2.3.1 Description of Stiffness

Trunk stiffness was determined by assuming either an elastic or a viscoelastic model of the trunk, lower back, or lumbar spine, depending on the study and the stiffness it measured (Beach et al., 2005; Brown and McGill, 2009; Cholewicki et al., 2000; Drake and Callaghan, 2008; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Parkinson et al., 2004; Shojaei et al., 2016; Shojaei et al., 2018; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). The studies that implemented an elastic model described stiffness as the change in moment over the change in angle between two time points (Drake and Callaghan, 2008; Shojaei et al., 2018) or by using moment-angle curves that were based on passive flexion that resulted from an externally-applied force and occurred while the subjects were lying down (Beach et al., 2005; Parkinson et al., 2004). Drake and Callaghan (2008) also used an externally-applied force, but this force resulted in axial rotation (passive), which occurred while their subjects knelt. Beach et al. (2005) used the trend-line slopes associated with their moment-angle curves to determine their stiffness measure, while Parkinson et al. (2004) used differentiation based on their moment-angle curves to determine their stiffness measure. In contrast, Shojaei et al. (2018) obtained their trunk kinematics and kinetics via passive rotation of their subjects' legs from upright standing to the appropriate angle to upright standing.

Most of the studies that implemented a viscoelastic model described stiffness via system identification (Brown and McGill, 2009; Cholewicki et al., 2000; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014); however, one study described stiffness as the change in moment over the change in angle between two time points (Shojaei et al., 2016). Shojaei et al. (2016) obtained their lower back kinematics and kinetics via passive rotation of their subjects' legs from upright standing to one of two angles to upright standing, and the angle was maintained for four minutes. The studies that employed system identification related kinetics (force and/or moment) to kinematics (displacement and/or rotation) to characterize the parameters (including stiffness) of the mechanical model (or models) that each study assumed to represent the mechanical behavior of the trunk (Brown and McGill, 2009; Cholewicki et al., 2000; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). Depending on the study, the kinetics corresponded to the applied force(s) (Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hodges et al., 2009; Vette et al., 2014), trunk kinetics (Hendershot et al., 2011; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016), the moments related to trunk mass and the applied force(s) (Cholewicki et al., 2000; Vette et al., 2014), or zero torso moment (Brown and McGill, 2009). The kinematics corresponded to trunk displacement (Gardner-Morse and Stokes, 2001; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016), trunk rotation (Brown and McGill, 2009; Cholewicki et al., 2000), both trunk displacement and trunk rotation – depending on the model (Vette et al., 2014), or torso (T8 level) displacement (Granata and Rogers, 2007). These kinetics and kinematics were obtained under force perturbations tests (Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Vette et al., 2014), including weight release (Hodges et al., 2009) and quick release (Brown and

McGill, 2009; Cholewicki et al., 2000), or position perturbations tests (Hendershot et al., 2011; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016). To determine the parameters (e.g., stiffness) of the mechanical model (or models) that was (were) used, least squares-related methods (Brown and McGill, 2009; Granata and Rogers, 2007; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016), error minimization (Hendershot et al., 2011), good/best match procedures (Cholewicki et al., 2000; Vette et al., 2014), or nonlinear curve-fitting (Gardner-Morse and Stokes, 2001) was/were employed. Although these studies implemented a viscoelastic model, some of them determined their results while disregarding damping; however, each system's damping response probably influenced the corresponding results (Gardner-Morse and Stokes, 2001; Hendershot et al., 2011; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016).

2.3.2 Time-Related Changes

Six of the twelve articles that discussed time-related changes pertained to trunk stiffness (Beach et al., 2005; Drake and Callaghan, 2008; Hendershot et al., 2011; Miller et al., 2013; Parkinson et al., 2004; Toosizadeh et al., 2013), while the other six pertained to range of motion of the lumbar spine or trunk (Adams et al., 1987; Callaghan and McGill, 2001; Dunk and Callaghan, 2010; Ensink et al., 1996; Fathallah et al., 1995; Kastelic et al., 2018).

2.3.2.1 Trunk Stiffness

Hendershot et al. (2011), Miller et al. (2013) and Toosizadeh et al. (2013) measured "intrinsic trunk stiffness" using perturbations applied to the T8 spinal level. The perturbations in Hendershot et al. (2011) occurred before and after each subject's legs were rotated upwards from standing to the appropriate angles (based on a flexion-relaxation angle of trunk muscles) and remained at these angles for either 2 minutes or 16 minutes. Hendershot et al. (2011) reported a 23% decrease in trunk stiffness (from ~4230 N/m to ~3250 N/m) after their subjects had remained at maximum flexion for 2 minutes and a 22% decrease in trunk stiffness (from ~4230 N/m to ~3296 N/m) after their subjects had remained at maximum flexion for 16 minutes,[1] but the significance of these decreases with respect to time was not clearly mentioned. The study conducted by Toosizadeh et al. (2013) included "repetitive dynamic lifting" that lasted for 40 minutes and involved bending forward from standing to both pick up the load to be lifted and then replace this load (with load handles at certain percentages of each subject's maximum flexion). They reported a decrease of ~6.98% in "intrinsic trunk stiffness" (from ~7550 N/m to ~7030 N/m)[1] over 40 minutes when all of the conditions (three angles, two rates for lifting) were considered together (Toosizadeh et al., 2013). However, they mentioned how this decrease may have been underestimated due to the method used in this study (Toosizadeh et al., 2013). Miller et al. (2013) required their subjects (i.e., individuals who experienced exercise-induced LBP and controls) to sit during testing, and this testing occurred 1-2 days post-triathlon and then 4-5 days post-triathlon (same timeframe for both groups). Miller et al. (2013) reported a lower (~7 N/mm [~7000 N/m]) "intrinsic trunk stiffness" at the 4- to 5-day mark compared to the 1- to 2-day mark (~9 N/mm [~9000 N/m]) – a decrease of ~22.2% – for the control group but the same "intrinsic trunk stiffness" (~9 N/mm [~9000 N/m]) at both the 1- to 2-day mark and 4- to 5-day mark for the exercise-induced LBP group.[1]

[1] These values were estimated using data presented in the cited study.

Parkinson et al. (2004) reported stiffness values for varying proportions of the maximum flexion that was measured at the beginning of their testing period, and these stiffness values were obtained before any lifting (subjects lifted and carried an object a certain distance before replacing it on the ground) and after each of the three periods of lifting (30 minutes/period). They found that although changes in stiffness did exist between the periods of lifting, stiffness at each of the included angles was not significantly affected by the lifting involved in their study (Parkinson et al., 2004). Beach et al. (2005) reported stiffness-related values for three sessions (before two hours of sitting and after each hour) and three different stiffness zones. Only one of these zones, the zone corresponding to the middle range of the initial trial's maximum lumbar flexion, illustrated session-related statistical significance in that the first session (before two hours of sitting) significantly differed from both the second (after sitting for one hour) and third (after sitting for two hours) sessions, but the second and third sessions did not significantly differ from each other (Beach et al., 2005). More specifically, the stiffness-related value increased from before two hours of sitting to after sitting for one hour but did not change from after sitting for one hour to after sitting for two hours (Beach et al., 2005). However, Beach et al. (2005) did not rigorously control what their subjects did or how long they had been out of bed before coming in for testing, did not measure the activation of the abdominal muscles, and mentioned how tissue loads varied between subjects while sitting. Furthermore, Drake and Callaghan (2008) found that "average axial twist stiffness" did not exhibit diurnal variations (between 8 a.m. and 3 p.m.).

2.3.2.2 Range of Motion of the Trunk/Lumbar Spine

The methods that were used to measure the range of motion of the lumbar spine varied. Adams et al. (1987) measured this range of motion with electronic inclinometers positioned on the L1 spinous process and the S1 spinous process of their subjects as they bent forward maximally while sitting with straightened legs. Ensink et al. (1996) used inclinometers positioned on the T12 spinous process and the S1 spinous process and had their subjects undergo maximum flexion. Kastelic et al. (2018) and Dunk and Callaghan (2010) measured this range of motion using inertial measurement units or accelerometers while their subjects underwent maximum flexion from upright standing, but Dunk and Callaghan (2010) also instructed their subjects to touch their toes. Callaghan and McGill (2001) used a 3SPACE ISOTRAK with the sacrum as the source location and the T12/L1 level as the sensor location, and they used a protocol that began with testing range of motion, followed by 3 minutes of standing, then a second testing of range of motion, followed by 2 hours of sitting, then a third testing of range of motion, followed by a second 3 minutes of standing, and finally, a fourth testing of range of motion. Fathallah et al. (1995) measured trunk range of motion using a motion monitor-harness system on the thorax and pelvis of subjects while they moved from an initial posture to their "maximum range of motion" and then back to the initial posture.

Adams et al. (1987) reported a 5.0° increase in lumbar flexion from early morning to late afternoon. Callaghan and McGill (2001) reported a 1.1% increase in "[p]eak lumber spine flexion" after the first three minutes of standing compared to before this standing, a 0.1% increase in "[p]eak lumber spine flexion" after two hours of sitting compared to before the first three minutes of standing, and a 2.8% increase in "[p]eak lumber spine flexion" after the second three minutes of standing compared to before the first three minutes of standing – none of these had statistical significance. Ensink et al. (1996) reported an ~25.78% increase in "[t]otal lumbar range of motion" (from 54.30° to 68.30°) and an ~26.30% increase in range of flexion (from 42.20° to 53.30°) from 8-9 a.m. to 4-5 p.m. Fathallah et al. (1995) reported increases in the "percentage of maximum range of motion" from one hour after their subjects got up for the day (morning) to four hours after this (afternoon) to another four hours later (evening) (discrete time points) in the sagittal plane, but these did not have statistical significance. Kastelic et al. (2018) reported no changes in "lumbar range of motion" from before to after a work shift of their subjects, while Dunk and Callaghan (2010) reported how after their subjects had sat for 90 minutes, "lumbar spine range of motion" was lower, and this was the same for their subjects with and without LBP related to sitting.

2.4 Discussion

The purpose of this narrative review was to compile information that is relevant to work-related changes in trunk stiffness and/or other measures that are related to trunk stiffness (e.g., range of motion of the trunk). This review was structured in such a way so as to first introduce the motivation for the research and how this motivation, in a way, is related to spinal stability and then provide a summary of studies that discussed trunk stiffness or related measures.

When describing trunk stiffness, studies either assumed an elastic model or a viscoelastic model of the part of the trunk/spine that was investigated (Beach et al., 2005; Brown and McGill, 2009; Cholewicki et al., 2000; Drake and Callaghan, 2008; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Parkinson et al., 2004; Shojaei et al., 2016; Shojaei et al., 2018; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). The studies that implemented an elastic model determined stiffness from moment-angle curves (Beach et al., 2005; Parkinson et al., 2004) or by dividing the change in moment by the change in angle between two time points (Drake and Callaghan, 2008; Shojaei et al., 2018). These studies used protocols involving passive flexion (Beach et al., 2005; Parkinson et al., 2004), axial rotation (passive) (Drake and Callaghan, 2008), or passive rotation of the participants' legs (Shojaei et al., 2018). The studies that implemented a viscoelastic model determined stiffness by dividing the change in moment by the change in angle between two time points (Shojaei et al., 2016) or using a system identification methodology (Brown and McGill, 2009; Cholewicki et al., 2000; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). For all of the studies that involved system identification, kinetics were related to kinematics to characterize the corresponding model parameters; however, what the kinetics and kinematics corresponded to varied between these studies, in addition to how they were obtained and how the model parameters were determined (Brown and McGill, 2009; Cholewicki et al., 2000; Gardner-Morse and Stokes, 2001; Granata and Rogers, 2007; Hendershot et al., 2011; Hodges et al., 2009; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016; Vette et al., 2014). Furthermore, because some of the studies that implemented a viscoelastic model disregarded damping when determining stiffness (Gardner-Morse and Stokes, 2001; Hendershot et al., 2011; Miller et al., 2013; Toosizadeh et al., 2013; Vazirian et al., 2016), it is important to consider the potential implications of such an assumption on the results and their physiological accuracy and ability to be interpreted (Toosizadeh et al., 2013).

Time-related changes in trunk stiffness that were reported in the literature were contradictory and included decreases, with some potentially being non-significant with regard to time (Hendershot et al., 2011; Miller et al., 2013; Toosizadeh et al., 2013); an increase (Beach et al., 2005); non-significant changes (Parkinson et al., 2004); and/or no changes/no diurnal variations (Beach et al., 2005; Drake and Callaghan, 2008; Miller et al., 2013). As evidenced, Miller et al. (2013) and Beach et al. (2005) reported a decrease or increase and no change for their data, depending on the group (Miller et al., 2013) or the session (Beach et al., 2005), while the other studies reported either changes or no diurnal variations (Drake and Callaghan, 2008; Hendershot et al., 2011; Parkinson et al., 2004; Toosizadeh et al., 2013). Hendershot et al. (2011) and Toosizadeh et al. (2013) reported decreases/a decrease in trunk stiffness over time; however, Hendershot et al. (2011) reported larger, but not clearly defined as significant with respect to time, decreases (23% after 2 minutes of maximum flexion and 22% after 16 minutes of maximum flexion), while Toosizadeh et al. (2013) reported a smaller, but significant, decrease (~6.98% after "repetitive dynamic lifting" occurred over 40 minutes when all of the conditions were considered together). The magnitudes of their stiffness values also differed such that those reported by Toosizadeh et al. (2013) were >1.5 times larger than those reported by Hendershot et al. (2011). Miller et al. (2013) reported stiffness magnitudes that were similar to (~7000 N/m) or larger than (~9000 N/m) those in Toosizadeh et al. (2013), whose reported range was ~7030-7550 N/m, and >1.5 times larger than those in Hendershot et al. (2011), whose reported range was ~3250-4230 N/m.

Despite this large difference in magnitudes between Miller et al. (2013) and Hendershot et al. (2011), trunk stiffness decreased similarly in both studies (~22.2% [for one group; the other group exhibited no change] vs. 22% and 23%, respectively). Additionally, among the reviewed articles that discussed stiffness, only Drake and Callaghan (2008) considered a length of time (seven hours) that was similar to the length of a workday.

The differences in trunk stiffness between the Hendershot et al. (2011), Miller et al. (2013), and Toosizadeh et al. (2013) studies may have resulted from the different activities (passive rotation for Hendershot et al. (2011), lifting for Toosizadeh et al. (2013), and triathlon for Miller et al. (2013)) the participants performed before any testing or performed or underwent between pre- and post-testing. The differences in trunk stiffness between Hendershot et al. (2011), Miller et al. (2013), and Toosizadeh et al. (2013) also may have resulted from the posture adopted during the perturbations: sitting upright (Miller et al., 2013) vs. standing upright (Hendershot et al., 2011; Toosizadeh et al., 2013). When standing upright, the tissues of the lower back have only a small passive contribution to stiffness (Shojaei et al., 2016). Additionally, according to a study that compared sitting and standing, when sitting, certain tissues' "passive force contribution" was greater; however, the subjects sat with greater flexion than when they were standing and did not always stand in an upright manner and the study investigated range of motion, not stiffness (Callaghan and McGill, 2001).

Time-related changes in range of motion were also mixed, with some studies reporting increases/an increase, not all of which were significant (Adams et al., 1987; Callaghan and McGill, 2001; Ensink et al., 1996; Fathallah et al., 1995), and others reporting no change (Kastelic et al., 2018) or a decrease (Dunk and Callaghan, 2010).

Adams et al. (1987) and Ensink et al. (1996) investigated similar measures over a similar period of time; however, the increase in the range of motion reported by Ensink et al. (1996) was >2 times larger than the increase reported by Adams et al. (1987). Additionally, the increases in range of motion reported by Callaghan and McGill (2001) and Fathallah et al. (1995) had no statistical significance. Dunk and Callaghan (2010) included a time period for testing of only 90 minutes, which was much shorter than the time periods of Adams et al. (1987), Ensink et al. (1996), Fathallah et al. (1995), and Kastelic et al. (2018) but slightly similar to the time period of Callaghan and McGill (2001). Of these six studies, Kastelic et al. (2018) seemed to be the only one in which data were collected based on an actual workday, with subjects coming in before they worked and after they worked.

Two of the studies that were mentioned in this review compared LBP and control groups in relation to trunk stiffness (Hodges et al., 2009; Miller et al., 2013). Hodges et al. (2009) reported a significantly lower “effective trunk stiffness” (1641 N/m) for the control group compared to 1997 N/m for the recurrent LBP group for forward perturbations – the LBP group had an ~1.217 times larger stiffness. Compared to Hodges et al. (2009), Miller et al. (2013) reported larger stiffness values (~7000-9000 N/m), with a similar “intrinsic trunk stiffness” (~9000 N/m) for their two groups at the 1- to 2-day mark and a significantly higher “intrinsic trunk stiffness” (~9000 N/m) for the group with exercise-induced LBP than for the control group (~7000 N/m) at the 4- to 5-day mark. Two of these three scenarios demonstrated higher trunk stiffness values for people with LBP (either recurrent or exercise-induced), potentially illustrating some kind of relationship between trunk stiffness and LBP.

2.5 Conclusion

Despite the association of trunk stiffness with spinal stability and spinal stability with LBP (with its link to missing work), there seems to be a limited amount of information concerning work-related changes in trunk stiffness. Of the articles that were reviewed and that discussed stiffness, only one used a large enough timeframe (seven hours) that could be considered to be similar to the length of a workday. Additionally, only one of the reviewed articles seemed to base their data collection on an actual workday and it investigated range of motion, not trunk stiffness. Therefore, future studies should investigate how trunk stiffness is affected by 8-hour (at least) workdays, considering various types of jobs and both control and LBP populations. This would aid in understanding workday-related changes in trunk stiffness and how trunk stiffness may differ between people with and without LBP while considering their workdays.

CHAPTER 3: METHODS

3.1 Study Design

This study was a repeated measures study that involved 24 research participants (33 total, but stiffness data were collected from 24 only) who each completed two data collection sessions. Participants were nursing personnel, including RNs (two were Board Certified, two were CPNs, two were CCRPs, two were CCRNs, and two were TCRNs), NCTs, and an FNP-BC, who worked 8- to 12-hour shifts and were employed by the University of Kentucky HealthCare System. They were recruited into two equal-sized groups based on their job activity levels: more physically demanding (denoted 'active') vs. more sedentary (sitting for ≥50% of their shifts; denoted 'inactive'). The demographic data of the study population are provided in Table 3. The inclusion criteria were an age between 20 and 60 years old, employment as a nurse or as other nursing personnel with 8- to 12-hour shifts, and freedom from back pain over the past 12-month period that would have necessitated missing work or visiting a doctor. The primary exclusion criterion was a history of spinal surgery. The presence of certain musculoskeletal disorders that were deemed by the researchers to have potentially negative effects on participant safety and the study's results also was considered to be an exclusion criterion. Data were not collected until each participant had completed consenting and screening procedures that were approved by the University of Kentucky Institutional Review Board.

Table 3. Demographic data (mean ± S.D. for age, body mass, and height) of the two study groups along with their *p*-values from independent t-tests.

	Job Activity Level		
	Inactive	**Active**	***p*-value**
Gender	---	---	---
Male	0	3	---
Female	12	9	---
Age (years)	46.8 ± 9.5	30.6 ± 10.2	0.001*
Body Mass (kg)	67.6 ± 13.6	68.3 ± 10.7	0.887
Height (cm)	163.46 ± 3.86	166.79 ± 9.56	0.281

*statistically significant

3.2 Data Collection Procedure

Each participant came in for data collection before and after his or her work shift, and each session took ~30 minutes to complete. The session before the participant's shift involved the consenting and screening processes and the pre-shift data collection, while the session after the participant's shift involved collecting the post-shift data and establishing the activities he or she had performed during the shift so that a better understanding of the participant's job activity level could be obtained. Data collection for both sessions involved several tests:

- two forward bending and backward return tests – one at a slow, comfortable pace and one at a faster pace (both with self-selected paces, three repetitions each);
- a manual material handling test with an ~15-lb load (three repetitions); and
- two passive flexion tests in an in-house testing frame – one test involving an ~7.5-lb load being held by the participant and the other test not involving this load.

In each session, the forward bending and backward return tests were performed first, followed by the manual material handling test, and then the two passive flexion tests. However, both the order of the two forward bending and backward return tests (slow pace and faster pace) and that of the two passive flexion tests (with and without the ~7.5-lb load) were randomized for both sessions per participant.

Before data collection occurred, each participant was instrumented with inertial measurement units (IMUs; Xsens, Enschede, The Netherlands) that were placed on straps on the back at about the T12 spinal level, on the sacrum at about the S1 spinal level, on the outside-facing portion of the shanks right above the ankles, and on the outside-facing portion of the thighs right above the knees (Figure 1). The participant then was instructed to stand on a force plate (AMTI, Watertown, Massachusetts) to perform the forward bending and backward return tests and the manual material handling test. For the forward bending and backward return tests, the participant began in an upright position with his or her arms crossed over his or her chest, bent forward to his or her maximum lumbar flexion, and then returned to the upright position. Additionally, for the slow forward bending and backward return test, the participant held the initial and the maximum lumbar flexion positions for ~5 seconds each, while for the fast forward bending and backward return test, the participant bent forward to his or her maximum lumbar flexion and immediately returned to the upright position. These tests were performed in a manner similar to earlier studies – Shojaei et al. (2018) and Shojaei et al. (2017). Manual material handling involved the participant starting in an upright position, waiting ~5 seconds, bending forward (while also bending his or her knees) to pick up an ~15-lb load from blocks on the floor and bringing this load to chest height, holding the load at chest height for ~5 seconds, bending forward and placing the load back on the blocks near its initial position, and then returning to the upright position (Figure 2).

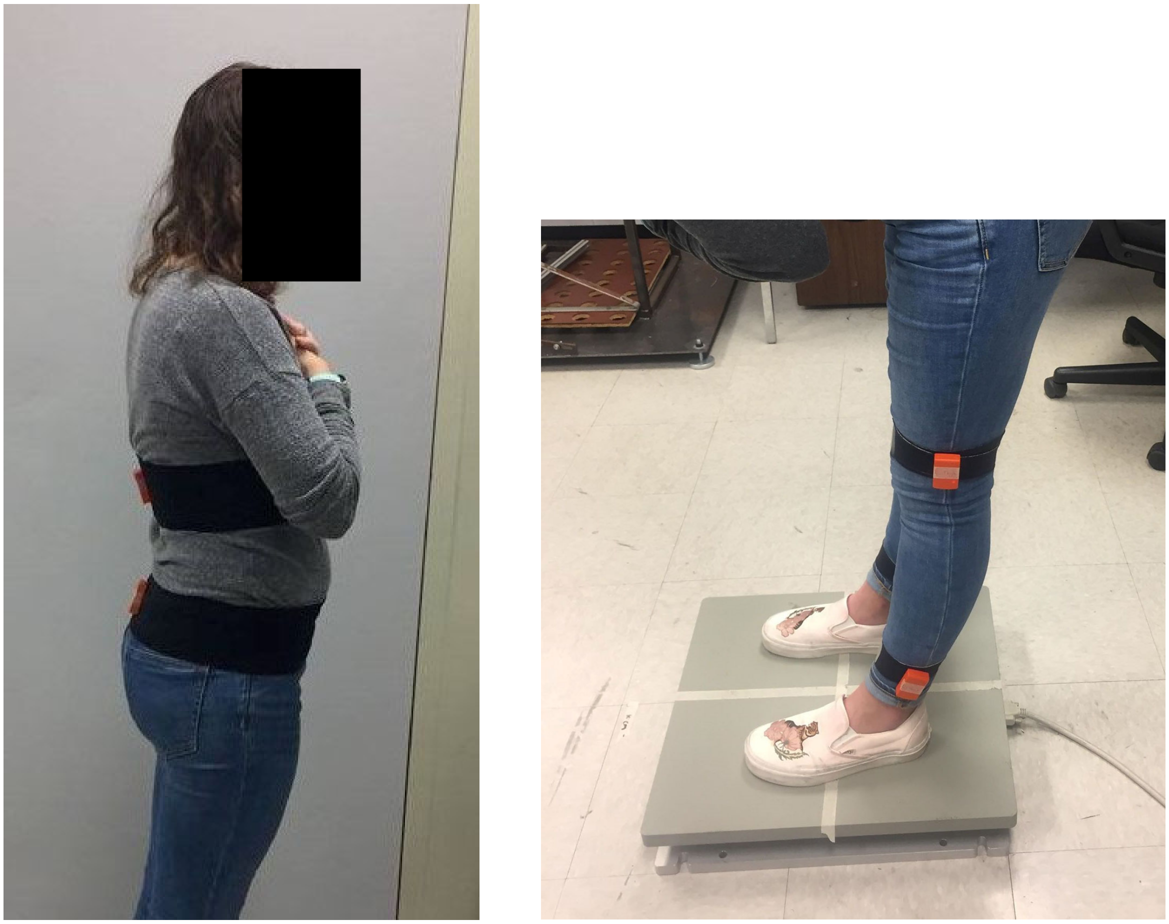


Figure 1. The orange IMUs are located on the back at about the T12 spinal level and on the sacrum at about the S1 spinal level (left) and on the outside-facing portion of the shanks right above the ankles and on the outside-facing portion of the thighs right above the knees (right).

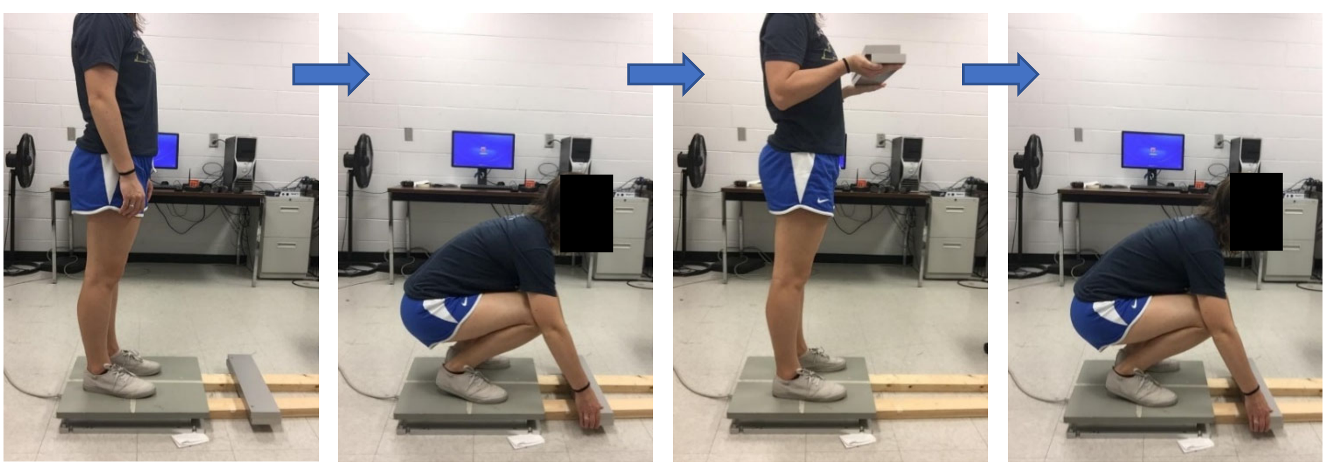


Figure 2. The manual material handling test. Participants ended this test in the posture shown in the leftmost image of this figure.

For the passive flexion tests, each participant was fitted with a harness around his or her chest and thoracic spine prior to standing on the platform of the in-house testing frame (Figure 3). The center of rotation of this platform was (approximately) aligned with the participant's hip by adjusting the platform's height. A seatbelt-type restraint was buckled around the participant's pelvis for safety reasons. Additionally, a rod was attached to the harness and adjusted horizontally so that the participant's upper body was almost purely vertical in the initial position. For the passive flexion test with the ~7.5-lb load, the participant held the load beneath this rod and approximately in line with the participant's chest (Figure 3). Furthermore, during the passive flexion tests, the platform on which the participant was standing was rotated upward to 70% of the maximum lumbar flexion observed during the slow forward bending and backward return test and then immediately brought back to approximately its initial position so that the legs were nearly vertical. This rotation was achieved via an actuator that rotated the platform at ~3°/second, and the corresponding kinematic data were collected at 60 Hz via an IMU located on the top portion of the platform. The kinetic data corresponding to the tension or compression in the rod between the harness and the testing frame that occurred during this rotation were collected at a sampling rate greater than 2500 Hz via a load cell (Interface SMT2-2000N, Scottsdale, Arizona) positioned on the rod. MT Manager (Xsens, Enschede, The Netherlands) was used for the kinematic data collection, while MATLAB (The MathWorks, Inc., Natick, Massachusetts) was used for the kinetic data collection. Synchronization of the kinematic and kinetic data occurred via a trigger signal that was generated by MT Manager at the time the kinematic data first began to be collected and was detected by MATLAB, which already was running and collecting kinetic data. After the participant's legs were returned to a (nearly) vertical position, another signal was generated by MT Manager that indicated the end of kinematic data collection. This procedure for the passive flexion tests is similar to that of a previous study – Shojaei et al. (2018).

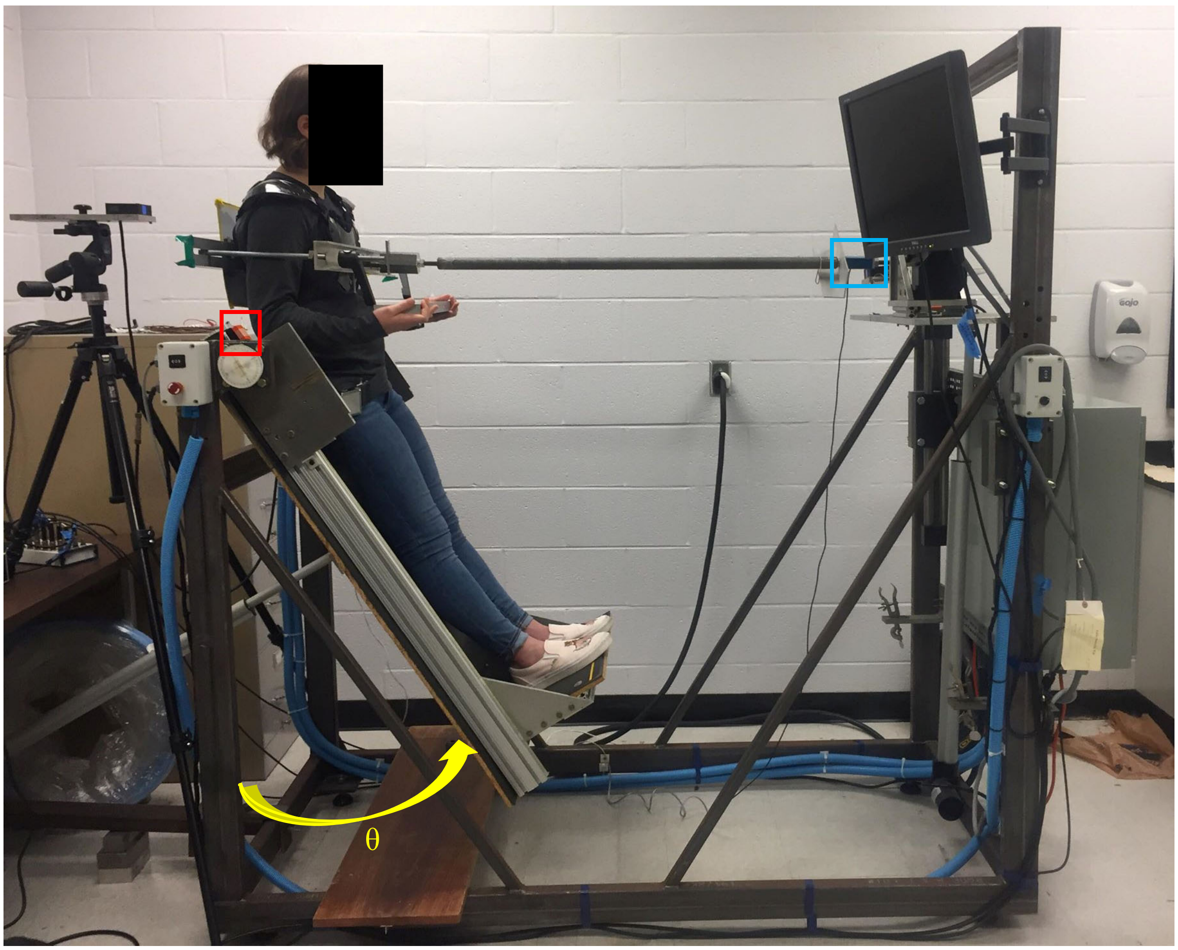


Figure 3. The passive flexion test with the ~7.5-lb load. The passive flexion test without this load would look similar, but there would not be a load in the participant's hands and the hands would be relaxing next to his or her thighs. (The red box outlines the IMU that was used to measure the platform kinematics, while the blue box outlines the load cell that was used to measure the corresponding kinetic data. The yellow arrow illustrates the direction in which the legs were rotated to reach 70% of the participant's maximum lumbar flexion.)

3.3 Data Analysis

The kinematic data corresponding to the rotation of the participant's legs by the testing frame were filtered via a fourth-order low-pass Butterworth filter with a cut-off frequency of 6 Hz (Shojaei et al., 2018). The kinetic data were filtered via a fourth-order low-pass Butterworth filter with a cut-off frequency of 50 Hz (Shojaei et al., 2018). Additionally, in-house MATLAB codes were developed to calculate two measures of trunk stiffness for each participant: 1) the average trunk stiffness over the entire flexion portion of each passive flexion test (i.e., from the beginning of the rotation of the participant's legs [initial angle] to the maximum flexion angle) (hereafter called Stiffness Measure 1; Equation 1; Figure 4) and 2) the average trunk stiffness over a fixed range of flexion from the initial angle to a specific target angle that was the same for almost all of the participants' data (hereafter called Stiffness Measure 2; Equation 2; Figure 5). This target angle was the minimum flexion angle used for the passive flexion tests among all participants, sessions, and conditions and had a value of approximately 12°.

$$Stiffness\ Measure\ 1 = \frac{\Delta M}{\Delta \theta} = \frac{M_{maximum\ angle} - M_{initial\ angle}}{\theta_{maximum} - \theta_{initial}} = \frac{\left(F_{maximum\ angle} - F_{initial\ angle}\right) * d}{\theta_{maximum} - \theta_{initial}} \tag{1}$$

Wherein $M_{maximum\ angle}$ is the moment at the maximum flexion angle, $M_{initial\ angle}$ is the moment at the beginning of rotation, $\theta_{maximum}$ is the maximum flexion angle, $\theta_{initial}$ is the angle at the beginning of rotation, $F_{maximum\ angle}$ is the force at the maximum flexion angle, $F_{initial\ angle}$ is the force at the beginning of rotation, and d is the vertical distance from ~1.25 in. below the S1 spinal level to the rod attached to the harness.

$$Stiffness\ Measure\ 2 = \frac{\Delta M}{\Delta \theta} = \frac{M_{specific\ angle} - M_{initial\ angle}}{\theta_{specific} - \theta_{initial}} = \frac{\left(F_{specific\ angle} - F_{initial\ angle}\right) * d}{\theta_{specific} - \theta_{initial}} \tag{2}$$

Wherein $M_{specific\ angle}$ is the moment at the specific target angle, $\theta_{specific}$ is the specific target angle, $F_{specific\ angle}$ is the force at the specific target angle, and the other variables are defined the same as above.

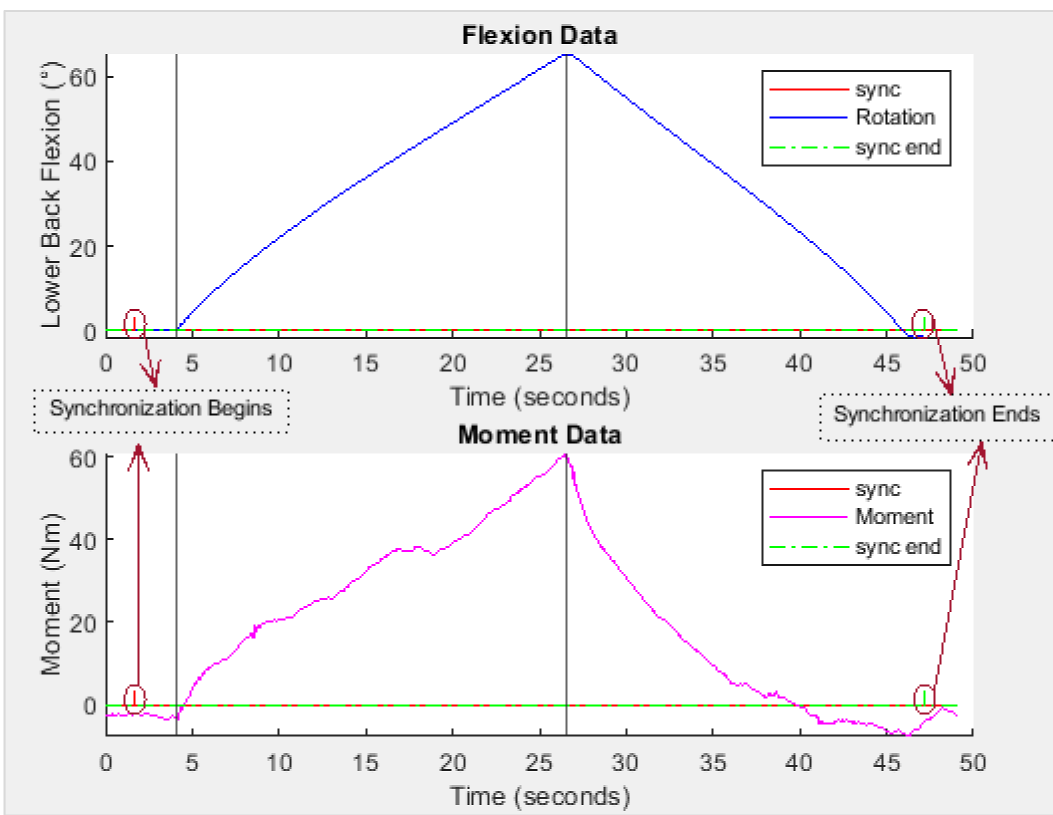


Figure 4. Example data from one participant illustrating the beginning (black vertical line on the left) and end (black vertical line towards the middle) points for the calculation of Stiffness Measure 1.

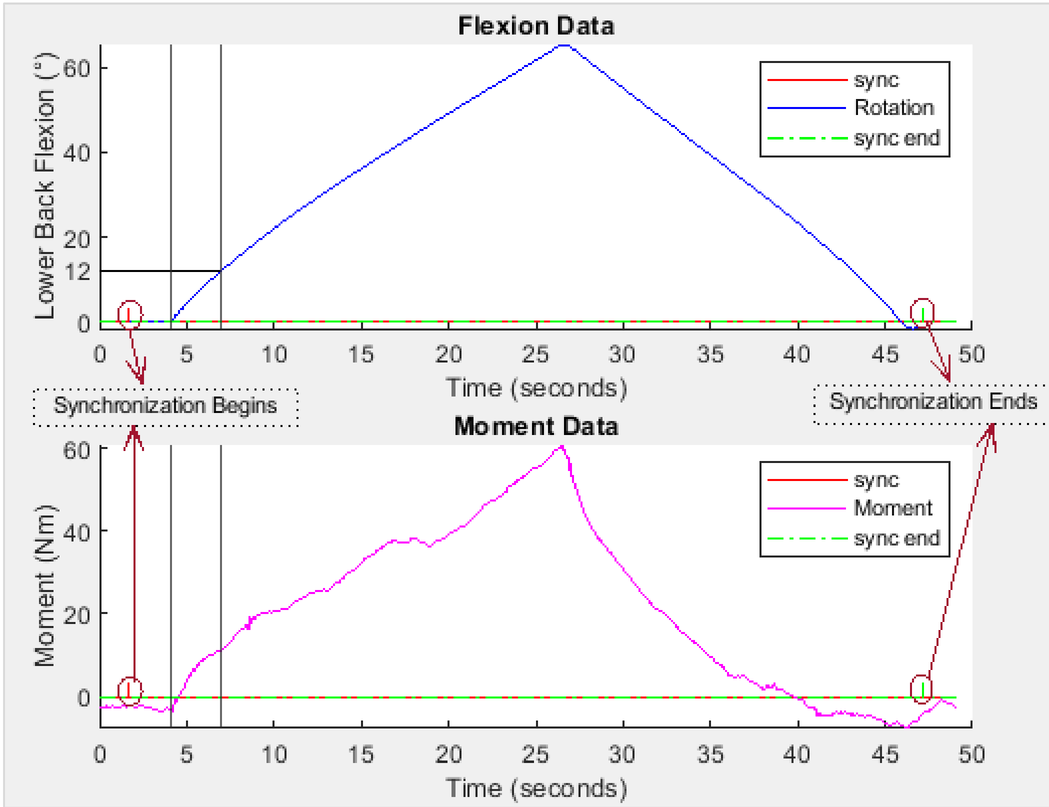


Figure 5. Example data from one participant illustrating the beginning (left black vertical line) point and the point at which the specific angle occurred for these data (right black vertical line) for the calculation of Stiffness Measure 2.

3.4 Statistical Analysis

For each of the four main stiffness measure-loading condition combinations (excluding without load vs. with load), dependent and independent t-tests were performed using SPSS (IBM SPSS Statistics 26, IBM, Armonk, New York). For the dependent t-tests, the dependent variable was either Stiffness Measure 1 or Stiffness Measure 2 and the independent variable was session (pre-shift vs. post-shift). For the independent t-tests, the dependent variable was the difference in the stiffness measure (either Stiffness Measure 1 or Stiffness Measure 2) between pre-shift and post-shift and the independent variable was job activity level (‘inactive’ vs. ‘active’). Additional analyses involved investigating the difference in trunk stiffness between the two loading conditions (with and without the ~7.5-lb load in the participant's hands) for both stiffness measures using dependent t-tests. Depending on the data being analyzed, 0-3 participants' data were excluded due to errors in the collected data. One-tailed *p*-values were calculated by hand using the outputs from SPSS, and adjusted *p*-values were calculated by hand using the Bonferroni-Holm correction. For the statistical analyses, $p \leq 0.05$ indicated statistical significance. Power analyses were performed in R (R Version 4.0.4 [2021-02-15], The R Foundation for Statistical Computing, Vienna, Austria) using the 'pwr' package (R Package Version 1.3-0, Stephane Champely [2020]).

CHAPTER 4: RESULTS

The results of this study are summarized in Tables 4, 5, and 6 and described in more detail in the following sections.

Table 4. Mean ± S.D. of Stiffness Measure 1 and Stiffness Measure 2 for each session and loading condition, along with the corresponding *p*-values.

	Session		
	Pre-Shift	**Post-Shift**	***p*-value**
Stiffness Measure 1 (Nm/rad)	---	---	---
Without Load *(n=22)*	47 ± 23	39 ± 19	0.156 [adjusted]
With Load *(n=21)*	53 ± 25	48 ± 25	0.260 [adjusted]
Stiffness Measure 2 (Nm/rad)	---	---	---
Without Load *(n=24)*	44 ± 25	45 ± 30	0.553 [adjusted]
With Load *(n=23)*	54 ± 30	52 ± 27	0.768 [adjusted]

Table 5. Mean ± S.D. of the difference in Stiffness Measure 1 and the difference in Stiffness Measure 2 for each job activity level and loading condition, along with the corresponding *p*-values.

	Job Activity Level		
	Inactive	**Active**	***p*-value**
Difference in Stiffness Measure 1 (Nm/rad)	---	---	---
Without Load *(n=22)*	0.86 ± 23	-15 ± 27	0.156 [adjusted]
With Load *(n=21)*	0.36 ± 22	-10 ± 19	0.260 [adjusted]
Difference in Stiffness Measure 2 (Nm/rad)	---	---	---
Without Load *(n=24)*	14 ± 49	-11 ± 31	0.146 [adjusted]
With Load *(n=23)*	-0.21 ± 29	-3.3 ± 27	0.768 [adjusted]

Table 6. Mean ± S.D. of Stiffness Measure 1 and Stiffness Measure 2 for each loading condition along with the corresponding *p*-values.

	Loading Condition		
	Without Load	**With Load**	***p*-value**
Stiffness Measure 1 (Nm/rad) *(n=42)*	43 ± 21	51 ± 25	0.002*
Stiffness Measure 2 (Nm/rad) (*n=46*)	45 ± 28	53 ± 28	0.086

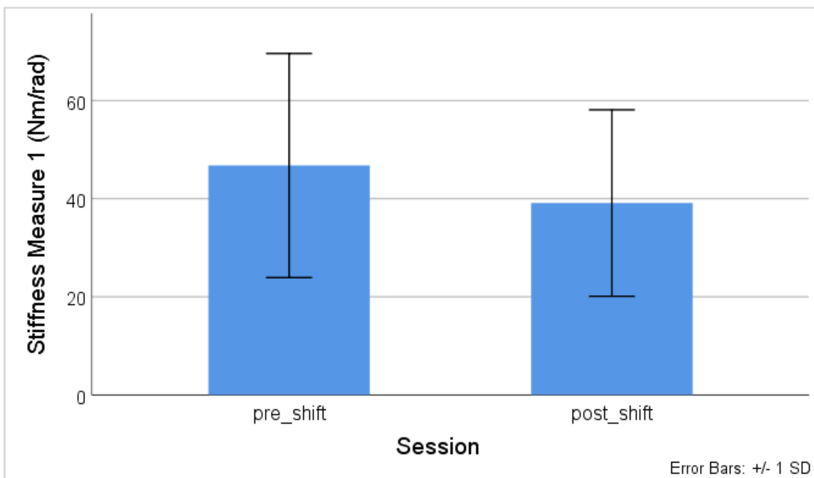
*statistically significant

4.1 Stiffness Measure 1

4.1.1 The Effects of Work-Related Activities

For the loading condition without the load (n=22: 10 inactive, 12 active), the mean difference in Stiffness Measure 1 for post-shift minus pre-shift was not statistically significant (p=0.156 [adjusted]), with 39 ± 19 Nm/rad for post-shift and 47 ± 23 Nm/rad for pre-shift (Figure 6A). For the loading condition with the load (n=21: 10 inactive, 11 active), the mean difference in Stiffness Measure 1 for post-shift minus pre-shift was also not statistically significant (p=0.260 [adjusted]), with 48 ± 25 Nm/rad for post-shift and 53 ± 25 Nm/rad for pre-shift (Figure 6B).

A



B

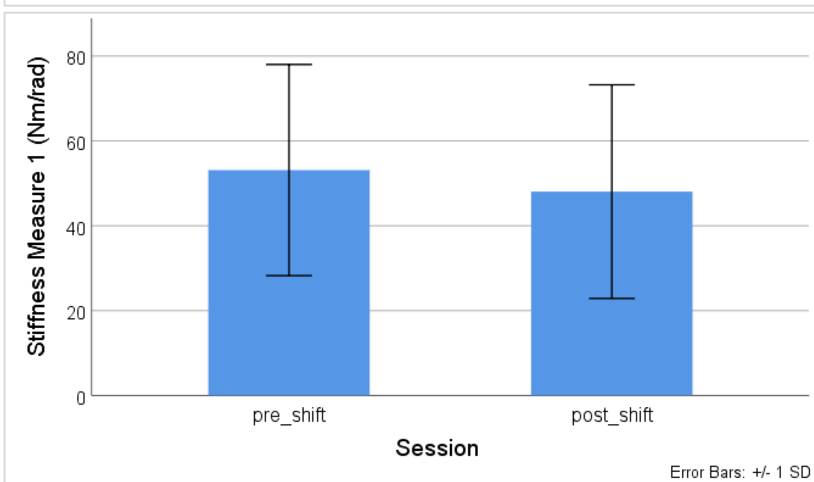


Figure 6. Mean ± S.D. of Stiffness Measure 1 for pre-shift vs. post-shift for the loading conditions without the load (A) and with the load (B). The error bars represent ± 1 S.D.

4.1.2 The Effects of Physical Activity

For the loading condition without the load (n=22: 10 inactive, 12 active), job activity level had no statistically significant effect on the difference in Stiffness Measure 1 between pre-shift and post-shift (p=0.156 [adjusted]), with 0.86 ± 23 Nm/rad for 'inactive' and -15 ± 27 Nm/rad for 'active' (Figure 7A). For the loading condition with the load (n=21: 10 inactive, 11 active), job activity level also did not statistically significantly affect the difference in Stiffness Measure 1 between pre-shift and post-shift (p=0.260 [adjusted]), with 0.36 ± 22 Nm/rad for 'inactive' and -10 ± 19 Nm/rad for 'active' (Figure 7B).

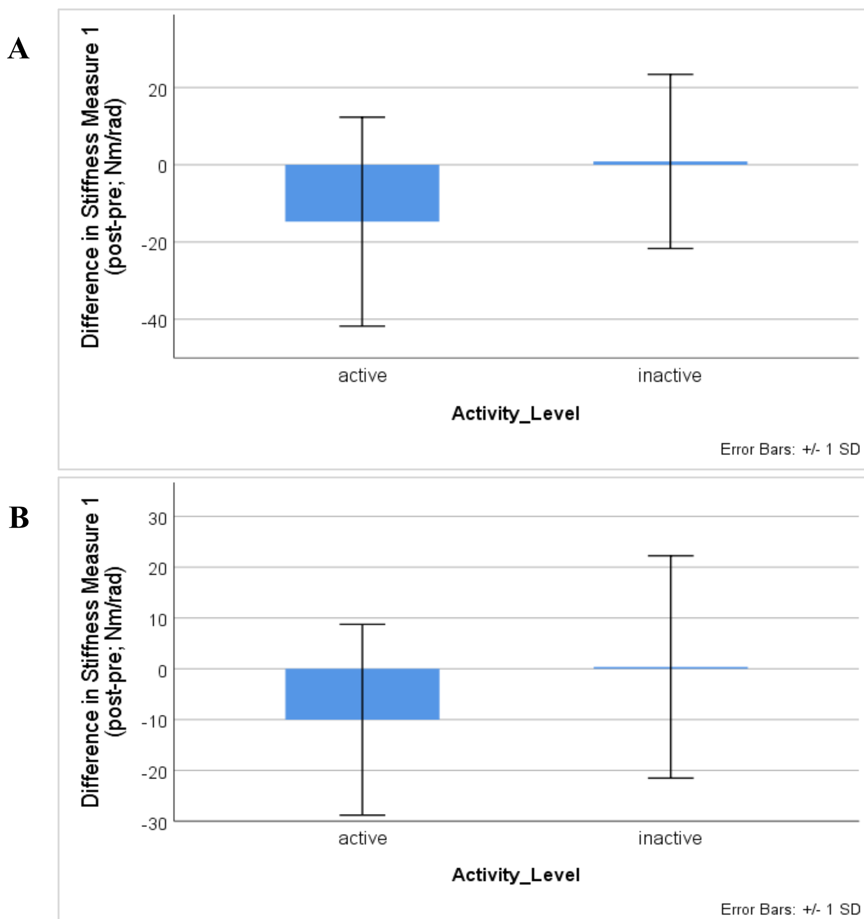


Figure 7. Mean ± S.D. of the difference in Stiffness Measure 1 (post-shift minus pre-shift) for the 'active' vs. 'inactive' job activity levels for the loading conditions without the load (A) and with the load (B). The error bars represent ± 1 S.D.

4.1.3 The Effects of Loading Condition (Without vs. With Load) [n=42]

The mean difference in Stiffness Measure 1 for the loading condition without the load minus the loading condition with the load was statistically significant (p=0.002), with the loading condition with the load (51 ± 25 Nm/rad) having an ~7.1 Nm/rad greater Stiffness Measure 1, on average, than the loading condition without the load (43 ± 21 Nm/rad; Figure 8).

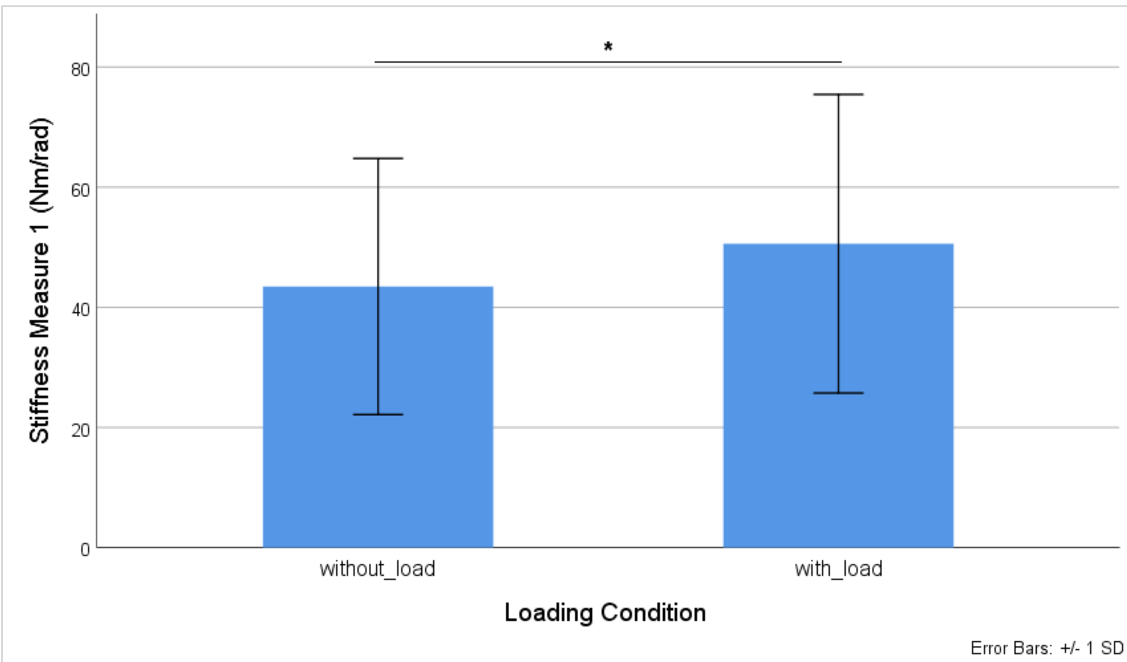


Figure 8. Mean ± S.D. of Stiffness Measure 1 for the loading condition without the load vs. the loading condition with the load. The error bars represent ± 1 S.D.

4.2 Stiffness Measure 2

4.2.1 The Effects of Work-Related Activities

For the loading condition without the load (n=24: 12 inactive, 12 active), the mean difference in Stiffness Measure 2 for post-shift minus pre-shift was not statistically significant (p=0.553 [adjusted]), with 45 ± 30 Nm/rad for post-shift and 44 ± 25 Nm/rad for pre-shift (Figure 9A). For the loading condition with the load (n=23: 12 inactive, 11 active), the mean difference in Stiffness Measure 2 for post-shift minus pre-shift was also not statistically significant (p=0.768 [adjusted]), with 52 ± 27 Nm/rad for post-shift and 54 ± 30 Nm/rad for pre-shift (Figure 9B).

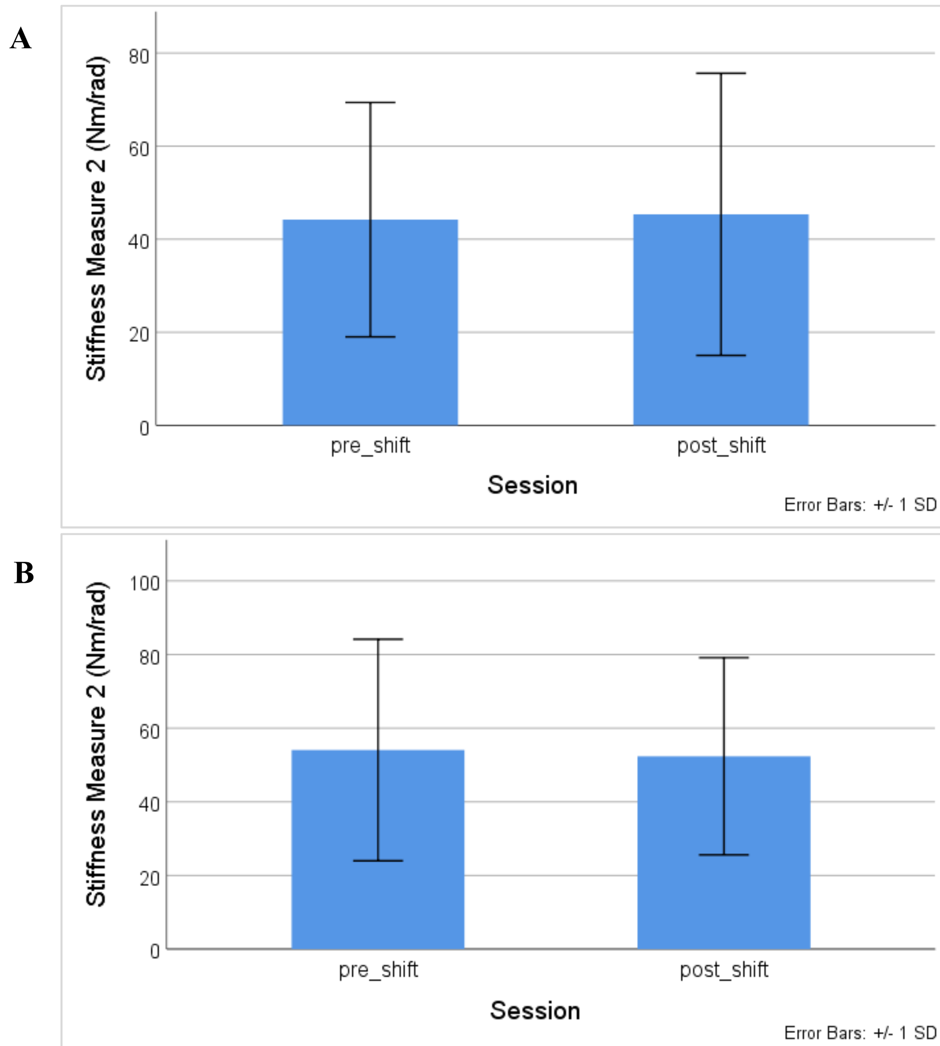


Figure 9. Mean ± S.D. of Stiffness Measure 2 for pre-shift vs. post-shift for the loading conditions without the load (A) and with the load (B). The error bars represent ± 1 S.D.

4.2.2 The Effects of Physical Activity

For the loading condition without the load (n=24: 12 inactive, 12 active), job activity level had no statistically significant effect on the difference in Stiffness Measure 2 between pre-shift and post-shift (p=0.146 [adjusted]), with 14 ± 49 Nm/rad for ‘inactive’ and -11 ± 31 Nm/rad for ‘active’ (Figure 10A). For the loading condition with the load (n=23: 12 inactive, 11 active), job activity level also did not have a statistically significant effect on the difference in Stiffness Measure 2 between pre-shift and post-shift (*p*=0.768 [adjusted]), with -0.21 ± 29 Nm/rad for 'inactive' and -3.3 ± 27 Nm/rad for 'active' (Figure 10B).

A

B

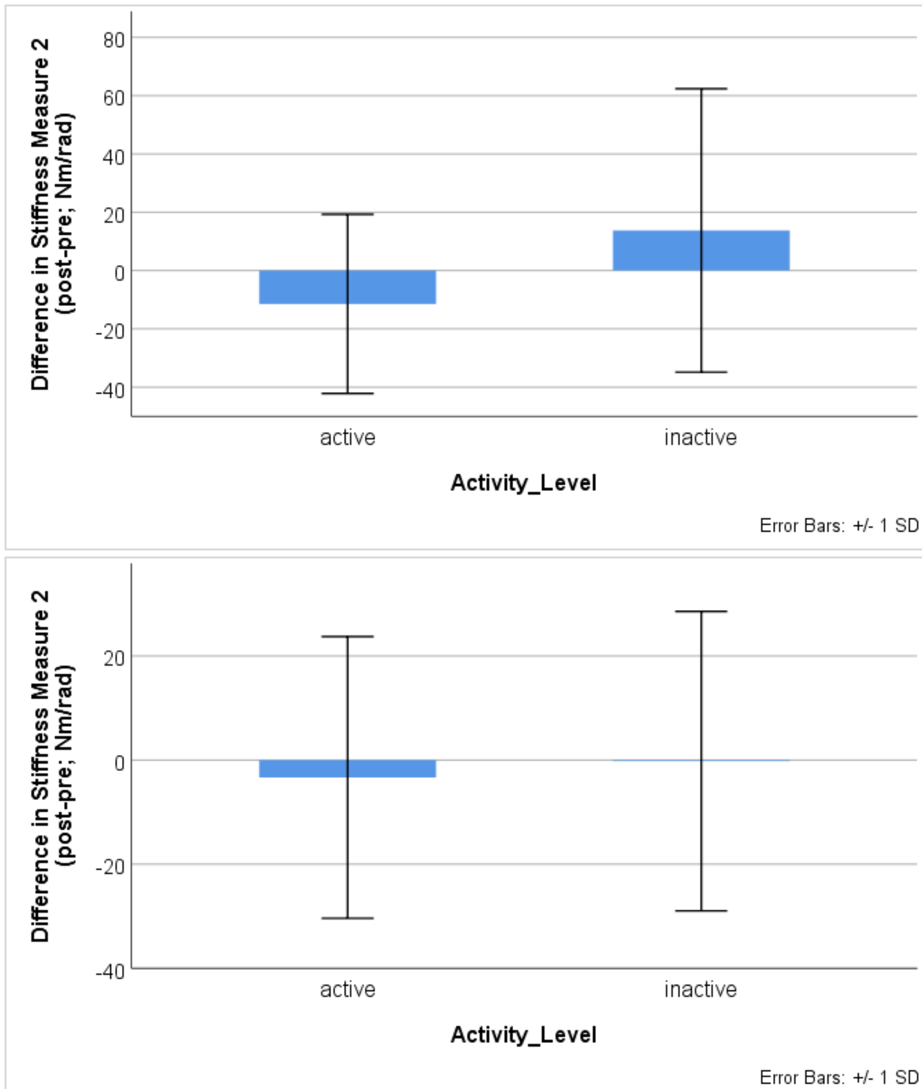


Figure 10. Mean ± S.D. of the difference in Stiffness Measure 2 (post-shift minus pre-shift) for the 'active' vs. 'inactive' job activity levels for the loading conditions without the load (A) and with the load (B). The error bars represent ± 1 S.D.

4.2.3 The Effects of Loading Condition (Without vs. With Load) [n=46]

The mean difference in Stiffness Measure 2 for the loading condition without the load minus the loading condition with the load was not statistically significant (p=0.086), with 45 ± 28 Nm/rad for the loading condition without the load and 53 ± 28 Nm/rad for the loading condition with the load (Figure 11).

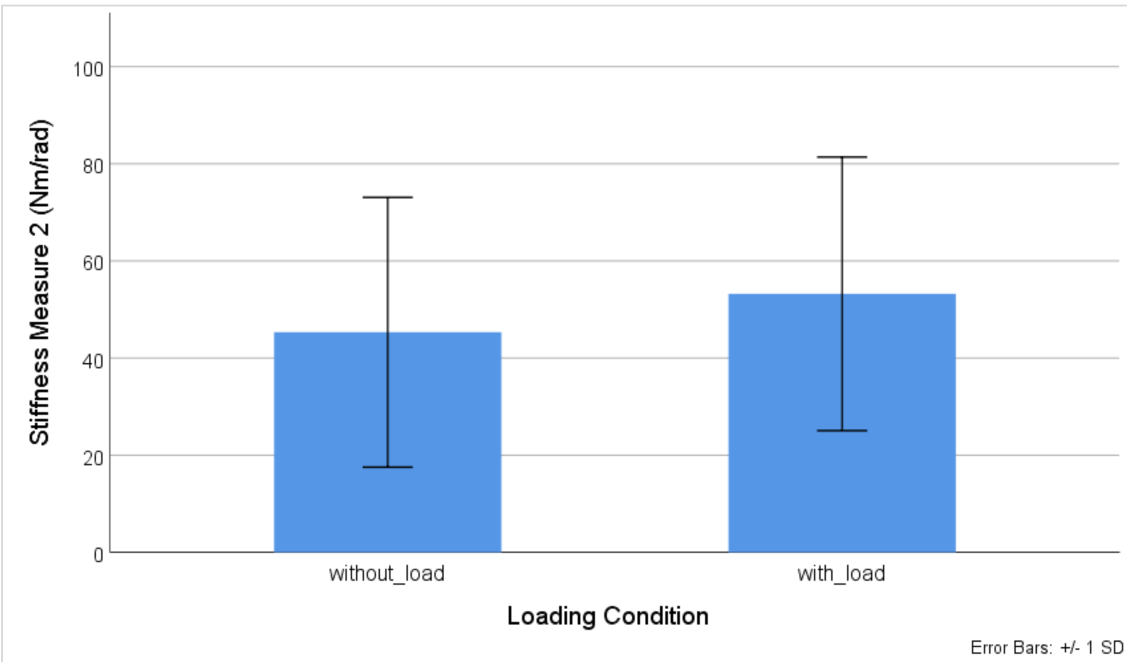


Figure 11. Mean ± S.D. of Stiffness Measure 2 for the loading condition without the load vs. the loading condition with the load. The error bars represent ± 1 S.D.

CHAPTER 5: DISCUSSION

The objective of this study was to investigate potential occupational and work-related effects on trunk stiffness in nursing personnel. It was hypothesized that trunk stiffness would decrease over the course of a work shift for all nursing personnel but more so in personnel with more physically demanding job activity levels. Overall, the findings of this study did not support what we hypothesized since no significant changes occurred from pre-shift to post-shift and both job activity levels had statistically similar differences in the corresponding trunk stiffness measure (post-shift minus pre-shift) for our four trunk stiffness measure-loading condition combinations (excluding without load vs. with load).

5.1 Analysis of Results

Our hypothesis concerning the decrease in trunk stiffness over the course of a work shift for nursing personnel was motivated by the reported changes in stiffness measures and range of motion of the lumbar spine mentioned in earlier studies. For example, Adams et al. (1987) reported an increased range of motion of the lumbar spine from early morning to late afternoon. Furthermore, short periods of exposure to potential physical risk factors for LBP (e.g., lifting (Pope et al., 2002) or work-related trunk flexion (Hoogendoorn et al., 2000)) have been reported in the literature to result in decreases in trunk stiffness measures (Hendershot et al., 2011; Toosizadeh et al., 2013). Due to the work environment of nursing personnel, who perform such activities as lifting and transporting patients (Jang et al., 2007) and are exposed to prolonged standing (Mendelek et al., 2011), they are exposed to various LBP risk factors for longer durations than those mentioned in earlier studies. Therefore, it was expected that there would be a work-related decrease in the trunk stiffness of nursing personnel; however, our results did not support this hypothesis. It is possible that certain potential LBP risk factors, such as prolonged sitting (Mendelek et al., 2011), could have an effect on trunk stiffness opposite to that mentioned previously. For instance, Beach et al. (2005) reported an increased stiffness occurring after sedentary activities. Therefore, our findings of no work-related changes in our trunk stiffness measures could have resulted from the effects of potential LBP risk factors contradicting each other such that there would have been no net work-related change in trunk stiffness. This is consistent with Drake and Callaghan (2008) who reported no variations in their stiffness measure ("axial twist stiffness") between 8 a.m. and 3 p.m. (similar length of time to our study but a different stiffness measure) and Kastelic et al. (2018) who reported no work-related changes in "lumbar range of motion" (corresponding to an actual workday, similar to our study).

Other reasons for the lack of significant work-related changes in the trunk stiffness of the nursing personnel in this study could be the time between the end of the subjects' shifts and when they arrived at the lab for data collection and their modes of transportation to the lab. Some subjects may have come soon after their shift ended, while others may have spent some more time at their job location before leaving to come to the lab for data collection. In addition, some subjects may have walked or ridden their bicycles to the lab, while others may have driven. The extra time and the different activities may have affected trunk stiffness by negating any changes that may have occurred during the subjects' work shifts or by allowing the subjects to recover their initial, or almost their initial, trunk stiffness. As discussed by Hendershot et al. (2011), after 16 minutes of maximum flexion, trunk stiffness (intrinsic) was fully recovered at

~10 minutes. Thus, it is possible to recover trunk stiffness, even at ~10 minutes, which would have been close to the time it would have taken the subjects for this study to arrive at the lab for data collection.

Our only significant finding was the higher Stiffness Measure 1 for the loading condition with the load being held in the subjects' hands than for the condition without this load (p=0.002). This difference in trunk stiffness between loading conditions is consistent with Shojaei et al. (2018) who reported how "changes in trunk bending stiffness" were significantly affected by load magnitude such that increasing the magnitude resulted in increases in this stiffness. These corresponding increases in load magnitude and trunk stiffness could be due to increases in muscle activity that correspond to a higher equilibrium demand (Shojaei et al., 2018), as mentioned in Shojaei et al. (2018) who used a similar testing setup to ours. Similarly, Vazirian et al. (2016) reported a higher "trunk intrinsic stiffness" at their higher extension effort level (30% vs. 20%), and Gardner-Morse and Stokes (2001) reported a higher trunk stiffness at their 40% steady-state effort as compared to their 20% effort.

5.2 Limitations

There were several limitations in this study. Most importantly, this study was greatly underpowered. Based on the results of this study and power being set to 80%, the necessary sample size (>2000 subjects) is much larger than our sample size, illustrating the degree to which our study was underpowered. Additionally, our study population was not homogeneous since there were differences in age (age range = 21-58), gender (3 of the 24 subjects were male), nursing unit (14 different units), and length of work shift (8-12 hours). An error in the procedure for data collection resulted in the use of a flexion angle for a subject that was not equal to 70% of the subject's maximum flexion; however, since this angle was reasonable and similar to 70% of the maximum flexion for other subjects, the corresponding data were analyzed. The rod was not consistently adjusted horizontally to ensure an upright posture; thus, trunk stiffness would have been measured from an initial posture of flexion or extension. The largest positive force at the initial angle corresponded to a trunk extension of ~5.7° and the largest negative force at the initial angle corresponded to a trunk flexion of ~4.4°, but the corresponding changes in trunk stiffness were <10%. Due to the shapes of the force curves, the target angle for Stiffness Measure 2 could not be used for part of two subjects' data. Therefore, the end point force and angle were based on the first peak in the force data after each subject's legs had begun to be rotated. In addition, due to the shapes of the rotation curves for part of two subjects' data, the codes picked the wrong index for the rotation angle and trunk stiffness was calculated by hand. Regarding statistical assumptions, for Stiffness Measure 1 and the loading condition without the load, the Q-Q plot for the 'active' data was somewhat curvilinear, mainly in the middle, but was still considered to be approximately normal. In addition, for Stiffness Measure 2 and the loading condition with the load, the Q-Q plot for the 'active' data was slightly curvilinear in the middle but did not appear to be too non-normal.

CHAPTER 6: FUTURE STUDIES

Future studies should try to decrease the variability of their study population so that a large sample size could be avoided but significant work-related changes in trunk stiffness could still be detected. One potential method to form a less variable sample population could be recruiting subjects from one job population (e.g., nurses who work only in the Emergency Department) and with similar lengths of their work shifts (e.g., only ~8 hours or ~12 hours and not a range from 8-12 hours). Another method could be setting up the equipment for data collection closer to where the subjects work so that there would be less time between the end of their work shifts and the start of the post-shift data collection session and fewer extraneous, non-work-related activities between the end of their work shifts and the start of the post-shift session. It may also be more beneficial to study subjects with either more physically demanding job activity levels or more sedentary job activity levels instead of including subjects with both job activity levels, which could allow for a deeper focus on potential time-related changes.

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
Korbin Jackson, College of Engineering, UK
Elizabeth Powell, Stroke and Spinal Cord Rehabilitation Program, UK
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Participant #: _________ (filled out by the experimenter)   **Date:** __________

Part I – Verification of Advertised Criteria

Age group: <u>21-60</u>   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   <u>No</u>

Are you a nurse?   <u>Yes</u>   No

Does your job require you to sit most of the day?   <u>Yes</u>   <u>No</u>

***** 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

Adams, M.A., Dolan, P., Hutton, W.C., 1987. Diurnal variations in the stresses on the lumbar spine. Spine 12, 130-137.

Beach, T.A.C., Parkinson, R.J., Stothart, J.P., Callaghan, J.P., 2005. Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine. The Spine Journal 5, 145-154.

Bergmark, A., 1989. Stability of the lumbar spine: A study in mechanical engineering. Acta Orthopaedica Scandinavica 60, 1-54.

Brown, S.H.M., McGill, S.M., 2009. The intrinsic stiffness of the in vivo lumbar spine in response to quick releases: Implications for reflexive requirements. Journal of Electromyography and Kinesiology 19, 727-736.

Callaghan, J.P., McGill, S.M., 2001. Low back joint loading and kinematics during standing and unsupported sitting. Ergonomics 44, 280-294.

Cholewicki, J., Simons, A.P.D., Radebold, A., 2000. Effects of external trunk loads on lumbar spine stability. Journal of Biomechanics 33, 1377-1385.

Dieleman, J.L., Baral, R., Birger, M., Bui, A.L., Bulchis, A., Chapin, A., Hamavid, H., Horst, C., Johnson, E.K., Joseph, J., Lavado, R., Lomsadze, L., Reynolds, A., Squires, E., Campbell, M., DeCenso, B., Dicker, D., Flaxman, A.D., Gabert, R., Highfill, T., Naghavi, M., Nightingale, N., Templin, T., Tobias, M.I., Vos, T., Murray, C.J.L., 2016. US spending on personal health care and public health, 1996-2013. JAMA 316, 2627-2646.

Drake, J.D.M., Callaghan, J.P., 2008. Do flexion/extension postures affect the *in vivo* passive lumbar spine response to applied axial twist moments? Clinical Biomechanics 23, 510–519.

Dunk, N.M., Callaghan, J.P., 2010. Lumbar spine movement patterns during prolonged sitting differentiate low back pain developers from matched asymptomatic controls. Work 35, 3-14.

Ensink, F.-B.M., Saur, P.M.M., Frese, K., Seeger, D., Hildebrandt, J., 1996. Lumbar range of motion: Influence of time of day and individual factors on measurements. Spine 21, 1339-1343.

Fathallah, F.A., Marras, W.S., Wright, P.L., 1995. Diurnal variation in trunk kinematics during a typical work shift. Journal of Spinal Disorders 8, 20-25.

Gardner-Morse, M., Stokes, I.A.F., Laible, J.P., 1995. Role of muscles in lumbar spine stability in maximum extension efforts. Journal of Orthopaedic Research 13, 802-808.

Gardner-Morse, M.G., Stokes, I.A.F., 2001. Trunk stiffness increases with steady-state effort. Journal of Biomechanics 34, 457-463.

Granata, K.P., Rogers, E., 2007. Torso flexion modulates stiffness and reflex response. Journal of Electromyography and Kinesiology 17, 384–392.

Hendershot, B., Bazrgari, B., Muslim, K., Toosizadeh, N., Nussbaum, M.A., Madigan, M.L., 2011. Disturbance and recovery of trunk stiffness and reflexive muscle responses following prolonged trunk flexion: Influences of flexion angle and duration. Clinical Biomechanics 26, 250-256.

Hodges, P., van den Hoorn, W., Dawson, A., Cholewicki, J., 2009. Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. Journal of Biomechanics 42, 61–66.

Hoogendoorn, W.E., Bongers, P.M., de Vet, H.C.W., Douwes, M., Koes, B.W., Miedema, M.C., Ariëns, G.A.M., Bouter, L.M., 2000. Flexion and rotation of the trunk and lifting at work are risk factors for low back pain: Results of a prospective cohort study. Spine 25, 3087-3092.

Jang, R., Karwowski, W., Quesada, P.M., Rodrick, D., Sherehiy, B., Cronin, S.N., Layer, J.K., 2007. Biomechanical evaluation of nursing tasks in a hospital setting. Ergonomics 50, 1835-1855.

Kastelic, K., Voglar, M., Šarabon, N., 2018. Acute effect of full time office work in real environment on postural actions and lumbar range of motion. Journal of Electromyography and Kinesiology 43, 82-87.

McGill, S.M., Grenier, S., Kavcic, N., Cholewicki, J., 2003. Coordination of muscle activity to assure stability of the lumbar spine. Journal of Electromyography and Kinesiology 13, 353-359.

Mendelek, F., Kheir, R.B., Caby, I., Thevenon, A., Pelayo, P., 2011. On the quantitative relationships between individual/occupational risk factors and low back pain prevalence using nonparametric approaches. Joint Bone Spine 78, 619-624.

Miller, E.M., Bazrgari, B., Nussbaum, M.A., Madigan, M.L., 2013. Effects of exercise-induced low back pain on intrinsic trunk stiffness and paraspinal muscle reflexes. Journal of Biomechanics 46, 801-805.

Parkinson, R.J., Beach, T.A.C., Callaghan, J.P., 2004. The time-varying response of the in vivo lumbar spine to dynamic repetitive flexion. Clinical Biomechanics 19, 330–336.

Pope, M.H., Goh, K.L., Magnusson, M.L., 2002. Spine ergonomics. Annual Review of Biomedical Engineering 4, 49-68.

Reeves, N.P., Cholewicki, J., van Dieën, J.H., Kawchuk, G., Hodges, P.W., 2019. Are stability and instability relevant concepts for back pain? Journal of Orthopaedic & Sports Physical Therapy 49, 415-424.

Reeves, N.P., Narendra, K.S., Cholewicki, J., 2007. Spine stability: The six blind men and the elephant. Clinical Biomechanics 22, 266-274.

Shojaei, I., Allen-Bryant, K., Bazrgari, B., 2016. Viscoelastic response of the human lower back to passive flexion: The effects of age. Annals of Biomedical Engineering 44, 2817-2826.

Shojaei, I., Suri, C., van Dieën, J.H., Bazrgari, B., 2018. Alterations in trunk bending stiffness following changes in stability and equilibrium demands of a load holding task. Journal of Biomechanics 77, 163-170.

Shojaei, I., Vazirian, M., Salt, E.G., Van Dillen, L.R., Bazrgari, B., 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, 71-77.

U.S. Bureau of Labor Statistics, 2019. TABLE R19. Number of nonfatal occupational injuries and illnesses involving days away from work by part of body and selected natures of injury or illness, private industry, 2018. https://www.bls.gov/iif/oshwc/osh/case/cd_r19_2018.htm

Toosizadeh, N., Bazrgari, B., Hendershot, B., Muslim, K., Nussbaum, M.A., Madigan, M.L., 2013. Disturbance and recovery of trunk mechanical and neuromuscular behaviours following repetitive lifting: Influences of flexion angle and lift rate on creep-induced effects. Ergonomics 56, 954-963.

van Dieën, J.H., Cholewicki, J., Radebold, A., 2003. Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. Spine 28, 834-841.

Vazirian, M., Shojaei, I., Tromp, R.L., Nussbaum, M.A., Bazrgari, B., 2016. Age-related differences in trunk intrinsic stiffness. Journal of Biomechanics 49, 926-932.

Vette, A.H., Masani, K., Wu, N., Popovic, M.R., 2014. Multidirectional quantification of trunk stiffness and damping during unloaded natural sitting. Medical Engineering & Physics 36, 102-109.

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Presentations

Apr. 2019	**Work-Related Changes in Trunk Stiffness of Nursing Personnel** (Poster) ***Tyler C**, McDonald M, Ballard M, Bazrgari B; 14th Annual CCTS Spring Conference 2019, Lexington, KY*
Apr. 2019	**Work-related Changes in Lumbo-Pelvic Coordination During Trunk Forward Bending and Backward Return Among Nurses** (Poster) ***McDonald M**, Ballard M, Tyler C, Bazrgari B; 14th Annual CCTS Spring Conference 2019, Lexington, KY*
Oct. 2020	**Work-Related Changes in Lumbo-Pelvic Coordination During Trunk Movement Among Nurses** (Poster) ***McDonald M**, Tyler C, Sawaki Adams L, Bazrgari B; BMES 2020 Virtual Annual Meeting*

Clare Tyler