AN ANALYSIS OF MUSCLE ACTIVITY DURING LOAD CARRIAGE, ACFT SCORES, AND BACK PAIN IN ARMY ROTC CADETS

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DOCTOR OF PHILOSOPHY

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ABSTRACT

Context: Low back pain (LBP) is a leading musculoskeletal complaint among the military population. Load carriage tasks are a frequently reported mechanism of injury for low back pain (LBP) in the Army. Furthermore, researchers have demonstrated a clear association between physical fitness and injury incidence. **Objectives:** 1) to analyze changes in muscle activity during load carriage and how LBP relates to changes in muscle activation; and 2) to analyze a possible relationship between performance on the Army Combat Fitness Test (ACFT) and LBP, muscle activity, and kinesiophobia in Army Reserve Officer Training Corps (ROTC) cadets. **Methods:** 30 Army ROTC cadets (age 21±1.82) completed a 5-kilometer walk with and without a 35-pound load. Electromyography (EMG) data were obtained of the rectus femoris (RF), rectus abdominis (RA), gluteus medius (GM), gluteus maximus (GMx), erector spinae (ES), and biceps femoris (BF), and a questionnaire was used to assess LBP. Twenty-one cadets from the initial sample completed the six-event ACFT, the Tampa Scale of Kinesiophobia (TSK), and visual analog scales (VAS). ANOVA models were estimated for each muscle with time and load as independent factors. Correlations were used to assess relationships between pain and muscle activity. Regression was used to model the ability of muscle activity, MMBQ, TSK, and VAS scores to predict performance on each component of the ACFT. **Results:** Muscle activation for all muscles declined significantly over time ($p<.001$). Amplitude of RF ($p=.014$), GM ($p<.001$), and GMx ($p=.007$) significantly increased in the LC condition. Cadets who reported pain had greater average muscle activation; however, only the RF showed a significant association ($p=.01$). Significant regression equations were found for the Sprint-Drag-Carry ($p=.009$) and two-mile run ($p=.004$). **Conclusion:** Due to the associations between LBP and increased muscle activation with added loads, cadets displaying muscle activity at greater

percentages of their MVC should consider adopting a core strengthening program prior to embarking on foot marches with load carriage. Additionally, cadets with poor performance on the SDC and 2MR should require a fitness program focused on improving these measures, as they are significantly associated with LBP.

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LIST OF ABBREVIATIONS

LBP	Low Back Pain
BMI	Body Mass Index
APFT	Army Physical Fitness Test
ACFT	Army Combat Fitness Test
ROTC	Reserve Officers’ Training Corps
RF	Rectus Femoris
RA	Rectus Abdominis
ES	Erector Spinae
BF	Biceps Femoris
GM	Gluteus Medius
GMx	Gluteus Maximus
EMG	Electromyography
sEMG	Surface Electromyography
MMBQ	Modified Military Back Pain Questionnaire
VAS	Visual Analog Scale
TSK	Tampa Scale of Kinesiophobia
PRT	Physical Readiness Training
BCT	Basic Combat Training
MDL	3 Repetition Maximum Deadlift
SPT	Standing Power Throw
HRP	Hand Release Push-Up
LTK	Leg Tuck
SDC	Sprint-Drag-Carry
CLBP	Chronic Low Back Pain

1. INTRODUCTION

1.1. An Analysis of Muscle Activity during Load Carriage in Army ROTC Cadets

1.1.1. Overview of the Problem

Every year approximately 3,300 Army Reserve Officers' Training Corps (ROTC) cadets from over 270 different programs attend advanced training camp for 40 days in the summer. During this training, they are required to walk well over 20 miles while wearing full gear, including a rucksack with a load consisting of weapons, equipment, body armor, as well as other protective gear and supplies while in a constantly changing terrain.[1,2] One of the requirements of advanced training camp is to complete a 12-mile foot march with a load of a minimum of 35 lbs. in under four hours. Military personnel carry loads as part of their occupation, and long road marches are a substantial component of military training. Research has demonstrated that as the weight of the occupational load increases, the physiological cost of carrying the load increases as well.[1]

Several studies have been conducted on the military population investigating kinetic and kinematic effects of load carriage as well as other physiological measurements including heart rate and VO_2. However, little research exists utilizing electromyography (EMG) to investigate changes in muscle activation when carrying a load in military personnel. The majority of load carriage studies that do utilize EMG are not focused on the military population. Therefore, many studies implement backpacks and weight vests that differ from military load carriage systems, potentially leading to conclusions that are inconsistent with what would be found utilizing military equipment. [1,3–6] Moreover, the majority of studies utilizing EMG to evaluate changes in muscle activation during load carriage have assessed the lower extremity alone, thereby neglecting the muscular changes that may occur in the core.[3,4,7,8]

Lack of information regarding changes in core muscle activation is significant because researchers have reported the spine is one of the most commonly injured body regions during tasks that require the addition of an occupational load. In fact, in a study evaluating load carriage injuries in the Australian Army researchers reported the back was the leading location of injury at 23% of all injuries.[2] In numerous studies of muscle activation with added loads, researchers have utilized percentages of body weight to determine the weight of the load carried,[3–5,9] however, this is not how load weight is determined in the US Army. Therefore, it is important to establish how load carriage affects muscle activity and how this relates to the development of back pain.

1.1.2. Statement of Purpose

The purpose of this study was to explore a possible relationship between back pain and muscle activity measured via surface electromyography of the lower back, abdominal, and leg musculature during military load carriage. A secondary purpose was to compare muscle activation patterns to past and current patient-reported back pain to determine whether activity of these muscles during load carriage can be used as a predictive model for military personnel.

1.1.3. Research Questions

Q1: What are the differences in muscle activation in the core and lower extremity of Army ROTC cadets walking with and without a 35 lb. load carried on the back?

Q2: What is the relationship between the presence of back pain and muscle activation of the lower extremity and core?

Q3: To what extent do muscle activation patterns predict the development of low back pain?

1.1.4. Definitions

Load Carriage: an external load carried by professionals as part of the demands associated with their occupation.[1,10]

Low Back Pain: pain, muscle tension, or stiffness localized below the costal margin and above the inferior gluteal folds, with or without leg pain.[11,12]

Electromyography (EMG): a technique used to obtain quantitative information regarding muscle activity.

1.1.5. Limitations

Some limitations of the present study include use of a treadmill, which does not accurately represent environmental factors cadets would experience during a traditional ruck march such as hills, heat, humidity, weather, etc. Secondly, the three-mile distance is relatively short when compared to the 12 mile road march requirement at cadet summer training. An additional limitation is the use of subjective reports of back pain as opposed to referring to cadet profiles/medical records. Lastly, EMG data were collected unilaterally thus limiting the analyses that can be conducted.

1.1.6. Delimitations

The researchers chose to include a limited participant population of cadets from North Dakota State University's Army Reserve Officer Training Corps (ROTC) program. Although the ROTC population may not be generalizable to the rest of the Army, this unique subset of military personnel is understudied and thus underrepresented in the literature. Additionally, four out of six muscles selected (erector spinae, rectus abdominis, gluteus medius, and gluteus maximus) for analysis have little to no data available in the existing research. Therefore, the ability to compare the findings to existing work is limited.

1.1.7. Assumptions

Assumptions have been made that participants honestly reported their current back pain/disability and history of back pain/disability over the last year. Additionally, it was assumed that participants walked as normally as possible without altering their gate mechanics.

1.1.8. Variables

The independent variables in the current study included load condition and time. Dependent variables include scores on the modified-MBQ and activity of six muscles (rectus femoris, biceps femoris, gluteus medius, gluteus maximus, rectus abdominis, and erector spinae). Covariates in this study were biological sex and body mass index (BMI).

1.1.9. Significance of the Study

Research evaluating muscle activation during load carriage is lacking, and research specific to load carriage and EMG in the military population is further limited. Since load carriage is a frequently reported mechanism of injury in the military population, accounting for approximately 34% of all injuries in the Army population,[2] it is important for athletic trainers to be educated on specific causes of injury, predisposing factors for injury, and prevention of load carriage-related injuries. We anticipate that the results of this study can be used by athletic trainers in the military setting to treat the root cause of injuries associated with load carriage as well as prevent injuries from occurring based on the muscular physiological demands and activation patterns associated with load carriage.

1.2. A Comparison of ACFT Scores, Back Pain, & Muscle Activity in Army ROTC Cadets

1.2.1. Overview of the Problem

Musculoskeletal injuries are one of the most prevalent heath concerns within the military population[13] with reported injury rates as high as 61%.[14] Based on the significance of this issue, numerous investigations have been conducted evaluating risk factors contributing to training-related injuries in military personnel. As a result of numerous investigations, researchers have identified physical fitness as a key factor contributing to injury incidence.[15–19] Prior studies suggest that trainees with lower fitness levels have significantly higher rates of injury compared to their more fit counterparts.[15–18] Specifically, researchers have utilized the Army Physical Fitness Test (APFT) to assess trainees' risk for sustaining a musculoskeletal injury and found cardiovascular fitness, as measured by the two-mile run, is the strongest indicator of injury risk.[14–16,19–21]

The Army is in the process of transitioning to a new fitness test, the Army Combat Fitness Test (ACFT). The ACFT is a much more functional and physically demanding assessment as compared to the APFT. While the APFT was focused solely on activities using the soldiers own body weight, the ACFT has components that require the use of added weight resulting in a test that is more applicable to the physical activities soldiers complete. The new test consists of six events including a two-mile run. The inclusion of the running component is vital, as it is the strongest indicator of injury risk within the existing literature.

An additional factor that has been assessed with regard to back pain and muscle activity is perceived disability, as measured by the Tampa Scale of Kinesiophobia (TSK), visual analog scale (VAS), and numerous other measures of self-identified pain and disability.[22–25] Due to conflicting results of studies evaluating these measures, it is unclear whether there is a relationship between muscle activation and clinical measures of perceived disability.[22–25]

While there is a clear relationship between cardiovascular fitness and injury incidence, there is a need for information related to the ACFT. Further, analyses of perceived disability in conjunction with muscle activity and back pain have not focused on military personnel or military training. Therefore, this study fills several research gaps pertaining to fitness and musculoskeletal injuries in military personnel.

1.2.2. Statement of Purpose

The primary purpose of this study was to explore a possible relationship between fitness of cadets, presence of back pain, and muscle activation patterns. A secondary goal of this research is to examine relationships between kinesiophobia, self-reported pain, and performance on the Army Combat Fitness Test (ACFT).

1.2.3. Research Questions

Q1: What is the relationship between muscle activation in the core and lower extremity of Army ROTC cadets and performance on the ACFT?

Q2: What is the relationship between self-reported back pain during performance of ACFT skills in Army ROTC cadets?

Q3: What is the relationship between kinesiophobia and performance on the ACFT in Army ROTC cadets?

1.2.4. Definitions

Low Back Pain: pain, muscle tension, or stiffness localized below the costal margin and above the inferior gluteal folds, with or without leg pain.[11,12]

Visual Analog Scale: a measurement instrument that assesses a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured.

Kinesiophobia: an excessive, irrational and debilitating fear to carry out a physical movement, due to a feeling of vulnerability to a painful injury or re-injury.

Army Physical Fitness Test (APFT): A standardized assessment tool used to assess the fitness level of Army personnel. This test consists of two-minutes of push-ups and sit-ups, and a two-mile run.[26]

Army Combat Fitness Test (ACFT): A newly implemented, functional fitness assessment consisting of the following: three repetition maximum deadlift, standing power throw, hand release push-ups, sprint-drag-carry, leg tuck, and two-mile run.[27]

1.2.5. Limitations

Data were collected the first time the cadets attempted the ACFT. Thus, they had limited experience with this fitness test prior to the study as compared to previous studies utilizing the APFT. An added limitation was the subjective nature of pain assessment as compared to review of medical records.

1.2.6. Delimitations

The researchers chose to this study population because they had already participated in a previous study dedicated to muscle activation. Additionally, the ACFT was used as opposed to the APFT because of the recent transition to the new fitness test. Lastly, the specific time frames to ask about pain and fear were selected because of the focus on back pain, which is more prevalent with the deadlift and running components of the test.

1.2.7. Assumptions

Assumptions have been made that participants honestly reported their pain on the visual analog scale. Additionally, it was assumed that participants honestly reported their fear of activity on the Tampa Scale of Kinesiophobia. Lastly, it was assumed that participants performed to the best of their ability on all components of the ACFT.

1.2.8. Variables

The independent variables in the current study included the six events of the ACFT: three repetition maximum dead lift, standing power throw, hand release push-ups, sprint-drag-carry, leg tuck, and two-mile run. Dependent variables included performance on the ACFT (number of weight lifted, distance of throw, repetitions completed, and time to complete the task), scores on the TSK, and VAS scores. Additional independent variables from the prior study include load condition and time, while dependent variables from the prior study include scores on the modified-MBQ and muscle activity.

1.2.9. Significance of the Study

While the APFT has been used in the to assess fitness level of soldiers for over 40 years, the Army is currently in the process of transitioning to a new fitness test called the Army Combat Fitness Test (ACFT). The ACFT is a much more functional fitness assessment that consists of six events, one of which is the two-mile run. The inclusion of the running component is vital, as it is the strongest indicator of injury risk within the existing literature. However, due to the recent implementation of the ACFT, the relationship between fitness and injuries using this new assessment has not been evaluated. Furthermore, evidence suggests individuals with back pain demonstrate increased activation of the erector spinae muscles and different patterns of activation during completion of functional activities. Therefore, gaining an understanding of how muscle activity relates to ACFT performance and back pain may help develop a method for identification of at risk cadets so early intervention can take place, thus reducing the negative impacts of musculoskeletal injuries in this population.

2. LITERATURE REVIEW

2.1. Introduction

Musculoskeletal injuries continue to be one of the most prevalent health concerns plaguing members of the Armed Services.[13] In 2006, injuries were the leading cause of medical encounters[13] with reported rates as high as 61%.[14] As a result of several investigations, risk factors contributing to training-related injuries have been identified with a primary factor of general physical fitness.[15–19] More specifically, findings within the literature suggest trainees with the slowest two-mile run times and thus an implication of lower cardiovascular fitness are at greater risk of subsequent injury compared to their more fit counterparts.[14–16,19–21]

Important aspects of injury incidence that need to be considered to determine the best injury prevention methods include location and mechanism of injury. Current information suggests injuries in military personnel are most common in the back and lower extremities with researchers reporting injury rates to these areas as high as 83%.[2,20,21,28,29] Additionally, researchers have found load carriage tasks are a commonly reported mechanism of injury[1,10,30] with injury rates from load carriage activities averaging approximately 34%.[30] Moreover, an analysis of injuries associated with load carriage activities found all injuries associated with one strenuous road march involved the lower extremity and/or back.[31]

Military personnel carry loads as part of their occupation, and long road marches are a substantial component of military training. Such marching often includes carrying gear consisting of weapons, equipment, and body armor, as well as other protective gear and supplies while in a constantly changing terrain.[1,2] Heavy loads carried by military personnel result in increased and earlier onset of fatigue as well as altered biomechanics of posture and gait, thus resulting in adverse effects on the musculoskeletal system.[1,10,29]

One method that can be effective for measuring muscular changes that occur as the result of carrying a load is electromyography (EMG). While EMG has been utilized to assess the impact of load carriage on muscle activity, the majority of these studies do not incorporate military personnel as participants; therefore, they have not utilized military load carriage systems.[1,3–6] Further, most studies utilizing EMG to evaluate changes in muscle activation during load carriage have assessed the lower extremity alone, neglecting the muscular changes that may occur in the core and pelvis musculature.[3,4,7,8] Since research suggests the back may be a significant source of injuries associated with load carriage,[2] the lack of information regarding changes the effects of load carriage on back and core muscle activation is problematic.

Overall, the purpose of this review is to provide a comprehensive examination of musculoskeletal injuries in the military with a specific focus on back pain. Additionally, mechanism of injury for back pain will be addressed with a focus on muscle activation as a potential source of pain. Secondly, this review will focus on electromyography (EMG) as an objective measure of muscle activity and how EMG has been implemented in investigations of back pain and load carriage. Back pain is a widespread problem in the military population; therefore, there is a need to capture objective data pertaining to sources of injury.

2.2. Injuries in the Military

2.2.1. Relationship between Fitness and Injuries

Musculoskeletal injuries are prevalent in military personnel. Many factors have been assessed in an attempt to determine the primary risk factors for injuries. As a result of numerous investigations, researchers have determined that low physical fitness is associated with greater risk for sustaining a musculoskeletal injury in soldiers.[14–21] As of 2020, the Army was using a standardized assessment known as the Army Physical Fitness Test (APFT) to determine the fitness of soldiers and the effectiveness of the prescribed training. The APFT is an assessment used to evaluate effectiveness of the physical readiness training (PRT) program, which is designed to ensure soldiers' fitness levels are maintained regardless of duty assignment.[26] The APFT provides a measure of upper and lower body muscular endurance using the soldier's own body weight, and the scoring is normalized to account for age and gender differences. The APFT consists of three physical tests including two minutes of push-ups, two minutes of sit-ups, and a two-mile run, which are completed in that order on the same day. Soldiers are given a minimum of ten minutes and maximum of twenty minutes rest between events, and all three events must be finished within two hours. The APFT is scored out of 300; soldiers must score a minimum of 60 points on each event, which equates to an overall score of 180 to achieve a rating of pass.[26]

While the Army has utilized the APFT as the standard fitness measure for many years, they are currently in the process of transitioning to a new test, the Army Combat Fitness Test (ACFT). The ACFT consists of six events and provides a more practical assessment of soldiers' fitness. The components of the ACFT include a three repetition maximum deadlift, standing power throw, hand release push-up, sprint-drag-carry, leg tuck, and two-mile run.[27] Since the implementation of the ACFT is not yet complete, there is currently no data pertaining to this new test. Thus, this review focuses on performance on the APFT, or a modified version of the test, to assess injury risk in soldiers based on their overall fitness level.

2.2.1.1. 2-2-2 Test (Standard APFT)

The standard APFT was used in two studies by Knapik et al.[20,21] to investigate the association between fitness levels and risk of injury in soldiers. In the initial study, subjects completed the APFT to assess physical fitness, and injury data were obtained retrospectively via review of medical records over a six-month period prior to the administration of the APFT.[20]

Medical records were reviewed for 298 soldiers, and the researchers found soldiers who were in the lowest quartile for sit-ups resulted in a 1.9 fold increased risk of sustaining an injury when compared to individuals who scored in the highest quartile.[20] The slowest quartile in running times were 1.6 times more likely to be injured than those in the fastest quartile, but no association was found between injury occurrence and push-ups.[20] In a related portion of results, the researchers analyzed the distribution of injuries by body part and age. They discovered that the greatest number of injuries involved the feet (16.1%), followed by ankles (13.2%), and knees (11.8%); overall, lower extremity and low back injuries accounted for 65% of all documented injuries. [20] In order to evaluate the distribution of injuries by age, the subjects were divided into three age groups (<20 years, 20-24 years, >24 years). The researchers determined there was no difference in incidence of musculoskeletal injury between the three age groups (p=.24); however, the proportion of soldiers injured tended to decrease with age (linear trend, p=.09).[20]

In a later study, Knapik et al.[21] confirmed their original findings related to muscular and aerobic endurance. Methods for this study included administration of the APFT, physiological testing, completion of a questionnaire, and examination of medical records for data related to injuries as well as gender, age, stature, and body mass. The initial sample for this study consisted of 756 men and 452 women participating in basic combat training (BCT). However, due to several limitations only 182 men and 168 women underwent physiological tests whereas 225 men and 186 women were administered questionnaires. [21] The researchers found fewer sit-ups were associated with an increased injury risk in men. Additionally, they found lower numbers of push-ups and slower run times were associated with an increased injury risk in both men and women (Table 1).[21] Slower run times have consistently been associated with increased injury risk, but the finding that fewer push-ups was associated with an increased injury risk differs from outcomes of the previous study.

Table 1. Relative risk of time-loss injury among the physical characteristics and APFT measures[a]

Variable	**Variable Ranges (men)**	**Relative Risk (men)**	**p-value (men)**	**Variable Ranges (women)**	**Relative Risk (women)**	**p-value (women)**
Push-ups	0-22	1.8(1.2-2.8)	<0.01	0-2	1.6(1.1-2.5)	0.02
	23-31	1.8(1.2-2.8)	<0.01	3-5	1.6(1.1-2.3)	0.02
	32-41	1.3(0.8-2.1)	0.23	6-13	1.6(1.1-2.4)	0.02
	42-86	1.0	--	14-50	1.0	--
Sit-ups	0-31	1.6(1.0-2.4)	0.03	0-22	1.3(0.9-2.0)	0.14
	32-41	1.4(0.9-2.1)	0.14	23-33	1.2(0.8-1.8)	0.29
	42-48	1.2(0.8-1.8)	0.43	34-44	1.1(0.7-1.6)	0.66
	49-85	1.0	--	45-80	1.0	--
2-mile run	10.38-15.40	1.0	--	13.00-19.48	1.0	--
	15.41-17.14	1.2(0.8-1.9)	0.32	19.49-21.65	1.5(1.0-2.3)	0.06
	17.15-19.20	1.4(0.9-2.0)	0.08	21.66-23.48	1.6(1.0-2.3)	0.04
	19.21-31.58	1.6(1.0-2.4)	0.04	23.49-28.68	1.9(1.2-2.8)	<0.01

[a]adapted from Knapik et al.[21]

In contrast to their original study, the researchers incorporated VO_{2max} and flexibility and found that lower peak VO_2 was associated with higher injury risk in men and women. Lower levels of muscular endurance were associated with increased injury risk in both men and women.[21] Based on flexibility testing, which consisted of the sit-and-reach test as a measure of hamstring flexibility, men with the greatest and least amounts of flexibility were at greater risk of injury than those in the middle, but no association was found with women.[21] Based on these findings it can be concluded that APFT scores are not the only indicator of injury risk, as many other aspects of physical fitness (e.g. flexibility, VO_2, and BMI) can be suggestive of injury risk as well.

In addition to the information acquired from the APFT, the researchers collected data on functional movements, including muscle strength measured by dynamic lifting with the incremental dynamic lifting device and a one-repetition maximum. Furthermore, isometric strength was measured using a seated arm and shoulder pull, a seated leg press, and a standing upright pull involving the legs and back. Leg power was measured using a vertical jump test. As depicted in Table 2, no correlation was found between dynamic strength, isometric strength, or leg power and injury.[21] The researchers also investigated the relationship between gender, age, and body composition measured by Dual-energy X-ray absorptiometry (DEXA) and injury risk. The researchers concluded women had over two times the injury rate of men, and there were significant gender differences (p<.01) for all variables except age. Body fat was only weakly associated with injury; these data are also presented in Table 2.[21]

Table 2. Descriptive statistics for physiological measures[a]

Variable	**N (men)**	**Mean (men)**	**SD (men)**	**N (women)**	**Mean (women)**	**SD (women)**
Incremental dynamic lift strength (kg)	170	76.8	15.7	166	40.4	10.7
Upper body static strength (kg)	170	113.4	17.5	165	65.3	11.9
Lower body static strength (kg)	137	159.9	42.6	143	97.6	25.0
Upright pull static strength (kg)	170	133.4	24.5	166	81.6	18.2
Vertical jump (cm)	170	51.4	8.2	166	33.1	6.1
Flexibility (cm)	169	30.3	8.2	166	34.6	8.9
Body fat (%)	169	16.7	6.3	166	28.8	6.5
Bone mineral density ($gm \cdot m^{-2}$)	169	1.288	0.101	166	1.204	0.086

[a]adapted from Knapik et al.[21]

Another component to this study was administration of a questionnaire addressing cigarette smoking habits and past physical activity of participants. Based on the survey researchers found smoking was an independent injury risk factor for both men and women. For men only, low physical activity prior to entry into the Army was associated with injuries (Table 3).[21] The lack of association between strength and power with injury suggests muscular and aerobic endurance is a stronger indicator of injury risk than muscle strength; moreover, the association between lifestyle characteristics (smoking and exercise levels) prior to entry into the Army show the importance of good general health and fitness practices on decreasing injury risk.

Table 3. Relative risk of injury among lifestyle characteristics[a]

Variable	Variable Ranges or Categories	N (men)	Relative Risk (95% CI) (men)	P-Value (men)	N (women)	Relative Risk (95% CI) (women)	P-Value (women)
Cigarette Smoking	Never	116	1.0	--	97	1.0	--
	Quit	59	0.7(0.3-1.7)	0.23	39	1.6(0.9-2.6)	0.09
	<11 cig/day	14	1.6(0.7-3.9)	0.27	21	1.7(0.8-3.3)	0.14
	11-20 cig/day	19	2.0(0.9-4.1)	0.07	21	1.8(0.9-3.5)	0.08
	>20 cig/day	17	2.8(1.4-5.6)	<0.01	7	4.4(1.9-10.0)	<0.01
Physical Activity	Less active	58	1.7(1.0-2.9)	0.07	56	0.7(0.4-1.2)	0.18
	Average	61	1.0(0.6-1.9)	0.96	54	1.0(0.6-1.6)	0.92
	More active	103	1.0	--	74	1.0	--

[a]adapted from Knapik et al.[21]

The final component examined in this study was the location of injury. The most common injury sites for men and women were similar with lower extremity and low back injuries accounting for 83% of injuries in males and 78% of injuries in females.[21] For male subjects, total injury incidence was 31% with overuse injuries accounting for 75% of injuries. In female subjects, the total injury incidence was 58% with 78% of injuries being overuse.[21] These results are consistent with the findings of Knapik's first study, indicating lower extremity and low back injuries are the most prevalent among this population.

The finding that APFT scores can predict a soldier's risk of sustaining a musculoskeletal injury is further supported by a study by Jones et al.[16] who reported those who did the least amount of push-ups were at a notably greater risk of injury than those who could do more. As evidenced by Table 4, the researchers also found the fastest quintile on the two-mile run was at lower risk than each successive slower group.[16] Furthermore, a U-shaped relationship was found between flexibility and injury incidence. Similar to the findings of Knapik et al.,[21] the researchers in this study reported that individuals at each extreme of flexibility were at more than two times greater risk of injury than those in the middle group.[16]

Table 4. Levels of physical fitness on entry to the Army with associated incidence and relative risk of lower extremity injuries during training and 95% confidence intervals[a]

Fitness Measure	(min-max)	Injury Incidence (%)	Relative Risk
Flexibility (cm)			
Q1 Low	(-23 to -4)	49.2	2.5 (1.5, 4.2)
Q2	(-4 to 1)	38.3	1.9 (1.1, 3.4)
Q3	(1 to 7)	20.0	1.0
Q4	(7 to 13)	33.3	1.7 (0.9, 3.1)
Q5 High	(13 to 24)	43.6	2.2 (1.3, 3.8)
Push-ups			
Q1 Highest 20%	(35-57)	18.5	1.0
Q2	(30-34)	46.5	2.5 (1.1, 5.7)
Q3 Mid	(25-29)	33.3	1.8 (0.7, 4.5)
Q4	(17-24)	58.3	3.2 (1.5, 6.8)
Q5 Lowest 20%	(1-16)	50.0	2.0 (1.2, 6.0)
2-mile run			
Q1 Fastest 20%	(11.9-13.8)	25.9	1.0
Q2	(13.9-14.8)	34.6	1.3 (0.6, 2.0)
Q3 Mid	(14.9-15.6)	42.9	1.7 (0.8, 3.5)
Q4	(15.7-17.0)	55.5	2.1 (1.1, 4.2)
Q5 Slowest 20%	(17.1-22.3)	40.7	1.6 (0.7, 3.4)

Abbreviations: Q1, first quintile; Q2, second quintile; Q3, third quintile; Q4, fourth quintile; Q5, fifth quintile
[a]adapted from Jones et al.[16]

To give further details related to the results reported by Jones et al.,[16] the researchers evaluated the training of different units and selected two units to assess based on the amount of emphasis placed on running within the unit. One unit was selected due to a heavy emphasis on running and marching, and the other unit was selected because it deemphasized running and marching as part of the training program. Aside from the amount of running and marching completed, the training among the two units was essentially identical.[16] The researchers in this study only evaluated the incidence of lower extremity injuries and found that the unit that heavily emphasized running had an injury incidence of 41.8% compared to the lower mileage unit at 32.5% (RR=1.3, 95% CI: 1.0-1.7). The total injury incidence of subjects with at least one lower extremity musculoskeletal injury was 45.9%. Of injured individuals, 28.4% experienced an injury that was overuse in nature.[16]

A history of ankle sprains was also identified as a significant indicator of risk for sustaining a secondary lower extremity injury during Army training (45.1% vs 32.1%, RR =

1.37, 95% CI: 1.03-1.84, p=.05).[16] The researchers noted that while ankle sprains were an indicator of increased risk of sustaining an injury, other past injuries were not associated with increased risk of new injury. Additionally, the researchers found age was a significant factor (p=.01) in injury risk; older soldiers (>24 years) were at greater risk of injury than younger soldiers (<19 years). There was no association identified between body fat percentage and injury risk.[16] Data were collected investigating the past activity levels of the subjects, and the researchers found trainees who identified themselves as being less active than average or who exercised less were at higher risk of injury than those who rated themselves more active. The strongest identified relationship was between lower running frequency and higher incidence of injury; these data are presented in Table 5.[16] These results indicate training prior to entry into the Army is an important part of injury prevention. The focus of the APFT is to assess the muscular and cardiovascular endurance of soldiers[26]; the finding that both of those factors are significant predictors of musculoskeletal injury risk supports use of the APFT as a tool for screening soldiers for risk of sustaining an injury.

Table 5. Physical activity and exercise prior to the Army with associated incidence and relative risks (RR) of lower extremity injuries during training with 95% confidence intervals (CI)[a]

	N	**Injury Incidence (%)**	**RR**	**(95% CI)**
Past activity				
Active	183	28.9	1.0	
Average	89	50.6	1.8	(1.3, 2.4) ($P \le 0.05$)
Inactive	30	46.7	1.6	(1.0, 2.5) ($P \le 0.05$)
Running frequency in previous month				
$\ge 4d \cdot wk^{-1}$	45	20.0	1.0	
$1\text{-}3d \cdot wk^{-1}$	149	37.6	1.9	(1.0, 3.5) ($P \le 0.05$)
$0\text{-}<1d \cdot wk^{-1}$	108	43.5	2.2	(1.2, 4.1) ($P \le 0.05$)
Exercise frequency in previous month (other than running)				
$\ge 4d \cdot wk^{-1}$	85	29.4	1.0	
$1\text{-}3d \cdot wk^{-1}$	150	38.0	1.3	(0.9, 1.9)
$0\text{-}<1d \cdot wk^{-1}$	68	44.1	1.5	(1.0, 2.3)

[a]adapted from Jones et al.[16]

Risk factors for injuries in soldiers in Army Ordnance Advanced Individual Training (AIT) were investigated in a study utilizing APFT scores, questionnaires, and injury data obtained from an injury surveillance system. This study is unique compared to the previously discussed studies because AIT occurs after basic combat training (BCT). Therefore, they were more trained than the BCT trainees in the previous studies. Participants included 3,757 men and 498 women in AIT. Based on a questionnaire completed by the trainees, the researchers found women were 2.3 times ($p<.01$) more likely to report having a current injury, which they perceived to negatively affect their performance in AIT than men.[14] Incidence of time-loss injuries were assessed and rates for men were 34.9/10,000 person-days and rates for women were 60.8/10,000 person-days ($p<.01$).[14] Total incidence of time-loss injury was 31% for men and 54% for women ($p<.01$). However, when accounting for both time-loss injuries and injuries not involving time-loss, 36% of men and 61% of women suffered at least one injury ($p<.01$). [14] These conclusions indicate that a greater percentage of women experience injuries compared to men, and this is supported by Knapik et al.[21] who reported women had over two times the injury rate of men in BCT.

Injury risk factors for males included lower military rank, self-reported injury, smoking, smokeless tobacco use, lower push-up performance, lower sit-up performance and slower two-mile run time (Table 6).[14] Moreover, self-reported injury, smoking, fewer repetitions of sit-ups, and slower two-mile run times were independently associated with higher risk of time-loss injury.[14] The findings related to performance on sit-ups and the two-mile run as injury risk factors are supported by previously discussed literature. Knapik et al.[20] reported those in the lowest quartile for sit-ups had a 1.9 fold increased risk of sustaining an injury when compared to individuals who scored in the highest quartile, and trainees in the slowest quartile in running times were 1.6 times more likely to be injured than those in the fastest quartile.

Injury risk factors for women included self-reported injury, smokeless tobacco use, lower push-up performance, and slower two-mile run times (Table 7).[14] This is comparable with the second study performed by Knapik et al.[21] where it was reported that they found lower numbers of push-ups was associated with an increased injury risk in both men and women. However, in the initial study by Knapik et al.,[20] the researchers reported no association between push-ups and injury risk. Along with these factors, self-reported injury and slower run times were independently associated with higher risk of time-loss injury.[14] For women, relative risk for time-loss injuries was 1.74 times greater than for men.[14] A previously discussed study utilizing a BCT population reported women had over twice the injury rate of men,[21] which corresponds with the results reported in this study. Based on these results, tests of aerobic and muscular endurance are a reliable method for identifying individuals at increased risk of injury.

Table 6. Risk Factors for Men Associated with Time-Loss Injuries (TLI) in Ordnance AIT[a]

Variable	Variable Level	*N* (% TLI)	HR (95% CI)	p-value
Rank	Private 1	2135 (32)	1.00	
	Private 2	911 (28)	0.87 (0.75-1.00)	0.05
	Private First Class	640 (29)	0.92 (0.78-1.08)	0.31
	Corporal/Specialist	71 (31)	0.92 (0.60-1.41)	0.69
Self-Reported Injury	No	3524 (30)	1.00	
	Yes	233 (51)	2.27 (1.88-2.75)	< 0.01
Smoking	Nonsmoker	2166 (26)	1.00	
	Occasional	201 (31)	1.19 (0.92-1.55)	0.19
	Frequent	1390 (38)	1.56 (1.38-1.75)	< 0.01
Smokeless Tobacco	Nonuser	3158 (30)	1.00	
	Occasional	171 (34)	1.13 (0.86-1.47)	0.38
	Frequent	428 (37)	1.31 (1.11-1.55)	< 0.01
Push-Ups (repetitions)	0-43	963 (38)	1.63 (1.38-1.93)	< 0.01
	44-50	967 (32)	1.38 (1.16-1.64)	< 0.01
	50-59	915 (29)	1.22 (1.02-1.46)	0.03
	60+	912 (24)	1.00	
Sit-Ups (repetitions)	0-55	962 (34)	1.47 (1.24-1.75)	< 0.01
	56-61	930 (34)	1.51 (1.27-1.80)	< 0.01
	62-68	972 (31)	1.34 (1.12-1.59)	< 0.01
	69+	893 (24)	1.00	
2-Mile Run (minutes)	0-13.91	921 (26)	1.00	
	13.92-14.77	979 (27)	1.02 (0.86-1.22)	0.80
	14.78-15.62	936 (31)	1.23 (1.03-1.46)	0.02
	15.63+	921 (40)	1.64 (1.39-1.93)	< 0.01

[a]adapted from Grier et al.[14]

Table 7. Risk Factors for Women Associated with Time-Loss Injuries (TLI) in Ordnance AIT[a]

Variable	Variable Level	*N* (% TLI)	HR (95% CI)	*P* Value
Self-Reported Injury	No	431 (52)	1.00	
	Yes	67 (66)	1.67 (1.21-2.30)	< 0.01
Smokeless Tobacco	Nonuser	481 (54)	1.00	
	Occasional	8 (75)	2.18 (0.97-4.90)	0.06
	Frequent	9 (67)	1.51 (0.67-3.38)	0.32
Push-Ups (repetitions)	0-23	132 (60)	1.47 (1.03-2.09)	0.03
	24-30	149 (58)	1.44 (1.02-2.04)	0.04
	31-36	106 (49)	1.04 (0.71-1.53)	0.84
	37+	111 (47)	1.00	
2-Mile Run (minutes)	0-17.00	126 (42)	1.00	
	17.01-18.08	124 (56)	1.46 (1.02-2.08)	0.04
	18.09-19.38	122 (51)	1.27 (0.88-1.83)	0.21
	19.39+	126 (68)	2.04 (1.45-2.88)	<0.01

[a]adapted from Grier et al.[14]

Many of the tasks completed in BCT and AIT require muscular endurance; consequently, trainees who performed fewer push-ups and sit-ups on the APFT were at greater risk of injury due to lower levels of muscular endurance putting them at greater risk of early fatigue and, therefore, heavier reliance on other muscles. Those with slower run times are likely to fatigue more quickly because they are exercising at a higher percentage of their aerobic capacity than those who performed better on the two-mile run, thereby placing them at higher risk of energy due to earlier onset of fatigue. Another factor that may have contributed to injury rates is the soldiers had just completed BCT and may have had injuries from BCT that carried over to AIT.[14]

A retrospective cohort study analyzed 184,670 Army trainees (143,398 men and 41,272 women) to determine the collective effects of physical fitness and body composition on risk of sustaining a musculoskeletal injury.[19] The researchers evaluated the relationship between age, gender, height, weight, APFT scores, and injuries reported during the 10 week BCT cycle. Injury risk was calculated as the number of trainees with at least one injury during the training cycle divided by the number of trainees in a particular group. Overall, compared to men, women had lower fitness levels measured by the APFT, lower BMI's, and were 2.6 times more likely to sustain an injury.[19]

The researchers grouped men and women into quintiles for two-mile run times and BMI to investigate the relationship between run times, BMI, and injury risk. When men were evaluated, the researchers reported that as run times slowed, the risk of injury progressively increased from 9.8% to 24.3%.[19] The relationship identified between BMI and injury risk was a slightly bimodal curve, where the smallest risk was in the middle quintile (BMIQ3) and highest risk was at each extreme (BMIQ1 and BMIQ5). The lowest risk of injury (8.5%) was found in the group with fastest run quintile and middle BMI quintile (RUNQ5-BMIQ3). The highest risk of injury (26.6%) was identified in the group with the slowest run times and lowest BMI (RUNQ5-BMIQ1), a risk 3.1 times greater than the lowest risk group (95% CI: 2.8-3.4).[19]

Women were evaluated in quintiles just as the men, and results were similar. As run times slowed, injury risk increased from 26.5% to 56%.[19] The relationship between injury risk and BMI was also a bimodal curve with the lowest risk in the middle quintiles of BMI (BMIQ2 and BMIQ3). Similar to the findings of the male trainees, both extremes of BMI (BMIQ1 and BMIQ5) displayed the greatest risk of musculoskeletal injury. Also for women, the lowest injury risk (24.6%) was in the group with the fastest run time quintile and middle BMI quintile (RUNQ1-BMIQ3). The highest injury risk (63.1%) was identified in the group with the slowest run times and lowest BMI (RUNQ5-BMIQ1), a risk 2.6 times greater than the lowest risk group (95% CI: 2.3-2.8, p<.00001).[19] The finding that the slowest group for run time is at the greatest risk for sustaining an injury is consistent with the findings of Knapik et al.[20] who reported the slowest quartile in running times were 1.6 times more likely to be injured than those in the fastest quartile. Additionally, Jones et al.[16] reported the fastest quintile on the two-mile run was at lower risk of injury than each successive slower group. Among both male and female trainees, the greatest injury risk across run time groups was found in those with the lowest BMI, while those with the highest BMI displayed some of the lowest injury risk.[19] In previous studies, BMI and aerobic fitness have not been examined collectively; however, aerobic fitness has been consistently correlated with injury risk among Army trainees.[14,16,20,21]

Associations between muscular endurance and injury risk were evaluated based on the push-up and sit-up components of the APFT, however, only statistics on the relationship between injury risk and push-up performance were reported.[19] As push-up performance increased, risk of sustaining a musculoskeletal injury decreased progressively for each quintile. For male trainees, injury risk decreased from 20.9% to 12.4% (RR = 1.7, 95% CI: 1.6-1.7, p<.0001). For female trainees, injury risk decreased from 48.8% to 31.6% (RR = 1.5, 95% CI: 1.49-1.61, p<.00001).[19] Comparable to these findings, a previously discussed study by Jones et al.[16] reported those who did the least amount of push-ups were at a notably greater risk of injury than those who could do more; however, Knapik et al.[20] reported no association was between injury occurrence and push-ups. Similar to the findings associated with aerobic fitness, the lowest risk was found among trainees with average BMI (BMIQ3) who performed the greatest number of push-ups (male trainees = 11.2%, female trainees = 29.2%).[19] For male trainees, those in the highest BMI quintile who performed the lowest number of push-ups were at the greatest risk (22.7%) of sustaining a musculoskeletal injury (RR = 2.0, 95% CI: 1.9-2.2).[19] This finding differs from the results associated with aerobic fitness and BMI, where trainees in the lowest quintile of BMI were at greatest risk of injury. For female trainees, the findings associated with muscular endurance were more aligned with those of aerobic endurance. Trainees in the lowest two quintiles for BMI who did the fewest number of push-ups were at the highest risk (50%) of sustaining an injury (RR = 1.7, 95% CI: 1.6-1.9).[19] Based on the literature surrounding muscular endurance as a measure of injury risk, it can be concluded that muscular endurance is not as strong of an indicator for determining musculoskeletal injury risk as aerobic fitness.

2.2.1.2. 2-2-1 Test

Another test has been used to evaluate the relationship between fitness levels and injuries in soldiers called the 2-2-1 test. This test is similar to the standard APFT, however, it modifies the run distance. This test consists of two-minutes of sit-ups, two-minutes of push-ups, and a one-mile run.

A study was conducted with BCT trainees completing the 2-2-1 test to evaluate if risk of injury correlated with overall performance. Researchers collected data on height, weight, and body fat percentage to evaluate the influence demographic elements had on injury incidence.[15] Medical records were then reviewed for the training period to assess injury occurrence. As detailed in Table 8, the researchers found slow run time increased the risk of injury; the slower runners were at greater risk for injury than their faster counterparts of the same gender.[15] Along with slower run times being an injury risk, men with lower scores on push-ups were at greater risk of injury. There was no association between injuries and push-ups for women.[15] On the sit-up portion of the assessment, researchers found no association between sit-ups and injury for men or women; these outcomes are displayed in Table 9. Furthermore, the researchers discovered those with the highest and lowest body mass index (BMI) had greater risk of injury than those in the middle group.[15]

Another aspect of injury risk was the difference in injury rates between men and women and the location of injuries. The researchers found significantly more women (p=.00001) reported musculoskeletal injuries than men.[15] The majority of injuries reported in this study for both men (77%) and women (88%) involved the lower extremity.[15] The researchers also found women were at a significantly (p=.002) greater risk of stress fractures than men; specifically, 2.4% and 12.3% of injuries were stress fractures in males and females, respectively.[15] The researchers in these studies and the preceding have consistently reported a larger proportion of injuries involving the lower extremities and low back as well as a higher rate of injuries among females compared to males.

Table 8. Incidence of time-loss injuries by quartile of measures of physical fitness level[a]

Push-ups	**N (men)**	**Incidence (%) (men)**	**N (women)**	**Incidence (%) (women)**
Q4 High	22	4.5	32	28.1
Q3	24	25.0	33	33.3
Q2	27	22.2	36	38.9
Q1 Low	24	20.8	37	24.3
Run time				
Q1 Fast	21	0.0	36	19.4
Q2	20	0.0	36	16.7
Q3	19	21.1	35	40.0
Q4 Slow	19	36.8	33	36.4

[a]adapted from Jones et al.[15]

Table 9. Incidence of time-loss injuries by quartile of measures of body stature[a]

BMI	**N (Men)**	**Incidence (%) (men)**	**N (women)**	**Incidence (%) (women)**
Q1 Low	31	25.8	45	35.6
Q2	32	9.4	48	29.2
Q3	29	13.8	47	23.4
Q4 High	31	32.3	46	37.0

[a]adapted from Jones et al.[15]

The previous studies show strong, consistent relationships between aerobic fitness and injury risk. These studies also present information about the most common injury locations and gender differences. Soldiers with poor aerobic fitness utilize a greater percentage of their maximal aerobic capacity than soldiers with higher aerobic capacity; therefore, they fatigue more quickly. Fatigue may result in compensations, which place increased musculoskeletal stress on different areas of the body resulting in injury. Women tend to have more injuries than men that could be attributed to the fact that men and women preform the same activities in basic training, which results in a greater relative activity intensity for women due to the lower average physical capacity of women compared to men.[21] In both studies, the researchers analyzed the association between run times and injury risk and found it was a consistent indicator for risk of sustaining a musculoskeletal injury.

2.2.1.3. 1-1-1 Test

The 1-1-1 test is another assessment that has been utilized to evaluate fitness of soldiers. This test includes one-minute of push-ups, one-minute of sit-ups, and a one-mile run. This modified version of the APFT has been utilized to assess fitness upon initial entry of soldiers to predict risk of sustaining a musculoskeletal injury.

In a study by Sefton et al.,[18] soldiers were monitored for the duration of their basic combat training cycle and musculoskeletal injury incidents were acquired from the Warrior Athletic Training Program musculoskeletal injury tracking database, which is a part of the

Armies electronic medical record system.[18] Using this assessment, researchers were able to predict if a soldier was likely to sustain an injury, as well as whether the injury was likely to be acute or chronic in nature. Additionally, they used the results to create a FitSum score, which is the combined number of push-ups and sit-ups. The FitSum score was used in conjunction with run time and age to create an equation, which predicted the risk of musculoskeletal injury in a specific soldier.[18]

One mile run times were positively associated with both overuse and acute injuries. A one-point increase in the natural logarithm of run times indicated nearly a 300% increase in the chances of sustaining an acute injury and approximately a 700% increase in the chances of sustaining an overuse injury.[18] FitSum score was not associated with overuse injuries, but higher FitSum scores indicated decreased likelihood of an acute injury. The lowest executing quartiles for each assessment (zero to 19 push-ups, zero to 26 sit-ups, and run times longer than 504 seconds) had higher incidences of acute and overuse musculoskeletal injuries.[18] The researchers discovered for every one-point increase in FitSum score, the chances of sustaining an acute injury decreased by approximately one percent. When controlling for program of instruction, one-mile run times predicted both overuse and acute injuries, while push-up and sit-up scores only predicted acute injuries.[18] These results indicate the 1-1-1 assessment can be a valuable tool in evaluating the injury risk of soldiers. In addition, the results compliment the conclusions made by previous researchers, which indicated run time was the greatest predictor of injury risk in soldiers.

Similar to the aforementioned study, Knapik et al.[32] conducted a study utilizing the 1-1-1 fitness test. The purpose of this study was to evaluate the effectiveness of a preconditioning program prior to entering BCT for those with lower incoming fitness levels. The researchers investigated the effect of preconditioning on injury incidence and attrition. In this study, the Army recruits completed the 1-1-1 fitness test immediately upon arrival at basic training and based on the results were divided into three groups.[32] The first group was comprised of recruits who failed the fitness test and were placed in a fitness assessment program (FAP). The FAP provided recruits with a training program to complete until they were able to pass the test and thus begin basic training. This group of recruits was called the preconditioning group (PC). The second group was recruits who also did not pass the fitness test but were allowed to enter basic training without any additional conditioning; this group was called the no preconditioning group (NPC).[32] The final group included those who passed the fitness assessment and, therefore, went directly into basic training. This group was given the title no need of preconditioning group (NNPC). The basic training cycle was nine-weeks in duration and at week seven, the recruits completed the standard APFT. At the end of the nine week basic training cycle, more recruits from the PC and NNPC groups had completed training (lower rates of attrition) and passed the APFT than those in the NPC group.[32] The researchers reported in the PC group, 83% of males and 69% of females completed the training cycle ($p<.01$) and 92% of males and females passed the final APFT ($p<.01$). In the NNPC group, 87% of males and 78% of females completed the training cycle ($p<.01$), and 98% of males and 97% of females passed the final APFT ($p<.01$).[32]

When evaluating injury risk, men in the PC group had 1.5 times greater risk of injury compared to those in the NNPC group (95% CI, 1.0-2.2).[32] Men in the NPC group were at 1.7 times greater risk than those in the NNPC group (95% CI, 1.0-3.1). Female recruits in the PC group were at 1.2 times greater risk for injury than those in the NNPC group (95% CI, 0.9-1.6), and those in the NPC group were at 1.5 times greater risk for injury compared to the NNPC group (95% CI, 1.1-2.1).[32] These results suggest completion of a preconditioning program for incoming recruits who are less fit could decrease rates of attrition as well as incidence of injury among Army recruits in basic combat training.

2.2.1.4. ARMS Test

The Assessment of Recruit Motivation and Strength (ARMS) study was created to identify recruits who lack the physical fitness and/or motivation needed to successfully complete BCT.[33] The study utilized a pre-accession fitness test including two pass/fail components, a modified Harvard step test and one minute of push-ups. The step test portion of the ARMS test is scored based on the amount of time the recruit is able to sustain the test, up to five minutes, and the recovery heart rate. The subjects step onto a 16 inch step for males and a 12 inch step for females, at a pace of 120 beats per minute controlled by a metronome.[33] One step is defined as the complete cycle of stepping up and down, which makes 120 beats per minute equivalent to 30 steps per minute. The subject completes the test for a maximum of five minutes or until they are unable to continue at the set pace. The subject was considered to have passed the step test if they completed the full five minute period at the correct pace.[33] The push-up portion of the test involves completing as many push-ups as possible in one minute. Male trainees were considered to have passed if they completed at least 15 push-ups, whereas female trainees were considered to have passed if they completed at least four push-ups.[33] A portion of the assessment utilized in the ARMS study has been used as a means to identify trainees who are at a potentially greater risk of injury.

Similar to the study by Knapik et al.[32] that implemented a pre-accession fitness test to categorize trainees and implement a training program, Bedno et al.[17] conducted a prospective study using a pre-accession physical fitness test to evaluate the impact of incoming fitness levels on injury risk in Army BCT trainees. Subjects in this study included 8,456 male Army trainees who completed the pre-accession fitness test, females were not included. Passing was defined as completing the full five-minute test.[17] The researchers found those who failed the test were 31% more likely to be injured compared to those who passed (adjusted hazard ratio (HR): 1.31, CI 95%1.20-1.43).[17] The finding that passing a pre-accession fitness test can indicate injury risk relates to the findings of Knapik et al.[32] that trainees in the PC group had fewer injuries than those in the NPC group**.** Bedno et al.[17] also noted an association between BMI and injury risk based on the fitness test. Trainees classified as underweight had 32% greater risk than those classified as normal (HR: 1.31, CI 95% 1.01-1.61). Trainees classified as overweight (HR: 0.98, CI 95% 0.89-1.07) and obese (HR: 1.12, CI 95% 0.99-1.26) were also at greater risk than trainees classified as normal BMI.[17] This is in agreement with the findings of Jones et al.[15] who reported that those with the highest and lowest BMI were at greater risk of injury compared to those in the middle group. Akin to the findings of Jones et al.,[16] assessment of injury risk based on age revealed older trainees were at greater risk for injury compared to their younger counterparts. Specifically, trainees 20-24 years were at 25% greater risk of injury than those 18-19 years old (HR: 1.25, CI 95% 1.14-1.36), and trainees 25 and older were at 63% increased risk of injury (HR: 1.63, CI 95% 1.44-1.83).[17] The final injury factor investigated in this study was the effect of smoking on injury risk. The researchers reported trainees who were current or former smokers were at 27% greater risk of injury (HR: 1.27, CI 95% 1.16-1.38) compared to those who never smoked.[17] Previously mentioned studies by Knapik and Grier had similar findings that those who smoked were at increased risk of injury compared to those who did not.[14,21] The findings in this study related to injury risk are aligned with the most recent results reported in the literature that lower fitness levels increase injury risk in Army BCT trainees.

Another component examined in this study was the incidence of types and locations of injury occurrence related to passing/failing the fitness test.[17] Trainees who failed the fitness test were at increased risk of sprains/strains (HR=1.32, CI 95%1.15-1.52), arthropathy (HR=1.62, CI 95% 1.22-2.15), and bone stress injuries (HR=1.60, CI 95% 1.14-2.24) than those who passed. Incidence of injuries to the foot/ankle (HR=1.37, CI 95% 1.19-1.57), lower leg (HR=1.20, CI 95% 1.04-1.39), back (HR=1.43, CI 95% 1.19-1.72), knee (HR=1.22, CI 95% 1.01-1.47), and thigh/pelvis (HR=1.46, CI 95% 1.13-1.89) were greater in those who failed the fitness test compared to those who passed.[17] Therefore, it can be concluded that trainees with lower fitness levels are at increased risk of overuse injuries and lower extremity injuries compared to there more physically fit peers.

The final component examined in this study was the impact of injury, age, and BMI on health care utilization.[17] The researchers reported trainees who failed the fitness test and had an overuse injury had 16% higher rates of health care utilization than those who passed the fitness test. They also noted health care utilization was elevated 14% among obese trainees who failed the fitness test compared to those who passed. Finally, health care utilization among those who failed the fitness assessment was increased 16% among the oldest age group compared to those who passed.[17] These findings suggest that less fit trainees are not only at greater risk of injury, but they utilize more healthcare resources than those who were more physically fit.

Similar to the 1-1-1 test, the ARMS test was found to be a successful method for determining injury risk in BCT trainees. This study did not utilize an intervention based on failing the pre-accession fitness test, but found those who failed were at increased risk of injury. The study completed by Knapik et al.[20] determined that a training intervention prior to entry into BCT was effective for reducing injury rick attrition. Using the ARMS test to identify individuals at greater risk of injury combined with a preconditioning opportunity for those individuals could be a successful method for reducing injury risk.

2.2.1.5. TMS Test

The global trunk muscle strength test (TMS) is a measure of the comprehensive muscular strength and endurance of the trunk, similar to the sit-up portion of the APFT.[34] The test involves holding a plank position while lifting the feet in an alternating fashion, according to the 1 Hz rhythm of a metronome.[34] The specific isometric position to be maintained in the test is described as a parallel forearm position, thumbs on top, legs elongated, posterior superior iliac spines in contact with the crossbar and elbows positioned below the shoulder joint. When the participant is no longer able to maintain the correct body position, the test is over and the time is recorded with an accuracy of one second.[34]

The TMS test has been used in conjunction with a one-minute sit-up test to determine whether the TMS test is an adequate alternative to the sit-up test in a military setting. The anticipated benefits of utilizing the TMS test over the traditional sit-up test is it places less stress on the lumbar spine and hip flexor muscles. Wunderlin et al.[34] conducted a study including 230 Swiss Army recruits who completed the two trunk performance tests and injury data were collected over a 13 week training cycle. The researchers compared the effectiveness of the TMS test and the sit-up test for predicting injuries; they reported the TMS test had significant discriminative power to predict total injuries ($p=.033$) and acute injuries ($p=.035$) but the sit-up test did not. Since this is the first study investigating use of the TMS test, further research is needed to determine the validity of the results regarding the TMS test compared to the sit-up test for predicting injuries. A previously described study by Sefton et al.[18] utilized a one-minute sit-up test and found the lowest executing quartile for sit-ups (zero to 26 sit-ups) had a higher incidence of acute and overuse musculoskeletal injuries, however, based on the findings of Wunderlin et al.,[34] the TMS test may be a stronger measure of injury risk. Few studies have used a one-minute sit-up test, so a comparison of the TMS to a two-minute sit-up assessment may provide more generalizable information since most of the existing literature uses the standard APFT, including a two-minute sit-up assessment.

As supported by the research, the standard APFT, as well as modified versions of the APFT, can be used as a tool for measuring injury risk in soldiers. In conjunction with the APFT, measures of body composition and flexibility can be helpful tools included in the risk assessment. The research has demonstrated that run times (aerobic fitness levels) are a strong and consistent measure of musculoskeletal injury risk in soldiers. However, there have been mixed results about the relationship between push-ups and injury risk as well as sit-ups and injury risk. The previously discussed studies utilizing the APFT also provide information related to gender differences and injury as well as nature and location of injury. When exercise practices prior to entry into the Army were evaluated, those who had completed exercise involving running prior to entering training had decreased injury incidence. This is consistent with the success of the PC approach leading to reduced injury rates. The APFT is a tool already in use by the Army for measuring physical fitness, making it an efficient way to monitor the injury risk in soldiers.

2.2.2. Injuries Associated with Load Carriage

Having an understanding of injuries commonly associated with load carriage is imperative for helping soldiers attain an adequate understanding of how to prevent, recognize, and treat injuries before they interfere with combat readiness. In a comprehensive evaluation of injuries occurring during a 20-kilometer road march with a 46-kilogram load, researchers took note of several commonly occurring pathologies.[31] To attain an accurate representation of injuries, both active and passive surveillance were used to collect data in a sample of 335 male soldiers. Passive surveillance included screening of medical records up to 12 days following the road march. Active surveillance involved a post-march examination of soldiers' feet for injuries such as blisters, contusions, and abrasions. To standardize the reporting of injuries, the researchers' defined an injury as any traumatic or overuse incident that occurred during the march or within 12 days after the road march took place.[31]

Overall, the researchers reported an injury incidence of 24%. It should be highlighted that all injuries involved the back and lower extremity.[31] The most common injuries were blisters (10%) and back pain (6%). During active surveillance, 69% of soldiers examined presented with at least one foot blister. Specific to back pain, 50% of soldiers who were unable to complete the road march were diagnosed with "back strains"; thus making back pain the most common reason soldiers could not continue marching. Following the road march, 13 soldiers were given limited duty profiles with the largest proportion of profiles resulting from blisters (Table 10). Although generally a minor condition, blisters have the potential to lead to musculoskeletal injuries as a result of altered movement patterns/compensation subsequent to pain experienced due to blisters. Based on these findings, it can be concluded that even a single, physically demanding road march can produce a high incidence of injuries, particularly involving the lower extremity and back.[31]

Table 10. Injuries resulting in limited duty profiles[a]

Type of Injury	**Soldiers (N)**	**Limited Duty Days (N)**
Foot blisters	7	18
Knee pain	2	14
Foot pain	2	6
Low back pain	1	3
Leg pain	1	3
Total	13	44

[a] adapted from Knapik et al.[31]

In an effort to determine the source of load carriage injuries in the Australian army, Orr et al.[2] conducted a retrospective review of reported injuries. The researchers examined the Australian Defense Force Occupational Health, Safety and Compensation Analysis and Reporting database. In total, 5,188 injuries were documented during the selected two-year time period.[2] Upon review of these injuries, 404 were found to be load carriage related, thereby representing 8% of the total injuries documented in this time frame.

When injury location was evaluated, researchers found the leading injury site was the back, which accounted for 23% of injuries.[2] Furthermore, 57% of back injuries specifically involved the lower back, thus low back injuries constituted 13% of all documented load carriage injuries. Following the back, the ankle, knee, and neck and shoulder, respectively, were the next leading injury sites.[2] Due to the documented impact of low back injuries on soldiers' ability to perform occupational tasks,[31] it is important to note potential causes of these injuries to gain information so prevention and early intervention plans can be implemented.

Table 11. Proportion of injuries based on aggregated injury sites and activity being conducted at time of injury

Injury site	Proportion of injuries (%)
Lower extremity	56
Back	26
Upper extremity	13
Pelvis	3
Head and abdomen	1
Upper torso	<1
Activity	**(%)**
Marching	62
Patrolling	13
Combat training	12
Physical training	6
Manual handling	5
Boarding a vehicle/walking	1
Other	1

As a whole, the findings of this study indicate load carriage is a considerable source of injuries in Army personnel.[2] More specifically, road marches are a major source of load carriage related injuries. Thus, it is likely that soldiers' physical training (PT) is not appropriately preparing them for these tasks. Based on these findings, PT activities should be reevaluated and adjusted to effectively prepare soldiers for the demands associated with long road marches with load carriage.

With a similar goal of investigating the most common injuries associated with occupational load carriage, researchers have conducted reviews of the literature to compile pertinent injury information.[1,35] Comparable to the studies described above,[2,31] the researchers indicated the lower extremity was the leading injury site and foot blisters are one of the most commonly occurring injuries associated with load carriage.[1,35] While blisters are often thought to be an insignificant issue, improper care for blisters can lead to infections, potentially resulting in more serious conditions such a cellulitis and sepsis.[1] Thus, it is imperative for soldiers to monitor foot blisters and be aware of the risks associated with improper care.

Stress fractures have been documented as another injury of concern related to load carriage, particularly stress fractures of the lower extremity.[1,35] Stress fractures result from repeated loading, which results in bone stress occurring faster than remodeling can take place.[35] Long road marches with heavy loads are a logical cause of this type of injury. Reports indicate the most common stress fracture locations in military personnel include the tibia, pelvis, calcaneus, and metatarsals with a higher rate of pelvic stress fractures in females.[35] As suggested by Orr[35] and Knapik,[21] the increased rate of pelvic stress fractures in females may be due to the greater relative work required for females to perform the same road marching activities as men.

The researchers also noted the knee, foot, and low back were common locations of pain associated with load carriage tasks. Incidence of knee pain vary between studies with some researchers reporting incidence less than 1%, while others have found rates upwards of 15%.[1] Based on the findings of their review, Orr et al.[35] indicated the occurrence of knee pain is likely the result of increased knee flexion that occurs during walking with an added load. Further, addition of a load results in greater force transmitted through the lower extremity, unsurprisingly resulting in knee pain/pathology.[35] Likewise, heavy loads change the mechanics of the foot during walking, thereby causing foot pathologies such as stress fractures, plantar fasciitis, digitalgia, and non-specific foot pain.

Similar to findings related to knee pain, back pain incidence varies between investigations. In the study detailed above by Knapik et al.,[31] back pain was the second leading cause of injury. Conversely, one investigation reviewed by Orr et al.[35] reported less than 1% of load carriage injuries involved the back. Researchers have suggested back injuries resulting from load carriage may be due to heavier loads causing changes in trunk angle, placing excess stress of the back muscles.[1] Another hypothesis is that heavier loads do not move synchronously with the trunk, thereby causing cyclic stress of spinal structures.[1] Due to inconsistent reports regarding injuries to the knees and back, more research is indicated to determine the incidence and optimal interventions to mitigate injury risk factors associated with load carriage.

While it is evident load carriage is a major source of injuries in Army personnel, less is known about the relative risks and patterns of injuries that occur in male compared to female soldiers. In an effort to determine possible differences, researchers conducted a retrospective cohort study including full-time Army personnel in the Australian Army over a two-year period.[36] Injuries reported as having occurred during a load carriage activity were extracted from all injuries reported during that time period. Additionally, severity of injuries were noted with serious personal injuries (SPI) defined as injuries requiring immediate medical care. To determine the incidence rate ratio (IRR) in females compared to males, a population estimate of the female: male IRR was calculated, keeping in mind the Australian Army population consists of approximately 90% males and 10% females.[36]

In total, 1,952 injuries were recorded during the two-year period, with 401 (20.5%) associated with load carriage.[36] Aligning with the female: male ratio, load carriage injuries, 90% of load carriage injuries were sustained by males, while 10% were sustained by females, resulting in an IRR of 1.02 (95% CI 0.74-1.41) for female soldiers compared to males. When mechanism of injury was assessed, road marching was the leading cause of load carriage related injuries for both sexes, followed by patrolling, combat training, and physical training (Table 12). Supporting previous reports, the most commonly injured body region was the back with most other injuries involving the lower extremity (Table 12).[36] Based on injury rates for the top five injury sites displayed in Table 12, IRR and 95% confidence intervals were calculated for female: male soldiers.[36] These values are displayed in Table 13.

Table 12. Leading injury sites and activities conducted at time of injury

Activity	**Female (%)**	**Male (%)**
Marching	69	59
Patrolling	10	13
Combat training	10	13
Physical training	8	5
Injury Site	**Female (%)**	**Male (%)**
Back	27	22
Foot	20	9
Neck & Shoulder	12	10
Knee	12	11
Ankle	10	17
Other	19	31

Table 13. IRR for female soldiers compared to male soldiers for five most common injury sites.

Injury site	IRR	95% CI
Back	1.26	0.67-2.37
Foot	2.37	1.09-5.15
Neck & Shoulder	1.24	0.49-3.16
Knee	1.15	0.45-2.91
Ankle	0.61	0.22-1.69

Abbreviations: incidence rate ratio, IRR; confidence interval, CI

As demonstrated by the IRR and associated confidence intervals, injury rates at each location were relatively similar with the exception of the foot.[36] The proportion of foot injuries experienced by female soldiers was more than twice that of their male counterparts. In addition, female soldiers experienced nearly three times as many SPI classified injuries (15%) as compared to males (6%). However, the leading cause of SPI injuries for both males and females was injury to the low back, which accounted for 29% and 43% of SPI injuries, respectively.[36] Thus, while both sexes demonstrated low back injuries were a significant source of load carriage related injuries, female soldiers may be more likely to sustain severe load carriage related injuries.

In a follow-up study, the researchers assessed self-reported injuries associated with load carriage in the Australian Army.[30] Using an online survey, the researchers collected data pertaining to injury occurrence, location, mechanism, as well as demographic information including biological sex, height, weight, and age. A total of 338 soldiers (female=7%, male=93%) completed the survey with the median length of service being 9.5 years (range 1-25+ years). In total, 34% of participants reported at least one load carriage-related injury during their military career with 42% of those indicating they sustained more than one load carriage injury. Furthermore, the relative injury risk for females compared to males was 1.21 (95% CI 0.71-2.04),[30] which is slightly higher than that of the researchers' prior study.[36] Interestingly, 47% of participants who reported experiencing a load carriage injury indicated they suffered at least one of those injuries during initial training. Further, of that 47%, 32% indicated they sustained another injury within the first year of service. As a whole, 52% of those who sustained a load carriage injury during initial training reported suffering an additional injury at some time during their military career.[30] Therefore, it should be considered that prior injury may be a significant risk factor for future injuries associated with load carriage.

Akin to findings of prior studies,[2,31,36] analysis of injury locations indicate the lower extremity and back are the most commonly injured sites (Table 14).[30] When nature of injuries was assessed, the researchers found the most frequently injured structures were bones and joints (39%) followed by muscle and tendon (36%). In addition, ligaments accounted for 15% of injuries, followed by 'other' structures (6%). In contrast to the findings of Knapik et al.,[31] foot blisters accounted for the smallest proportion of injuries, at only 4%. Lastly, activities conducted at the time of injury were reviewed, and findings paralleled those of other studies,[2,36] with road marching being the leading cause of load carriage related injuries (Table 15).[30] As a whole, the findings of this investigation indicate soldiers who experience one load carriage related injury may be more susceptible to future injuries. Further, findings related to injury site and mechanism appear to be consistent among investigations with the back and lower extremity being commonly injured and road marches being the most common cause.

Table 14. Proportion of self-reported load carriage injuries by aggregated body site[a]

Injury Site	Number of injuries (%)
Head	1
Upper Extremity	10
Back	27
Abdomen	1
Lower Extremity	54

[a]adapted from Orr et al.[30]

Table 15. Activities occurring at the time of self-reported load carriage injuries

Activity	Proportion of Injuries (%)
Endurance marching	38
Field training	28
Physical training	14
other	20

In a similar, survey-based assessment Schuh-Renner et al.[37] analyzed injuries associated with road marching while carrying a load. Data were collected from 831 participants (average age=25 years, male=99%) from two U.S. Army infantry battalions. Information attained from the survey included demographic information, most recent APFT scores, physical training (PT) and road marching participation in the previous six months, and injuries in the previous six months. Akin to the previously described study, this investigation was based on self-reported history of respondents.

Examination of survey responses revealed 310 participants, accounting for 37% of respondents, reported a total of 412 injuries.[37] The leading mechanism of injury was running during PT, which accounted for 27% of reported injuries. Paralleling findings of prior studies,[2,30,36] one of the leading activities associated with injury was road marching, which accounted for 23% of injuries and 21% of limited duty profiles during the six-month period. [37] Further supporting previous reports,[2,30,31,36] the leading injury sites involved the back (26%) and lower extremity, specifically the knee (23%) and ankle (18%).[37] Although the findings of this study indicate running was the leading cause of injury, when rates of injury by miles of exposure for running compared to load carriage are considered, the finding shifts. When accounting for exposure, injury rates for road marching exceed those of running (RR=1.8, 95%CI 1.38-2.37).

Based on the impact of exposure on injury rates, the researchers further investigated variables associated with road marching. Respondents who experienced road marching related injuries reported that they carried significantly heavier loads compared to those who did not sustain an injury. Those who reported road marching injuries also indicated they did less distance running and more frequent resistance training compared to those who did not experience an injury ($p<.05$). Additionally, individuals who reported a greater number of pound-miles per month (≥1,473) were at a higher risk of injury compared to those who reported fewer pound-miles (RR=1.92, 95%CI 1.17-2.41). Multivariate regression analysis of factors associated with road marching injuries revealed those age 35 or older were at greater risk of injury. Soldiers with jobs requiring regular lifting of 50 lbs. and occasional lifting over 100 lbs. also presented an increased risk for sustaining a road marching injury ($p \leq .05$). Furthermore, participation in five or more road marches per month, running less than five miles per week for personal PT, and carrying more than 25% of one's body weight during road marching were also factors significantly associated with increased injury risk ($p \leq .05$).[37] These findings suggest decreasing the percentage of body weight carried during road marches, as well as decreasing the total exposures/mileage may help reduce injury risk.

Taken together, findings regarding injuries during military load carriage tasks suggest the back and lower extremity are the most commonly injured sites. Additionally, soldiers should reduce the amount of weight carried as much as possible and place a special focus on limiting loads to 25% of total body weight or less, as this appears to be the threshold for sustaining a musculoskeletal injury. Finally, since the distance traveled as well as the amount of weight carried both impact injury risk, it may be beneficial to implement PT programs that coordinate progressive road marching with traditional PT to reduce cumulative exposures, thereby minimizing risk factors.

2.3. Anatomy

As the review of the literature pertaining to location and mechanism of injury suggests, it is imperative that a basic understanding of musculoskeletal anatomy of the hips, back, and abdomen are explored to understand the etiology of low back pain in military personnel. The spine and hip are complex joints, allowing motions to occur in multiple planes. Further, many bony articulations, ligaments, and muscles are involved in producing motion and providing support to the hip and vertebral column.

2.3.1. Osseous Structures of the Vertebral Column

The spinal column consists of 33 vertebrae and is divided into five distinct sections.[38] The three most cranial segments are composed of movable vertebrae and include the cervical, thoracic, and lumbar regions.[38] Conversely, the two caudal sections, which include the sacral and coccygeal segments, are composed of fixed vertebrae.[38] The cervical (n=7) and lumbar (n=5) regions form a lordotic curve, while the thoracic region (n=12) forms a kyphotic curve.[39] The sacral (n=5) and coccygeal (n=4) regions are composed of fused vertebra forming a kyphotic curve.[38] The sizes and shape of the vertebrae vary based on the necessary functions at each spinal level.[40]

Knowledge of the components of an individual vertebra is important to understanding muscular attachments, facet joint function and orientation, and other anatomical factors potentially associated with back pain. Each individual vertebra in movable regions of the spinal column is composed of a ventral body, which serves as the primary weight-bearing surface.[38,40] Dorsally, the vertebral arch is formed by a pair of pedicles and laminae, which enclose the vertebral foramen.[38,40] The pedicles are two short, thick processes projecting dorsally from the cranial aspect of the vertebral bodies, thereby connecting the transverse processes to the body.[38]

The pedicles are thinner in the middle portion, creating the superior and inferior vertebral notches. At the articulation of adjacent vertebrae, these notches form the intervertebral foramina, which provide an opening for spinal nerves to exit the vertebral foramen. Two broad plates, known as laminae, extend dorsally and medially from the pedicles and fuse in the midline to form the dorsal part of the vertebral arch, providing a base for the spinous process.[38] The spinous processes, which extend posteriorly, and transverse processes, which extend laterally, provide lever arms that allow for the attachment of muscles and ligaments.[38,39] Lastly, two superior articular processes extend cranially from the laminae, and two inferior articular processes extend caudally from the laminae. These articular processes interlock with the processes of adjacent vertebrae to form the facet joints.[39,41] The portion of the lamina between the superior and inferior articular processes, just below the pedicle, is referred to as the pars interarticularis, which is a common site of stress fractures.[40]

Each functional unit of the vertebral column is formed by two adjacent vertebral bodies, an intervertebral disc, and two facet joints.[41] The vertebral canal, formed by the vertebral foramina, follows the curvature of the spinal column and is large and triangular in the cervical and lumbar segments where more movement occurs, while it is smaller and round in the thoracic region where less motion occurs.[38] Figure 1 depicts the components of individual vertebra.

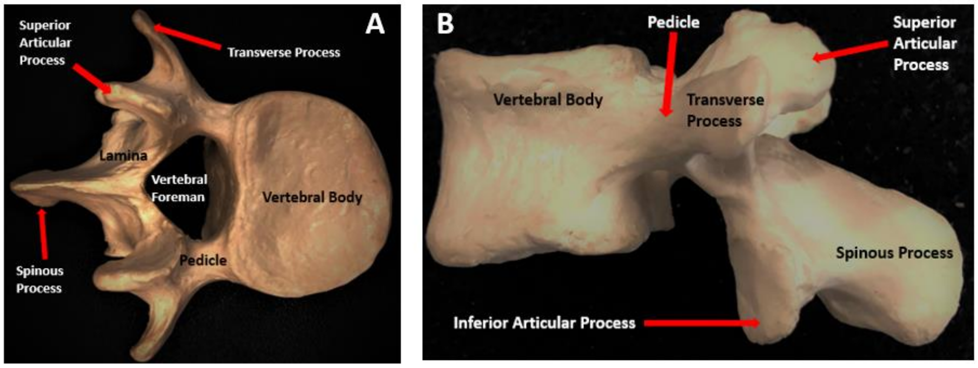

Figure 1. Vertebral components
A – Dorsal, B – Lateral Facet Joints

Facet joints are the only synovial joints in the spine,[41] and are comprised of adjacent superior and inferior articular processes.[40] Proper functioning of these joints is pivotal to ensuring adequate control of spinal motion and avoiding injury.[42] When the facet joints are functioning normally, they work in conjunction with the intervertebral discs to ensure appropriate transfer of physiologic loading of the spine, as the facet joints carry as much as 25% of axial spinal loads.[42] However, injury, degeneration, or dysfunction of structures of the facet joints can lead to pain, increased motion, and improper biomechanical function of the spine.[42] The facet joints are symmetrical synovial joints supported by a fibrous capsule connecting the articular facets of each vertebrae.[41] In addition to the capsule, various musculature as well as the posterior ligamentous complex provide support to the facet joints.[39,41,42] The articular surfaces of the facet joints are covered by hyaline cartilage,[42] allowing sliding/accessory motions to occur, which combine to create the various motions (flexion, extension, lateral flexion, rotation) that occur in the spinal column.[40,42]

The various regions of the vertebral column have separate orientation of the facet joints, resulting in production of different degrees of freedom in different vertebral segments.[42] Additionally, the forces at the facet joints are non-uniform, meaning they vary based on the spinal region and the load placed upon the spine. Thus, injury risk factors for the facet joints differ between regions of the spine.[42] In the cervical region, the articular surfaces of the facet joints have a more horizontal orientation,[42] with the superior articular process facing dorsally, cranially, and medially, while the inferior facets face ventrally, caudally, and laterally.[38] The orientation of these joints allows a great degree of lateral flexion and rotation to occur in the cervical region.[42] In the more distal regions of the spinal column, the facets become more vertically oriented, thus resulting in less ability to rotate and laterally flex in the lower thoracic and lumbar regions in comparison to the cervical spine.[42] In the thoracic region, the superior articular processes face dorsally and laterally, while the inferior facets face ventrally, caudally, and medially.[38] This coronal orientation minimizes extension, while allowing some degree of rotation. In contrast, the sagittal oblique orientation of the facets in the lumbar region minimize rotation.[41] In the lumbar segment, the inferior articular surface is convex and faces anterolateral, while the superior articular surface is concave and posteromedial facing; furthermore, the facet angles decrease relative to the sagittal plane as they travel caudally.[38,40] The decreased flexibility in the distal spinal column provides protection to the intervertebral discs and spinal cord from injurious forces.[42]

2.3.2. Intervertebral Discs

The function of the intervertebral discs is to assist with load transfer between adjacent vertebrae.[39] Dysfunction of the intervertebral discs is a common cause of back pain and most commonly occurs with tension or shearing forces.[39] These avascular structures consist of three primary components: the nucleus pulposus, annulus fibrosus, and cartilaginous end plates.[39,40] The nucleus pulposus is a semi-gelatinous substance that has been reported to range between 70-90% water,[40] and is easily deformable under stress, while still providing a stable cushion for the vertebral bodies.[39] The percentage of water in the nucleus pulposus decreases with age, which results in decreased ability to distinguish the nucleus pulposus from the annulus fibrosus, as well as a potential cause of disc degeration.[40] The annulus fibrosus is formed by multiple layers (lamellae) of collagenous fibers, which create a strong outer layer.[39,40] The lamellae are organized in concentric rings around the nucleus, and are thicker anteriorly.[39,40] The arrangement of the fibers of the annulus, being thinner posteriorly, is likely a contributing factor to increased incidence of posterior disc herniations.[40] The peripheral fibers of the annulus fibrosus insert securely into the cartilaginous vertebral endplates[39,40]; however, the endplates are weakly attached to the vertebral bodies, resulting in risk of the disc separating from the vertebral body.[39]

2.3.3. Ligaments of the Vertebral Column

There are several ligaments providing support and stabilization to the spine as a unit. Strengthening the anterior aspect of the vertebral column and limiting extension, the fibrous anterior longitudinal ligament (ALL) extends from the occiput to the sacrum, attaching to the vertebral bodies as well as the intervertebral discs.[39,40] The deepest fibers of the ALL extend over two vertebrae and attach firmly to the superior and inferior margins of adjacent vertebrae, while the more superficial fibers are longer, extending over three to four vertebrae.[40] Progressing down the posterior aspect of the vertebral column, the PLL attaches to the posterior aspect of the vertebral bodies and discs, ending at the sacrum.[40] The PLL extends laterally over the posterior aspect of the intervertebral discs, and provides support during spinal flexion.[39,40] Similar to the ALL, the deep fibers of the PLL span only two vertebrae, while the superficial fibers extend over up to five vertebrae.[39,40]

Posterior to the PLL, the interspinous and supraspinous ligaments attach to each spinous process and provide posterior support.[40] The thin, interspinous ligament extends from the lower border of one spinous process to the upper border of the next, filling in the space between spinous processes and preventing excessive flexion and rotation of the spine.[39,40] The stronger supraspinous ligament extends over the top of the spinous processes, originating on the occipital bone and inserting on the sacrum.[40] This “ligament” consists primarily of tendinous fibers of the paraspinal muscles; therefore, it is not a true ligament.[39]

Ligamentum flavum comprises the posterior margin of the vertebral canal and consists of a pair of ligaments that attach the lamina of consecutive vertebrae and fuse with each other in the midline.[39,40] Ligamentum flavum attaches on the lower portion of the anterior surface of the superior laminae and the upper portion of the posterior surface of the inferior laminae, covering the interlaminar space.[40] Laterally, the ligamentum flavum provides support to the facet joints, fusing with the capsule of the facet joints laterally.[40] In the lumbar region, ligamentum flavum is thicker, containing two layers: superficial and deep.[40]

2.3.4. Sacrum, Coccyx, and Sacroiliac Joint

The sacral and coccygeal vertebrae form the two fused regions at the caudal end of the spinal column. The sacrum is a large, triangular bone which sits at the dorsal aspect of the pelvis.[38] The base of the sacrum articulates with the fifth lumbar vertebra, forming the sacrovertebral angle, and further caudally the sacrum articulates with the coccyx. Similar to the rest of the spine, the sacrum contains foramina for nerves and blood vessels; in contrast, the coccyx does not contain a canal or any openings for nerves to pass through. The body of the first vertebral segment of the sacrum is large, similar to the lumbar vertebrae, and each succeeding vertebra decreases in size. The caudal end of the sacral canal is referred to as the sacral hiatus because it is incomplete due to the lack of laminae and spinous processes of the distal segments.[38] Components of the sacrum are displayed in Figure 2.

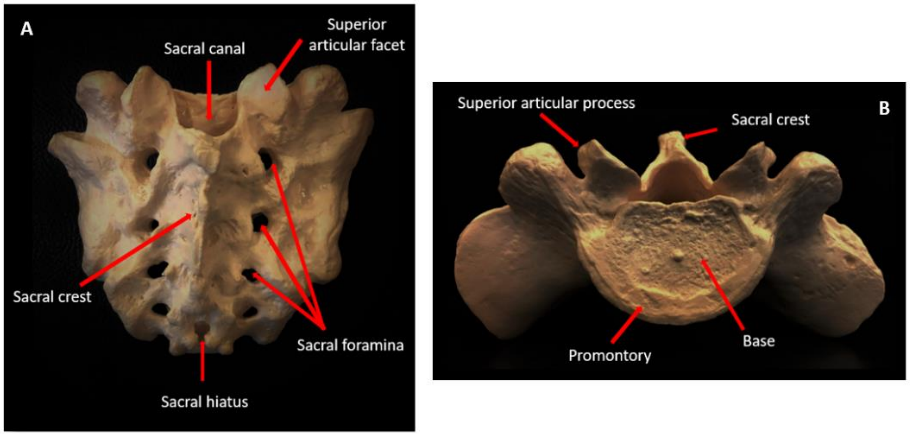

Figure 2. Sacral components
A – Dorsal, B – Superior

The sacroiliac joint (SIJ) is a diarthrodial synovial joint formed by the articulation of the sacrum and the ilium, generally within sacral segments S1, S2, and S3.[38,43,44] This joint is an often unrecognized cause of low back pain and may account for up to 30% of chronic low back pain cases.[45] The structure of the SIJ favors stability rather than motion.[44] The wide inferior end of the sacrum is "wedged" between the ilia, helping to resist shearing forces from vertical compression, as well as anteriorly directed forces.[43] The sacrum and ilium both contain cartilaginous plates at the junction of the two bones, with the cartilage being thicker on the sacrum compared to the ilium.[38] The two cartilaginous plates are separated by a space containing synovial fluid, which permits a gliding motion to occur between the two bones, thus displaying characteristics of a gliding joint.[38] Contrasting most other joints in the body, there are no muscles acting directly across the SIJ; therefore, it is a very stable joint.[45] The biomechanics of the SIJ are complex, as the axes of movement run obliquely across the pelvis. During hip extension, the ilium glides anteriorly and away from the sacrum, while during flexion the ipsilateral ilium glides posteriorly and inferiorly. Motion at the SIJ is small, generally less than two to three degrees in the transverse and longitudinal planes.[44,45] Although minimal movement occurs at this joint, failure of the joint to move results in biomechanical failure, often producing pain.

2.3.4.1. Ligaments of the distal spine and SIJ

In the distal portion of the spinal column the ALL, PLL, interspinous, and supraspinous ligaments continue down the vertebral column, connecting the fifth lumbar vertebra with the first sacral vertebra.[38] In addition to the continuation of these ligaments, two iliolumbar ligaments travel down each side of the spine, connecting the pelvis with the vertebral column. The iliolumbar ligament attaches to the transverse processes of L5 and splits as it passes laterally, attaching to the iliac crest of the pelvis and blending with the anterior sacroiliac ligament.[38,43]

Further caudally, the sacrococcygeal ligaments provide support to the articulation between the sacrum and coccyx. The ventral sacrococcygeal ligament descends from the ventral surface of the sacrum to the ventral aspect of the coccyx, blending with the periosteum. On the other side, the dorsal sacrococcygeal ligament completes the distal part of the sacral canal, originating at the distal aspect of the sacral canal and inserting into the dorsal aspect of the coccyx. The lateral sacrococcygeal ligaments connect the transverse processes of the coccyx to the inferior lateral angle of the sacrum.[38]

There are many ligaments that provide support to all aspects the sacroiliac joint.[45] Support between the ilium and sacrum is provided by the sacroiliac ligaments.[38] Ventrally, the anterior sacroiliac ligament is composed of thin bands, which attach the ventral surface of the lateral sacrum to the ilium.[38,43] On the dorsal side, the posterior sacroiliac ligament is located in a depression between the sacrum and ilium, connecting the sacrum to the posterior superior iliac spine (PSIS).[38,45] The posterior aspect is situated horizontally, while the inferior aspect sits obliquely. The interosseous sacroiliac ligament is deep to the dorsal sacroiliac ligament and is formed by several short, strong fibers that connect the sacrum and ilium.[38]

Support between the ilium and ischium is provided by the sacrotuberous ligament and the sacrospinous ligament.[38] The sacrotuberous ligament is a broad, flat ligament which extends from the posterior inferior iliac spine (PIIS) and posterior sacrum and coccyx to the ischial tuberosity. The sacrospinous ligament is a thin, triangular ligament that attaches the lateral margins of the sacrum and coccyx to the ischial spine.[38]

2.3.5. Thoracolumbar Fascia

Fascia is defined as connective tissue composed of irregularly arranged collagen fibers, distinctly unlike the regularly arranged collagen fibers seen in tendons, ligaments, or aponeurotic sheets.[43] In contrast to tendons, ligaments, and aponeuroses, which can only resist force in a limited number of planes, fascia is able to withstand stress in multiple direction due to the irregular arrangement of fibers.[43] Although traditionally classified as fascia, the thoracolumbar fascia (TLF) is composed of both aponeurotic structures and fascial sheets.[43] The TLF is an important structure to consider with regard to idiopathic low back pain, as researchers have provided evidence of the presence of nociceptive free nerve endings within the fascia, which display changes indicative of ischemia or inflammatory processes in individuals experiencing LBP.[46]

The TLF is a large fascial structure that forms a compartment around the paraspinal muscles and provides stabilization to the lumbosacral spine.[38,43] Cranially, the TLF is continuous with the fascia nuchae, and attaches to the iliac crests and lateral crests of the sacrum caudally.[38] Medially, it attaches to the spinous processes, supraspinous ligaments, and medial crest of the sacrum, and laterally attaches to the angles of the ribs and intercostal fascia, as well as the aponeurosis of the transversus abdominis muscle.[38] Moreover, the TLF is fused to the aponeurosis of the erector spinae and multifidi at the sacral levels.[43]

2.3.6. Muscles of the Back

Many muscles in the back have been assessed to determine their effects on presence and/or development of low back pain. The erector spinae muscle group is one of the most frequently evaluated.[5,6,23–25,47–53] This group of muscles is vertically oriented and extends the full length of the spine, lying underneath the thoracolumbar fascia.[40] The erector spinae includes three separate muscles, each consisting of three different segments. The lateral muscle of the group, iliocostalis, consists of lumbar, thoracic, and cervicis segments. The longissimus is the middle muscle of the group, and the spinalis sits medially, both of these muscles consist of thoracic, cervicis, and capitis segments. Although the erector spinae group extends from the pelvis all the way to the cervical spine and skull, this review will focus on the lumbar and thoracic regions, as they are the major contributors to low back pain.

As a whole, the primary function of the erector spinae muscle group is extension and lateral flexion of the vertebral column.[38] The iliocostalis lumborum arises from the posterior iliac crest and inserts into the inferior borders of the angles of the inferior six ribs.[38,40] The thoracic originates on the upper borders of the angles of ribs seven through twelve, medial to the insertion of lumborum, and inserts into the cranial borders of the angles of ribs one through six and the transverse process of C7.[38] In addition to extension and lateral flexion, due to their attachments on the ribs, the iliocostalis lumborum and thoracic draw the ribs caudally. Similarly, the longissimus thoracis draws the ribs inferiorly due to its insertion on ribs three through twelve and the tips of the transverse processes of T1 through T12, while the origin is on the transverse processes of the lumbar vertebrae.[38,40] Lastly, the spinalis, which is the smallest muscle of the group, originates on the spinous processes of T10 through T12, as well as L1 and L2, and inserts on the spinous processes of the upper thoracic vertebrae.[38,40] Since the spinalis does not have any attachments laterally or on the ribs, the action of this muscle is solely extension of the vertebral column.

While the erector spinae is a muscle group rather than a single muscle, it is often assessed as a single unit during EMG analysis, as the narrow, vertical orientation makes the muscles difficult to differentiate. A few other muscles of the back have been studied using EMG to assess their contribution to back pain. The multifidus, which extend along the entire length of the spinal column, is another frequently assessed muscle in the back.[54–60] This long muscle, with attachments on the sacrum and all vertebrae in the spinal column, serves to extend and rotate the vertebral column toward the opposite side.[38] In addition, the latissimus dorsi is a muscle researchers have frequently examined in relation to back pain.[48,51,61–63] This large, triangular muscle extends over the lumbar and caudal half of the thoracic region of the spinal column. The latissimus dorsi has attachments on the thoracolumbar fascia, spinous processes, and pelvis, and acts primarily at the shoulder, producing extension, adduction, and medial rotation of the joint; in addition, the latissimus dorsi draws the shoulder downward and posteriorly.[38] Although there are many muscles providing support to the spinal column, the erector spinae is the primary focus of this review.

2.3.7. Muscles of the Abdomen

Various abdominal muscles have been studied with regard to back pain such as the rectus abdominis,[22,23,48,49,51,52,56,57,59,61,63,64] transverse abdominis,[57,64] internal oblique,[22,47,48,51,56,57,61] and external oblique.[22,23,48,49,51,52,59,61,63] All of these muscles play important roles in producing movement and providing support to the core. As its name implies, the transversus abdominis runs transversely across the abdomen, and primarily functions to constrict and compress the abdominal contents. Immediately superficial to the transversus abdominis is the internal oblique, and these muscles work together to compress the abdominal contents. The internal oblique sits on the ventral, lateral abdominal wall and produces movement including flexion of the vertebral column during bilateral contraction, and lateral flexion and rotation of the vertebral column, bringing the shoulder of the opposite side forward during unilateral contraction.[38] More superficially, the external oblique, also sits on the ventral, lateral abdominal wall and assists with compressing the abdominal contents. Additionally, bilateral contraction of the external oblique produces flexion of the vertebral column and unilateral contraction produces lateral flexion and rotation, bringing the same side shoulder forward. Although the aforementioned abdominal muscles produce important motion and support in the core, they are not the primary focus of this review.

The principal abdominal muscle of interest is the rectus abdominis due to its range of supportive and movement related functions. The rectus abdominis is a superficial, long, flat muscle that spans the length of the abdomen bilaterally. The rectus abdominis arises from the pubic crest and inserts into the costal cartilage of the fifth, sixth, and seventh ribs, as well as xiphoid process.[38] This muscle has many functions including producing flexion of the spinal column as well as drawing the sternum toward the pubis. Additionally, the rectus abdominis tenses the anterior abdominal wall and assists with compression of the abdominal contents.[38]

2.3.8. Muscles of the Hip

Muscles of hip play an important role in stabilizing the pelvis and core; therefore, they are pertinent to the discussion of back pain. The psoas major is an anterior muscle that originates in the low back, but inserts on the femur, resulting in motion at the hip.[40] This primary hip flexor also assists with flexion and lateral flexion of the lumbar region.[38] The association between back pain and cross-sectional area and intramuscular fat of the psoas major have been studied using magnetic resonance imaging, but results were inconclusive.[65] However, this muscle has not been extensively studied using EMG, likely due to its deep location.

While some muscles of the hip are difficult to analyze using EMG, other large, superficial muscles are ideal for this type of analysis; thus, they are the focus of this review. The gluteus maximus is a large, powerful muscle, and its relationship to back pain has been modestly studied[51,62]; however, due to its contribution to knee and hip stabilization, more information is needed about the muscle’s involvement in the development of back pain. The gluteus maximus originates on the posterior gluteal line of the ilium, posterior surface of the lower part of the sacrum and the side of the coccyx, and the sacrotuberous ligament, and inserts into the iliotibial band and the gluteal tuberosity.[38] This muscle is a powerful hip extensor as well as a lateral rotator; additionally, it braces the knee via the iliotibial band when the hip is fully extended.[38] Deep to the gluteus maximus is the gluteus medius, which arises from the ilium between the iliac crest and posterior gluteal line dorsally, and the anterior gluteal line ventrally, and inserts on the lateral surface of the greater trochanter.[38] The actions of this muscle include abduction and medial rotation of the hip. The anterior portion flexes and rotates medially, while the posterior portion extends and rotates laterally.[38] The gluteus medius has been studied extensively with regard to back pain due to its major role in stabilization of the hip during weight bearing.[47,51,52,66,67]

Additional muscles of interest are the rectus femoris and biceps femoris, which both act at both the knee and the hip. These muscles have been evaluated during load carriage tasks,[3–5,7,8] but minimal information is available pertaining to their involvement in back pain.[62] The rectus femoris is part of the quadriceps femoris muscle group, located on the anterior aspect of the thigh. This muscle lies centrally on the thigh, originating on the anterior inferior iliac spine and superior to the acetabulum, and inserting into the tibial tuberosity. Due to its orientation crossing both the hip and knee joints, the rectus femoris performs both knee extension and hip flexion.[38] On the opposite side of the thigh, the biceps femoris is a member of the hamstring muscle group, and is the most lateral muscle in the group. As its name suggests, it has two heads. The long head originates on the ischial tuberosity, and the short head arises from the lateral lip of the linea aspera.[38] Similar to the rectus femoris, the biceps femoris acts on both the knee and the hip, producing knee flexion and lateral rotation of the flexed knee, and extension of the hip.[38]

Although this review focuses specifically on these four hip/lower extremity muscles, there are many more muscles that could be potential contributors to the development of back pain.

2.4. Low Back Pain

2.4.1. Introduction

Low back pain (LBP) is a widespread health problem in industrialized countries, often resulting in disability. Many people experience at least one episode of LBP in their life,[11] which may result in time off work and inability to complete daily tasks. LBP is defined as pain, muscle tension, or stiffness localized below the costal margin and above the inferior gluteal folds, with or without leg pain.[11,12] There are various classifications of LBP including acute, chronic, specific, and non-specific. Specific LBP is associated with symptoms caused by an identifiable pathophysiological mechanism, whereas non-specific LBP, which accounts for approximately 90% of all LBP, presents as symptoms with no clear cause.[11,12,68] LBP results in consequences extending beyond the patient, impacting employers, families, and society as a whole due to the economic impacts associated with disability.[12] There are a multitude of risk factors associated with development of LBP such as age, occupation, obesity, and muscle strength. Numerous prevention and treatment approaches have been described in the literature; however, the most effective strategy for addressing LBP remains unclear.[11]

2.4.2. Etiology

Although LBP occurs as the result of some degree of mechanical failure, the specific cause, location, and tissue(s) involved can vary greatly. The exact etiology of the majority of LBP is unknown, and it can vary dramatically.[11,12,68] When determining causes and treatments for LBP, it is important to consider the mechanism/onset of pain. For example, a traumatic injury with a specific, known mechanism will be evaluated and treated differently than insidious onset pain. Back pain can result from a variety of sources including bone, muscle, and other soft tissue such as intervertebral discs, ligaments, and fascia.

One of the most common sources of back pain is the intervertebral discs. Diagnoses involving the discs require imaging to confirm the disc is the cause of the pain/symptoms. Symptoms of disc pathologies often include referred pain and/or neurologic symptoms, which radiate into the buttocks and further distally.[69] Researchers have reported discrepancies between rates of disc pathology in physically active adults compared to active children/adolescents, with significantly higher rates in adults ($p=.05$).[69] Additionally, it is important to distinguish between disc degeneration and age-related biomechanical changes in the disc, as evidence suggests normal age related dehydration of discs does not elicit pain.[70] Therefore, MRI findings of age-related changes should not be considered the source of a patients pain.[70]

Researchers have indicated most back pain in the adult population is soft-tissue related,[71] resulting from etiologies such as muscle strains, atrophy, and fascial dysfunction. Muscle tissue is frequently involved in the development of back pain, with etiologies such as muscle strains. Muscle strains are defined as an acute injury to a muscle-tendon unit as a result of over-contraction or overstretching of the muscle-tendon unit. These injuries often occur at the musculotendinous junction, and produce point tenderness in a specific portion of the muscle as well as pain with provocative stretching or contraction of the muscle.[69] Back pain of muscular origin can also be the result of muscle degeneration.[65,72] It has been found that adults with low back pain often have decreased cross-sectional area of the erector spinae when compared to individuals without back pain.[65] Further, when thinking about muscular dysfunction as a source of pain, the thoracolumbar fascia should be considered due to its strong association with muscles of the back and core. Fascia-mediated pain may be the result of nociceptive input from muscle or other tissues with the same spinal segment innervation, which could cause increased sensitivity in the TLF.[46] Additionally, due to its nociceptive innervation, the TLF itself could be a source of pain. Microinjuries causing irritation of nociceptive fibers in the fascia may be a direct cause of back pain.[46]

While soft tissue injuries account for a large proportion of back pain diagnoses, there are many other relatively common causes. Facet joint pain is a contributing factor in 15-40% of low back pain cases, and there are a variety of pathologies that can occur in the facet joints.[73] Facet joint capsules are innervated structures with nociceptive fibers, which can result in pain when forces are applied to the joints. Facet joint dysfunction often presents as low back pain with no radicular symptoms. Pain resulting from facet joint pathologies is generally worsened with extension and rotation, while it is decreased with sitting and flexion. Unfortunately, it can be difficult to differentiate between facet joint dysfunction and other sources of pain such as injury to the pars interarticularis (spondylolysis/spondylolisthesis), pedicles, and SIJ, as pathologies in these regions often present similarly.[73] Furthermore, due to the biomechanical complexity of the facet joints within the vertebral column, dysfunction within a facet joint directly affects the mechanics of an entire motion segment at a minimum, but often impacts multiple segments or even the entire spinal region.[42]

The anatomy of the facet joints may be a contributing factor to another common cause of back pain, spondylolysis and spondylolisthesis. Spondylolysis and spondylolisthesis are injuries to the pars interarticularis in the lumbar region of the spinal column.[69,71] The facet joints generally absorb approximately 25% of the load applied to the vertebra; however, in individuals with spondylolysis, the total area of the facets at the L4-L5 levels is often significantly smaller and shallower, resulting in greater stress placed on the facets.[74] Spondylolysis usually occurs as a result of repetitive micro-trauma rather than a single traumatic event.[71] While a spondylolysis is described as a defect, such as a stress fracture, to the pars interarticularis, a spondylolisthesis occurs when the defect progresses and leads to slipping of one vertebral body on the other.[71] These injuries must be diagnosed via imaging such as bone scans or magnetic resonance imaging (MRI), in combination with appropriate corresponding symptoms, which often includes pain with extension.[69,71]

Another potential source of LBP is SIJ dysfunction. SIJ pathologies can occur as the result of a single traumatic event, or a series of microtraumas that occur over time,[75] with a history of trauma present in approximately 50% of cases.[45] The most commonly reported traumatic mechanism involves axial loading in combination with rotation.[44,75] Pain resulting from SIJ dysfunction often stems from mobility or alignment alterations within the joint; however, there are numerous etiologies associated with SIJ dysfunction, which can involve bone, ligament, muscle, or other soft tissues.[44] The most common presentation of SIJ dysfunction is low back, buttock, groin, or posterior lateral thigh pain with no radicular symptoms.[45,75] Often times pain resulting from SIJ pathology is unilateral, especially in many athletic populations as many sports require unilateral loading of the lower extremities.[45] However, if symptoms present above the level of L5, SIJ dysfunction can usually be ruled out as the cause of pain.[75]

2.4.2.1. Treatment

The best course of treatment for LBP will be dependent on the cause of the pain. As previously stated, the majority of LBP is soft-tissue related; as a result, most LBP can be treated with functional rehabilitation.[71] The focus of this review is the active adult population, therefore, minimizing downtime and deconditioning is essential. Conservative treatment of back pain can generally be divided into three phases including acute, recovery, and maintenance.[45]

The first step in the rehabilitation process should be reducing acute pain; however, long periods of inactivity should be minimized and walking should be encouraged in order to reduce strength and flexibility loss.[71] Nonsteroidal anti-inflammatories and ice may be used to help prevent and reduce inflammation.[45,71] Once the acute pain has diminished, the focus should switch to heating with progressive stretching/mobilization.[45,71] For many diagnoses associated with LBP, a special focus should be placed on hamstring flexibility.[71] The final step of the rehabilitation process is addition of strengthening exercises, which should be specific to the injury/diagnosis. As the patient progresses through their strengthening program, exercises should become more advanced and specific to the activities they desire to return to.

As previously stated, the prescribed strengthening program should be determined by the etiology of the pain. Most disc pathologies occur in the posterior direction; thus, strengthening should generally focus on the extensors.[71] In contrast, in injuries to the pars interarticularis and facet joint pathologies should be more focused on strengthening of the flexors. However, in cases of muscular strains, strengthening of both flexors and extensors should be included to attain a balance between the two.[71]

Diagnoses such as facet joint hypomobility and SIJ rotations/pathologies may require use of manual therapy treatment interventions such as joint mobilization and muscle energy techniques.[45] Furthermore, the health care provider should assess for anatomical causes for the pain/pathology such as leg length discrepancies or other anatomical abnormalities.

2.4.3. Incidence and Prevalence

Incidence and prevalence, although often used interchangeably, are two distinctly different measurements. Incidence refers to the proportion of people who develop a condition over a period of time, whereas prevalence describes the number of people in a population who have a particular diagnosis at a specific point in time/over a specified period of time.[76] Incidence of LBP is more difficult to assess due to the resources required to conduct longitudinal studies; however, prevalence can be measured somewhat easily by surveying a particular population of individuals regarding a specific condition.[76,77] There are different time estimates that can be used for assessing incidence and prevalence. For example, point prevalence refers to the number of people with the condition of interest at a single point in time; conversely, period prevalence is the number of people who have a specific condition over a set period of time (e.g. one year). Incidence can be assessed over varying time periods as well, with cumulative or lifetime incidence describing the total number of individuals who have or have had the specified condition in their lifetime.[76] Due to the resources required to examine incidence, more data is available regarding prevalence of LBP, as it can be evaluated via cross-sectional studies. Table 16 displays incidence and prevalence of LBP in studies of industrialized countries.

Table 16. Studies of incidence and prevalence of low back pain in various countries

Author	Country	Age (years)	Time Estimate	Incidence (%)
Cassidy et al.[78]	Canada	20-69	1 year	18.6
Mustard et al.[79]	Canada	24-34	1 year	7.5
Croft et al.[80]	England	18-75	1 Year	36
Leboeuf-Yde et al.[81]	Denmark	30-50	Lifetime	64
Hestbaek et al.[82]	Denmark	30-50	Point	56
			1 year	51
			5 years	66
Waterman et al.[83]	United States	20-99	4 years	0.14
Goetzel et al.[84]	United States	18-64	1 year	7.3
Author	**Country**	**Age (years)**	**Time Estimate**	**Prevalence (%)**
Walker et al.[85]	Australia	≥ 18	Point	25.6
			1 year	67.6
			Lifetime	79.2
Harkness et al.[86]	England	15-54	Point	8.1 (♂)/9.1 (♀)
Harkness et al.[86]	England	18-64	Point	17.8 (♂)/18.2 (♀)
Carmona et al.[87]	Spain	≥ 20	Point	14.8
Cassidy et al.[88]	Canada	20-69	Point	28.4
			6 month	48.9
			Lifetime	84.1
Carey et al.[89]	United States	≥ 21	1 year	7.6
Harreby et al.[90]	Denmark	38	Point	19
			1 year	63
			Lifetime	70
Palacios-Cena et al.[91]	Spain	≥ 16	1 year	8.56
Leboeuf-Yde et al.[81]	Denmark	30-50	1 year	54
Goetzel et al.[84]	United States	18-64	1 year	15.6
Joud et al.[92]	Sweden	--	1 year	3.8
Beaudet et al.[93]	Canada	≥ 18	1 year	1.33

Abbreviations: ♂, male; ♀, female

As a whole, research outcomes reporting on incidence and prevalence suggest rates of LBP vary greatly between populations and over time. In a systematic review, researchers reported the one-year incidence of people with a first ever diagnosis of LBP ranged from 6.3% to 15.4%.[77] Further, they report the one year incidence of people with any episode of LBP, first or recurrent, ranged from 1.5% to 36%.[77] Concerning prevalence, the researchers reported point rates ranging from 1% to 58.1% (mean: 18.1%), and one year estimates ranging from 0.8% to 82.5% (mean: 38.1%). Interestingly, many of the studies included in the review did not provide a minimum duration of the LBP episode. Further, several of the studies assessed prevalence of chronic LBP, but did not define the time period in which the pain was classified as chronic. However, the prevalence for chronic LBP was slightly lower (mean: 19.4%) than regular LBP.[77]

These findings involving prevalence clearly demonstrate the wide range of reported LBP rates, which may be the result of varying methodologies between studies.

Analogous to the previous review, Leboeuf-Yde et al.[81] conducted an evaluation of LBP prevalence and incidence estimates utilizing five studies of 30-50 year old individuals. The five studies included were methodologically comparable and had similar definitions of LBP. Based on the analysis of these studies, the researchers determined the most precise one-year prevalence rate is between 44%-54%. Furthermore, they indicated the lifetime cumulative incidence rate was between 60%-65%.[81] The authors recommend replicating studies with regard to design and population to attain important information concerning time-related trends. As a whole, the researchers suggested the prevalence rates of the included studies were relatively consistent, and they attribute these findings to the consistencies among study designs.

In a comparable review of 13 articles, researchers determined prevalence of LBP based on five studies and incidence based on 10 studies.[94] This review contains up-to-date information on the issue of LBP, as it includes reports through 2019. Based on the five studies addressing prevalence, the researchers reported a mean prevalence range from 1.4% to 20%. Analysis of the study's assessing incidence revealed a mean ranging between 0.024% and 7%.[94] However, the authors of this review did not report time estimates for their findings, so these values could be point or lifetime estimates, but the exact time period is unknown.

While the three previously discussed review articles addressed both incidence and prevalence, in a review of 18 studies, Loney et al.[76] focused specifically on prevalence of LBP. In addition, the authors used predetermined criteria to define how methodologically sound the included studies were. Ultimately, it was concluded 13 studies were methodologically acceptable, with three of those studies being considered high quality. The researchers indicated analyses of shorter duration LBP generally had higher rates compared to longer term LBP.[76] Further, this trend was present for both point and period prevalence estimates. The range of prevalence rates was large for both point and period prevalence, and the standard deviations were relatively large as well. Point prevalence rates ranged from 4.4% to 33% (mean 19.2%, SD 9.6%), and one year prevalence rates ranged from 3.9% to 63% (mean 32.37%, SD 23.6%).[76] Additionally, the point prevalence rate for North America approximated by three studies was 5.6%. Based on this estimate, the researchers concluded roughly ten million people experience LBP on any given day in North America. Table 2 displays prevalence rates found in various studies and demonstrates the magnitude of the issue of LBP in industrialized countries, as well as the wide range of findings regarding prevalence.

As a whole, the data related to incidence and prevalence of LBP is composed of studies with vastly different methods, populations, and locations. All of these factors contribute to outcomes and are likely the reason for the considerably dissimilar findings between many researchers. As demonstrated by the analyses conducted in the reviews discussed above, the ranges of incidence and prevalence rates are substantial and mean values vary greatly as well. Thus, the heterogeneity among LBP studies limits the ability to compare data and draw accurate conclusions.

2.4.4. Risk Factors

2.4.4.1. Physical Activity

There are a variety of personal and environmental risk factors potentially associated with development of LBP. While some risk factors may be modifiable (e.g. weight, occupation), others are not (e.g. age, biological sex). One modifiable risk factor is physical activity, which can come in the form of occupational or leisure activity. Occupational exertion may have different effects on LBP risk compared to leisure time physical activity. To investigate these relationships, researchers utilized a questionnaire assessing how much time participants spent working in various positions (e.g. twisting, kneeling, squatting, etc.), as well as what physical activity they completed outside of work.[95]

As demonstrated by Table 17, a total of 16 different work postures were evaluated. Ultimately, the researchers determined occupational postures associated with increased risk of LBP were lifting or carrying heavy weight on the trunk while inclined (p=.02) and any awkward posture at work (p=.04). Other occupational postures were non-significant (Table 17). Taken as a whole, these findings suggest occupation can be a risk factor for LBP. In particular, occupational tasks that involve heavy lifting and awkward postures, such as lateral bending and twisting, are associated with higher rates of LBP. On the other hand, less complex postures such as sitting, standing, walking, or maintaining upright positions, showed no association with LBP.

Table 17. Association between occupational activities and presence of LBP (Most → Least Significant)[a]

Posture	p-value
Heavy weight on trunk while inclined	0.02*
Any awkward posture at work	0.04*
Sitting	0.12
Straight upright	0.13
Any inclination	0.24
Walking	0.26
Slightly inclined	0.31
Light weight on trunk upright	0.35
Standing	0.44
Squatting	0.44
Kneeling	0.50
Light weight on trunk while inclined	0.53
Trunk twisted	0.62
Heavy weight on trunk upright	0.89
Always upright	0.95
Strongly inclined	0.95

*significant

[a] adapted from Amorim et al.[95]

To compare occupational and non-occupational physical activity with respect to risk for developing LBP, the researchers measured leisure physical activity separately from work-related activity. Non-occupational physical activity was examined via a survey investigating walking, moderate-intensity physical activity, and vigorous-intensity physical activity. In contrast to findings regarding occupational activity, non-occupational physical activity was inversely associated with LBP. Moderate (p=.006), vigorous (p=.041), and total (p=.001) physical activity were significantly negatively associated with LBP. Thus, leisure physical activity was associated with lower prevalence of LBP.[95]

Comparably, the association between non-occupational physical activity and LBP was assessed in a survey based evaluation of potential risk factors for development of LBP.[80] This study design differed from the previously discussed study in that it was a prospective evaluation, with a risk factors questionnaire implemented at baseline, and information regarding episodes of LBP collected one year later. Risk factors addressed in the questionnaire included previous back pain, weight, height, and self-rated overall health. In contrast to the findings of the abovementioned study,[95] both males and females demonstrated no association between physical activity and LBP.[80] The only exception was women involved in regular sporting activities demonstrated higher risk of new episodes compared to those who did not regularly participate in sports. The researchers found the strongest predictor of LBP development for both sexes was self-rated overall health, irrespective of history of LBP. Additionally, heavier body weight and higher BMI at baseline were associated with increased risk of LBP in females, with a relative risk for first-ever episodes of 1.8 for females in the heaviest quintile compared to the lightest quintile. Conversely, there was no association between weight and back pain in males. Finally, no association was found between height and LBP development. Thus, the findings suggest physical activity is not associated with increased risk of back pain, while poor physical health in both sexes and increased weight/BMI in females was associated with increased risk of LBP.

The aforementioned studies provide conflicting information regarding the relationship between physical activity and development of LBP. However, these studies provided short-term data with respect to both variables. Being regularly physically active throughout one's life may result in different benefits for LBP prevention, or conversely, different risks for development of LBP. In a longer term prospective cohort study, researchers investigated the relationship between physical activity and LBP over a period of 25 years.[90] The initial assessment took place when participants were 14 years old and included an interview by a doctor regarding history of LBP. Twenty-five years later, participants completed a follow-up questionnaire focused on LBP and physical activity. The cohort was separated into two groups based on reported physical activity, with one group including those completing minimal leisure time activity, while the other group participated in some form of physical activity for at least three hours per week.[90]

The researchers determined the risk of developing symptoms was reduced in the group who completed at least three hours per week of physical activity compared to the sedentary group.[90] There is inconsistency in the literature regarding this findings, as some researchers have reported leisure physical activity is associated with lower prevalence of LBP,[90,95] and others have indicated no relationship.[80] In the physically active group, 31% of participants experienced LBP within the last month, compared to 56% in the sedentary group. Further, the rate of LBP within the past week was 10% higher in the physically inactive group compared to the active group. It is also interesting to note 85% of individuals who participated in regular physical activity were also involved in sports during school; therefore, they had been physically active for the majority of their life. Likewise, 60% of those in the minimal physical activity group did not have a history of participation in athletics. Additionally, 20% of physically inactive participants were also sedentary at work.[90] Based on these findings, it seems as though physical activity during adolescence is a contributing factor to LBP development later in life, as physical activity habits appear to be associated with LBP.

In a similar prospective cohort study, researchers assessed possible risk factors for first time LBP via a survey.[79] At the time of enrollment in the study, participants ranged from 4-16 years of age. Follow-up assessment occurred 18 years later. Relevant risk factors included occupational demands, BMI, and smoking. The Borg scale was used to assess physical job demands, with a score of zero representing very, very light, and 14 representing very, very demanding. Based on Borg scale ratings, participants were separated into two groups: 1) less physically demanding occupations, and 2) more physically demanding occupations. BMI was calculated, and participants were categorized into three groups based on percentile, including <70th, 70-85th, and >85th percentiles. Lastly, current and past smoking habits were assessed. Heavy smoking was considered 10 or more cigarettes per day, light smoking included those who smoked 1-9 cigarettes daily, and individuals who did not smoke daily were considered occasional smokers.

The researchers found no association between age or sex and incident LBP.[79] As presented in Table 18, heavy and light smoking were both associated with increased rates of LBP. Similar to the previously discussed study of physical demands associated with occupation,[95] the researchers found physically demanding jobs resulted in increased rates of LBP.[79] Further, in alignment with prior reports,[80] the researchers found an association between LBP development and increased BMI.[79] Additionally, psychological distress was noted as a risk factor for the development of back pain. Based on these findings, there appears to be a relationship between LBP prevalence and lifestyle factors in adolescence as well as physical demands associated with occupation.

Table 18. Factors associated with LBP based on univariate analysis

Factor	OR	95% CI
Physically demanding job	1.66	1.12-2.46
BMI>85th percentile	1.74	1.22-3.03
Light smoking	1.83	1.14-2.94
Heavy smoking	2.23	1.43-3.49

Abbreviations: odds ratio, OR; confidence interval, CI

2.4.4.2. Other Factors

In a study with cross-sectional and longitudinal components, researchers assessed the effect of lifestyle factors during adolescence on development of LBP in adulthood.[96] Participants included 9,600 twins between the age of 12 and 22. Predictor variables included smoking, alcohol consumption, and weight. A questionnaire was used to assess LBP as well as lifestyle factors, and all variables were self-reported. Eight years after baseline data were collected, a follow-up assessment of LBP was conducted, and LBP was correlated to lifestyle factors at baseline. Findings from initial and follow-up assessments regarding age, sex, and predictor variables in relation to LBP are presented in Table 19.

Table 19. Distribution of factors at baseline and follow-up in relation to LBP[a]

Factor		LBP > 0 days in past year		LBP > 30 days in past year	
		Baseline (%)	**Follow-up (%)**	**Baseline (%)**	**Follow-up (%)**
Age	12-15	14	36	2	10
	16-19	37	38	7	9
	20-22	48	43	11	11
Sex	Female	36	42	8	12
	Male	29	35	5	7
Smoking	0	30	37	5	9
	1-10	46	44	10	13
	11-20	72	49	15	17
	>20	72	48	30	11
Alcohol consumption	<0.2	24	38	4	10
	0.2-0.6	43	40	9	9
	0.6-1.0	46	39	9	8
	>1.0	48	42	10	10
BMI	<17	15	35	3	10
	18-24	34	39	6	10
	25-29	45	42	10	10
	>29	49	47	10	12

[a]adapted from Hestbaek et al.[96]

As demonstrated by Table 19, a drastic increase in prevalence of LBP was seen in the youngest group from initial assessment to follow-up. Additionally, females consistently displayed higher prevalence than males. Further analysis revealed a statistically significant positive association between present LBP and all three predictor variables (smoking, alcohol consumption, and BMI); however, being overweight was not associated with future LBP, while smoking and alcohol consumption were (Table 20). Furthermore, smoking at follow-up was significantly associated with development of LBP in previously asymptomatic individuals (OR 1.88, 95%CI 1.32-2.69). Based on these findings, it was concluded smoking was significantly associated with development of LBP, whereas BMI and alcohol consumption demonstrated less association.

Table 20. Multivariate logistic regression analyses -- odds ratios with 95% confidence intervals for LBP[a]

	LBP > 30 days past year at baseline	**LBP > 30 days past year at follow-up**
Smoking	1.77 (1.44-2.17)*	1.69 (1.36-2.11)*
Alcohol consumption	1.66 (1.20-2.31)*	0.74 (0.58-0.94)*
Overweight	1.38 (1.06-1.79)*	1.12 (0.84-1.49)

*statistically significant
[a]adapted from Hestbaek et al.[96]

Building on the factors investigated in the aforementioned study,[96] researchers assessed the association between LBP and various socio-demographic factors.[91] Relevant factors analyzed included sex, age, self-rated health status, smoking, and obesity/BMI, and data were collected via two health surveys from a sample of 43,072 participants. Findings related to pertinent factors are displayed in Table 21. Prevalence of low back symptoms increase with age, with the highest values in the >70 group. Similar to previous findings,[80] individuals who self-reported fair/poor/very poor health had significantly higher likelihood of LBP (p<.05).[91] Additionally, paralleling prior findings,[96] smokers had increased prevalence of LBP compared to non-smokers, and overweight individuals were at higher risk than those with a BMI < 30.[91] Based on the findings from these surveys, it was concluded the prevalence of LBP increased over the study period. Additionally, older age, smoking, poor self-reported health, and obesity were all associated with increased prevalence of LBP.

Table 21. Prevalence (%) of LBP based on different factors, and factors significantly associated with a higher likelihood of LBP (adjusted OR 95%CI)[a]

Factor	**Categories**	**LBP %**		**LBP adjusted OR (95% CI)**
		2009	**2012**	
Biological sex	Male	8.10	8.60	1
	Female	7.62	8.52	0.91 (0.83–1.01)
Age *§	16-30	3.97	3.20	1
	31-50	8.03	8.38	2.19 (1.83–2.61)
	51-70	9.67	11.45	2.82 (2.35–3.39)
	>70	10.52	11.52	2.46 (1.99–3.04)
Self-rated health *§	Excellent/good	5.96	6.58	1
	Fair/poor/very poor	12.48	13.61	2.13 (1.90–2.38)
Smoking *§	Non-smoker	7.32	7.92	1
	Smoker	7.81	7.95	1.14 (1.02–1.28)
Obesity *§	BMI < 30	7.29	7.74	1
	BMI ≥ 30	10.31	11.86	1.20 (1.07–1.35)

Abbreviations: low back pain, LBP; odds ratio, OR; confidence interval, CI

*Significant differences (p<.05) for 2009-2010

§ Significant differences (p<.05) for 2011-2012

[a] adapted from Palacios-Cena et al.[91]

2.5. Electromyography

2.5.1. Introduction

Abnormalities in magnitude or patterns of muscle activation are a factor that may be associated with pain development. Therefore, measuring muscle activity could be useful for identifying injury risk factors. Assessing muscle activation patterns in different conditions may allow researchers to determine normal/abnormal patterns that may be indicative of a pathomechanic. Dynamic electromyography (EMG) is a technique used to obtain quantitative information regarding muscle activity. There are two types of electrodes to consider when implementing EMG, surface and intramuscular. Surface electrodes are more commonly used due to their noninvasive nature, while intramuscular are generally better for analyzing small or deep muscles.[97,98] Surface EMG is often used to measure activity of large, superficial muscles during gait; however, a common problem with surface EMG is the issue of crosstalk from other muscles.[97,98] Thus, in deeper and smaller muscles where crosstalk is a concern, intramuscular EMG may be a better option. Intramuscular EMG requires a physician to insert wire electrodes directly into the desired muscle, allowing for precise measurement of the activity of that muscle.[97,98] Although intramuscular EMG offers a method for measurement of small and deep muscles, it is not as frequently utilized due to its invasive nature.[98]

Each electrode application, regardless of electrode type, samples a unique group of motor units, and the EMG signal voltage reflects muscle activity in that location.[98] Even with careful placement of electrodes on or within a muscle, each application produces slightly varying data. As a result, voltage differences between test conditions may reflect factors other than relative differences in muscle activity. Therefore, utilization of a normalized reference value for each trial is useful.[98] The maximal voluntary contraction (MVC) is often the value used for normalization, with the MVC as 100% of force/torque, and other levels of force presented as a proportion (%) of MVC.[99] Once normalized, the relative intensity of a single muscle in a test-retest condition, or two separate muscles, can be compared.[98]

2.5.2. Electrode Types

An important factor to consider when utilizing EMG is the type of electrodes that should be implemented based on the specific muscle being analyzed, as well as the conditions surrounding the analysis. Variance ratios (VR) can be used as a measure of repeatability to compare the quality of data obtained from both types of electrodes. VR is a statistical criterion used to measure the reproduction of phasic patterns of muscle activity with both surface and intramuscular electrodes, with a lower VR indicating more repeatability.[98] Multiple researchers have conducted studies comparing VRs of surface electrodes to intramuscular electrodes during gait with some discrepancies in the findings.

In one such study, researchers conducted measurements of the vastus medialis (VM) and biceps femoris (BF) during walking and jogging.[97] Selection of these two muscles was due to their large, superficial nature, making them easily identifiable through palpation. Surface electrodes were placed over the muscles with a 20 mm center-to-center separation, and wire electrodes were inserted to the VM and BF directly under their respective surface electrodes. After allowing a familiarization/warm-up period, data were collected with participants walking and jogging at a self-selected pace. Enough trials were performed to collect at least 25 cycles with adequate swing and stance phases for analysis. The recordings were rectified and normalized (via temporal and amplitude normalization) by software to allow researchers to make linear envelope shape comparisons. VRs were calculated over the 25 strides obtained from each electrode type for each muscle at each treadmill speed. In addition, inter-subject mean VRs were calculated for each muscle at each speed. Significant differences between surface and intramuscular VRs were determined, and Pearson product moment correlation coefficients were used to evaluate similarity of ensemble-averaged profiles of the two electrode types.[97]

As a whole, both electrode types had low VRs, indicating high repeatability (Table 21).[97] Assessment of the BF during walking revealed a significantly lower VR for the surface electrodes compared to intramuscular electrodes (p=.007), indicating better repeatability of the surface electrodes on the BF during walking. However, no significant difference was observed between electrode types during jogging. When the VM was evaluated, the findings were reversed. There was no significant difference between electrode types during walking, but during jogging the VR of the surface electrode was significantly greater than that of the intramuscular electrodes (p=.010) thereby, suggesting the intramuscular electrode has better repeatability in the VM during jogging. Interestingly, the mean VRs tended to decrease when the participants switched from walking to jogging (Table 22).[97] Additionally, it should be noted that both the BF and VR are large, superficial muscles, which are easily located upon palpation. This factor makes them ideal candidates for surface EMG. Although on average, the surface electrodes had lower VRs in all conditions except the VM during jogging, both muscles generally displayed low VRs, which indicates sound reproducibility for both electrode types.[97]

Table 22. Mean variance ratios for the biceps femoris and vastus medialis at walking and jogging speeds[a]

Biceps Femoris				**Vastus Medialis**			
Walking		Jogging		Walking		Jogging	
Surface	IM	Surface	IM	Surface	IM	Surface	IM
0.31	0.38	0.24	0.29	0.22	0.23	0.16	0.13

Abbreviations: IM, intramuscular
[a]adapted from Jacobson et al.[97]

In a similar study utilizing VRs to assess repeatability of surface and intramuscular EMG during gait, three different measurements were implemented to determine repeatability not only within the same electrode application, but also when reapplication is necessary.[100] Measurements were taken of the rectus femoris (RF), vastus lateralis (VL), semitendinosus (ST), tibialis anterior (TA), and gastrocnemius (G) while participants walked at a self-selected pace over a 9 m walkway. The three measurements included reproducibility (i.e. cycle-to-cycle within a single test trial), reliability (i.e. trial-to-trial within a single day), and consistency (i.e. measurements from day-to-day).[100] Analysis revealed that VRs for surface electrodes were significantly lower than for the wire electrodes for all muscles except the TA (p<.01).[100] The poorer performance of surface electrodes on the TA may be due to the smaller size of the TA in comparison to the larger quadriceps and hamstring muscles. Interestingly, in the previously described study, analysis of the quadriceps (VM) showed no difference in repeatability between electrode types,[97] whereas, surface electrode repeatability was significantly better in the RF and VL.[100] However, results regarding the hamstring muscles were consistent between the two studies with surface electrodes showing better repeatability.[97,100] Assessment of reproducibility and reliability indicated surface electrodes were superior to intramuscular electrodes, while consistency was fair for the surface electrodes and poor for intramuscular electrodes (Table 23).[100] Accordingly, it can be concluded that measurements requiring reapplication of electrodes may result in decreased repeatability.

Table 23. Median values of VRs representing reproducibility, reliability, and consistency[a]

	Reproducibility		**Reliability**		**Consistency**	
Muscles	**Surface**	**Wire**	**Surface**	**Wire**	**Surface**	**Wire**
Rectus femoris	0.209	0.278	0.267	0.357	0.563	0.671
Vastus lateralis	0.173	0.254	0.188	0.350	0.476	0.581
Semitendinosus	0.183	0.218	0.172	0.303	0.503	0.641
Anterior tibialis	0.230	0.171	0.255	0.205	0.480	0.516
Gastrocnemius	0.175	0.226	0.197	0.304	0.576	0.651

[a]adapted from Kadaba et al.[100]

Comparable to the aforementioned methodology,[100] Bogey et al.[98] evaluated the consistency component of repeatability of surface and intramuscular electrodes.[98] As reported in the aforementioned study, consistency (comparison across days) has been identified as the repeatability measurement with the lowest VR when compared to reliability and reproducibility, both of which do not require reapplication of electrodes.[100] Furthermore, previous studies have been conducted using the absolute measurements rather than relative effort, as determined by a normalized value[97,100]; therefore, the researchers utilized a maximum muscle test of the soleus to provide a normalization value and fill this research gap.[98] In this study participants walked at a self-selected speed across 6 m of a level walkway on two different days. It was found that overall, both electrode types demonstrated high levels of consistency, with the mean VR values for the intramuscular electrodes (M=0.187) being slightly lower than that of the surface electrodes (M=0.199) but not at a statistically significant level (p=.768).[98] These findings suggest that when normalization is used, the difference between intramuscular and surface electrodes is insignificant.

Both electrode types have benefits depending on the muscles being examined. Additionally, both electrode types have demonstrated low VRs, indicating high repeatability. Although intramuscular electrodes have the ability to be more specific and reach deeper muscles than surface electrodes, existing literature indicates that intramuscular electrodes often display higher VRs compared to surface electrodes, especially during functional movement.[97,98,100] Thus, when deep muscles are not the target, surface electrodes produce greater repeatability with the benefit of less invasive techniques.

2.6. Muscle Activation and Back Pain

2.6.1. Introduction

A foremost clinical problem, low back pain (LBP), has an ambiguous etiology and often becomes a chronic issue. Dysfunction of back and core musculature may be a contributing element in development of chronic LBP. As a result, electromyography (EMG) may be a useful tool for identifying potential risk factors. Numerous researchers have utilized EMG to compare muscle activation in individuals with and without LBP,[54–64,101] reporting distinct differences in results between asymptomatic participants and those who report symptoms. In analyses of muscle activation, researchers have reported more variation and less coordination in muscle activity in symptomatic individuals compared to healthy controls.[55,59,61,64] Much of the research investigating muscle activity in relation to back pain has been conducted in laboratory-controlled environments, during tasks such as isometric contraction and standing.[51,54,55,61,62,66,67] In recent years, the collection of research regarding muscle activity during gait has grown.[22–25,49,50,56,101] However, muscle activity analyzed during dynamic, functional and occupational tasks is lacking in evaluation. Table 24 displays an overview of some of the existing research evaluating muscle activity in individuals with LBP.

Table 24. Overview of investigations of back pain using EMG

Author	Sample Size	Inclusion criteria	Exclusion criteria	Study Protocol	Muscles Tested	Outcome Measures	Results
Roy et al.[54]	N=24 CLBP n=12 Control n=12	<u>CLBP:</u> persistent or frequently recurring pain over a period of ≥ 1 year	Acute exacerbation of back pain, previous back surgery or radiographic evidence of structural disorders of the spine	MVC was determined, then participants performed 3 isometric contractions at 40%, 60%, and 80% of their MVC for a duration ≤ 1 min.	Erector Spinae (longissimus & iliocostalis), Multifidus	sEMG (initial median frequency [IMF], median frequency [MF])	No isometric strength differences between groups. Median Frequency of longissimus correctly identified LBP and control participants. The LBP group displayed significantly higher MF slope values of iliocostalis and multifidus.
Radebold et al.[61]	N=34 CLBP n=17 Control n=17	<u>LBP:</u> periodic back pain episodes for more than 6 months <u>Control:</u> never experienced back pain lasting longer than 3 days	Neurologic deficits, structural deformities, genetic spinal disorders, previous spinal surgery	Participants completed 3 trials of isometric contractions at 2 force levels in trunk flexion, extension, and lateral flexion. Resistance was released and reaction time was measured.	Rectus Abdominis, External Oblique, Internal Oblique, Latissimus Dorsi, Erector Spinae	Roland-Morris disability scale, sEMG	LBP patients demonstrated a pattern of co-contraction. LBP patients had longer muscle reaction times LBP patients showed greater variability in muscle reaction times
Oddsson & De Luca[55]	N=34 CLBP n=14 Control n=20	<u>CLBP:</u> subjective reported pain in lumbar region	Spinal stenosis or other structural abnormality, prior back surgery, spondylolisthesis, cancer, conditions that are contraindications to sustained isometric resistance exercise.	The greatest of 3 MVC was used to indicate extension strength. Participants were tested at 2 different levels: 40% and 80% of MVC, and contractions were sustained for 30 s.	Multifidus, Erector Spinae	sEMG	The CLBP group showed less fatigue than controls at both contraction levels Contralateral amplitude imbalances were significantly larger in the CLBP group. Median frequency imbalances were significantly larger in CLBP group.

Table 24. Overview of investigations of back pain using EMG (continued)

Author	Sample Size	Inclusion criteria	Exclusion criteria	Study Protocol	Muscles Tested	Outcome Measures	Results
Pirouzi et al.[62]	N=60 CLBP n=30 Control n=30	CLBP: history of LBP > 6 months, which limited functional activity Control: no history of LBP	Previous lumbar surgery, neuromuscular or joint disease, signs of nerve root compression, evidence of systemic disease, pregnancy, fitness training involving the back or hip muscles within last 3 months	Participants performed 3 repetitions for 5 seconds each direction isometric trunk rotation contractions at 25% MVC while standing upright with different amounts of trunk support.	Latissimus Dorsi, Erector Spinae, Upper and Lower Gluteus Maximus, Biceps Femoris	sEMG, VAS, Roland Morris Disability Index	The CLBP group displayed significantly higher levels of recruitment of the upper and lower gluteus maximus, hamstrings, and erector spinae muscles compared to the control group.
Arendt-Nielsen et al.[101]	N=20 CLBP n=10 Control n=10	CLBP: diagnosed with idiopathic CLBP with VAS>3 Control: no known back problems	CLBP: VAS < 3	Participants walked on a treadmill at 4 km/h.	Erector Spinae	VAS, sEMG,	The CLBP group demonstrated greater ES activity. The CLBP group had a significantly longer stance phase, and significantly higher EMG activity in all phases of gait. VAS rating was significantly related to mean EMG activity
Hanada et al.[56]	N=18 LBP n=9 Control n=9	≥ 50 years old, able to walk independently ≥ 14 feet, adequate hearing and vision, sufficient cognitive ability to follow instructions and provide consent. LBP: LBP symptoms for ≥ 8 months	Back pain associated with a known specific disease or pathology, spinal fracture, back surgery.	Participants walked across a pressure-sensor at self-selected speeds. Gait was divided into 4 phases.	Lower Rectus Abdominis, Internal Oblique, Longissimus (Erector Spinae), Multifidus	sEMG	The control group displayed significantly greater activation of the lower rectus abdominis and right internal oblique. The LBP group demonstrated significantly greater activation of the left longissimus and both multifidi.

Table 24. Overview of investigations of back pain using EMG (continued)

Author	Sample Size	Inclusion criteria	Exclusion criteria	Study Protocol	Muscles Tested	Outcome Measures	Results
Hodges & Richardson[57]	N=30 LBP n=15 Control n=15	<u>LBP group:</u> LBP of insidious onset of ≥18 months and sought treatment, pain severe enough to result in restricted activity & ≥3 days missed work, but minimal or no pain at time of testing.	Neurologic symptoms, observable spinal deformity, previous back surgery, neuromuscular or joint disease, or undertaken abdominal or back muscle training in previous 3 months.	10 repetitions on each shoulder of flexion and abduction to ~60°, and extension to ~40° were performed as fast as possible in response to a visual command.	Transverse Abdominis, Internal Oblique, Deltoid, Rectus, Abdominis, Multifidus	sEMG, iEMG	LBP patient's demonstrated significantly delayed activation of the Transverse Abdominis with all movements.
Newcomer et al.[64]	N=40 LBP n=20 Control n=20	Currently employed <u>CLBP:</u> pain between L1 and gluteal folds for at least 6 months <u>Control:</u> free of LBP for at least 1 year and never had an episode of LBP lasting more than 3 months.	Unable to work due to disability, pregnant/lactating, history of back surgery, pain radiating below the knee, neurologic deficit, malignancy, diabetes, vertigo, lower extremity pain, impaired joint position sense, Scoliosis with curvature >15°	5 sets of 16 footplate perturbations in 3 directions (forward, backward, toes up)	Erector Spinae, Rectus Abdominis, Transverse Abdominis	sEMG	In the toes up direction, the LBP group was significantly less likely to activate the rectus abdominis, and more likely to exhibit asymmetric muscle activation in smaller forward movements.
Danneels et al.[58]	N=152 Acute LBP n=24 CLBP n=51 Control n=77	<u>Acute:</u> pain lasting up to 12 months <u>CLBP:</u> pain lasting more than 12 months <u>Control:</u> no history of disabling LBP or known pathology	Acute symptoms, prior back surgery, scoliosis curve >10°, neuromuscular or joint disease, evidence of systemic disease, carcinoma or organ disease, fitness training for low back muscles in past 3 months	15 exercises were performed from 3 categories: strength, coordination, stabilization	Erector Spinae, Multifidus	sEMG	The CLBP group had significantly lower EMG activity of the MF during coordination exercises. No significant differences were noted between groups for stabilization exercises. The CLBP group had significantly lower activity of ES and MF during strength exercises.

Table 24. Overview of investigations of back pain using EMG (continued)

Author	Sample Size	Inclusion criteria	Exclusion criteria	Study Protocol	Muscles Tested	Outcome Measures	Results
Hubley-Kozey & Vezina[59]	N=38 LBP n=14 Control n=24	LBP: pain between the lower ribs and gluteal folds ≥ 7 weeks, no radiation below the knee Control: no known neuromuscular, orthopedic, or cardiovascular conditions, or a history of LBP	Previous spinal surgery, spinal fracture, or structural deformity such as scoliosis of spondylolisthesis. nerve root pain, neurological signs and symptoms, or complications such as tumor or infections	Participants performed a leg-lifting task which required lumbar spine stability.	Lower rectus abdominis, upper rectus abdominis, external oblique, erector spinae, multifidus	sEMG, Roland-Morris disability scale, Oswestry disability questionnaire	Temporal patterns differed between groups and among muscle sites for the LBP group. LBP group did not co-activate the muscles examined in a synchronous temporal manner
Chiou et al.[63]	N=87 LBP n=47 Control n=40	LBP: recurrent back problems Control: no history of LBP	Neurologic deficit, back surgery, unable to complete tasks due to pain.	12 static holding tasks 3 times for 5 seconds, with a combination of 3 variables: knee posture (straight/semi-flexed), trunk posture (straight/semi-flexed), loads (light, moderate, heavy)	Rectus Abdominis, External Oblique, Erector Spinae, Latissimus Dorsi	Integrated sEMG	LBP patients produced less muscular activity during static holding tasks. The knee neutral, trunk flexed, light load task can be used to differentiate LBP patients from controls
MacDonald et al.[60]	N=27 LBP n=13 Control n=14	LBP/Remission: Recurrent unilateral LBP, currently in remission, pain severe enough to require medical intervention. Control: no history of LBP.	Spinal surgery, major spinal deformities, respiratory or neurologic conditions, or any orthopedic condition that would limit ability to complete the study	Predictable and unpredictable trunk loading was compared between sides, loading conditions, and groups.	Multifidus	iEMG, sEMG	iEMG bursts: smaller in the remission group and the non-painful side. Peak sEMG: earlier on the previously painful side in the remission group. iEMG and sEMG: less after unpredictable loads in the remission group.

Abbreviations: CLBP, chronic low back pain; LBP, low back pain; sEMG, surface electromyography; iEMG, intramuscular electromyography; VAS, visual analog scale; MVC, maximal voluntary contraction

As demonstrated by Table 24, EMG has been widely used to assess muscle activation in individuals suffering from LBP under various conditions. Evaluations of isometric contraction conditions have indicated that people with LBP demonstrate increased muscle recruitment as well as disorganized activation of back muscles compared to asymptomatic individuals.[55,62] Additionally, when isometric contractions were performed against a load, sudden release of the counterforce produced alternative muscle activation patterns in healthy participants compared to symptomatic individuals, with those experiencing pain displaying co-activation as well as longer muscle reaction times.[61] Likewise, individuals with LBP demonstrated increased back muscle activation compared to pain-free participants[56,101]; however, pain-free participants exhibited increased activity of abdominal musculature.[56] Based on these findings, it appears that individuals with LBP present with a variety of disorganized and inappropriate alterations in muscle activity compared to asymptomatic controls.

Similarly, in studies investigating participants' response to loading conditions, participants with LBP demonstrated diverging responses from the healthy control group. For example, researchers found evaluation of the erector spinae and multifidi can differentiate individuals with LBP from asymptomatic participants, as those with LBP tend to display smaller amplitudes (Table 25).[60,63] In a study of individuals with recurrent, unilateral LBP, those with LBP displayed smaller intramuscular EMG bursts in the multifidus during predictable and unpredictable static loading compared to healthy participants ($p<.05$).[60] Additionally, a different group of researchers found individuals with LBP demonstrated significantly less activity of ES during a static loading condition with knees neutral, trunk flexed, and a light load ($p<.05$), which allowed them to differentiate between the LBP and control groups.[63]

Table 25. EMG amplitudes of back musculature during loading conditions

	Right Erector Spinae[a]	**Left Erector Spinae**[a]
LBP	750 μV/s	750 μV/s
Control	950 μV/s	1000 μV/s
	Predictable[b]	**Unpredictable**[b]
Previously Painful Side	250 μV	275 μV
Non-Painful Side	175 μV	200 μV
Control Group	300 μV	350 μV

[a] Integrated EMG burst
[b] Root mean square EMG amplitude

Comparably, in an investigation of different types of exercise, researchers noted participants with LBP demonstrated decreased activity of the iliocostalis lumborum (p=.003) during strength activities and decreased activity of the multifidus during strength and coordination activities (p=.017 and p=.013, respectively) compared to asymptomatic controls.[58] The reports of decreased back muscle activity in individuals with LBP contradict the findings during isometric contractions as well as during gait,[56,62,101] which suggests the response of back muscles in LBP patients varies between situations for each patient.

Further, in evaluations of activities requiring core stability, researchers have noted delayed and disorganized activation of core musculature in individuals with LBP.[57,59,64] In particular, the transversus abdominis displayed delayed onset of activity during rapid shoulder movement.[57] Similarly, individuals with LBP were less likely to activate the rectus abdominis when standing on a footplate and experience sudden movements of the footplate in various directions.[64] Also, in a supine leg lift stability exercise, LBP patients displayed lack of synergistic core muscle co-activation (Table 26).[59] Altogether, it is evident individuals with LBP demonstrate alterations in core muscle activity compared to asymptomatic controls, although the differences are inconsistent based on the activity being tested.

Table 26. Coefficient of variation for each muscle for each group

	Lower Rectus Abdominis	Upper Rectus Abdominis	Right External Oblique	Left External Oblique	Erector Spinae	Right Multifidus	Left Multifidus
Control	6.5%	6.0%	4.6%	5.2%	4.7%	4.1%	4.5%
LBP	13.5%	9.0%	10.4%	10.7%	7.4%	6.6%	8.3%

2.6.2. Gait

EMG has been implemented in various investigations of gait to assess amount and patterns of muscle activation in individuals with LBP. In two studies by van der Hulst et al.[25,49] researchers compared muscle activation during gait in individuals with chronic low back pain (CLBP) to a control group of asymptomatic participants. In the initial study, the researchers explored whether patients with CLBP demonstrated abnormalities in erector spinae (ES) muscle action (guarded movement) during walking when compared to a healthy control group.[25] To observe bilateral ES activity during gait, participants walked on a treadmill at a speed of 3.8 km/h with surface EMG (sEMG) electrodes placed bilaterally on the muscle belly of the ES at the levels of L1 and L4.[25] Precise electrode location was determined according to the surface electromyography for the non-invasive assessment of muscles (SENIAM) guidelines.[102] Smooth rectified EMG (SRE) values per stride were calculated and divided into four periods including initial double support, contralateral swing, second period of double support, and ipsilateral swing phase.[25] Additionally, the ratio of SRE values in swing to double support was used as a measure of relative relaxation (SRE ratio). Overall, the objective of this study was to determine if the presence of CLBP is characterized by guarded movement or increased lumbar muscle activity during walking.

After analyzing EMG recordings, the researchers observed variances in ES activity between healthy controls and individuals with CLBP. Results from averaging SRE values per stride revealed sEMG activity was highest in double support and lowest in ipsilateral or contralateral swing for both groups. Additionally, analysis of SRE values per period of stride revealed the averaged natural logarithm SRE values were 16%-28% higher in patients compared to controls for all recording sites in all periods of stride. However, the interaction between groups and periods of stride was not statistically significant. When researchers evaluated the SRE ratio, the comparable ratios indicated activity during swing compared to double support was similar between groups. Based on these findings, the researchers concluded that patients with CLBP present with increased absolute ES activity levels during both the swing and double support phases; however, relative relaxation during the swing phase is comparable between groups.[25] This increased muscle activity may be a factor contributing to the patients' experiences of chronic pain.

Furthermore, variables related to perceived disability were assessed utilizing questionnaires to quantify the severity of disability. Factors analyzed included pain intensity, fear of movement, and level of activity limitation, assessed via visual analogue scale (VAS), Tampa Scale for Kinesiophobia (TSK), and the Roland Morris Disability Questionnaire (RMDQ), respectively.[25] The researchers' goal was to determine whether there was a relationship between SRE values and ratios and any of the above patient reported outcome measures. Ultimately, it was concluded there was no significant association between SRE values in different periods of stride and pain, disability, or fear avoidance beliefs. Additionally, there was no significant influence of the aforementioned variables on the SRE ratio.[25] Overall, there is not enough information to say a relationship exists between ES activity and perceived disability.

In a subsequent study, van der Hulst et al.[49] built upon previous findings by analyzing activity of abdominal muscles in addition to the ES in participants with and without CLBP. To assess muscle activity, the electrode placements on the ES at L1 and L4 were replicated from the previous study.[25,49] Diverging from the prior study, sEMG measurements of the rectus abdominis (RA) and external oblique (EO) were also included.[49] The researchers found the SRE values per stride corresponded to those of the initial study,[25] indicating the mean ES SRE values were an average of 1.2 times higher in the CLBP group compared to the control, in all four periods.[49] Similarly, the average RA SRE were an average of 1.36 times higher in the CLBP group compared to the control. Finally, when the EO was evaluated, the average SRE values were comparable between groups.[49] Taken together, the findings of these two studies indicate individuals with CLBP demonstrate increased activity of the ES[25,49] as well as the RA[49] compared to asymptomatic individuals.

To enhance previous findings, the researchers evaluated muscle activity at various walking speeds, ranging from 1.4-5.4 km/h, to determine the effect of velocity on muscle activation.[49] For all three muscles, SRE values were significantly higher in periods of double support compared to swing, and there was a significant interaction between velocity and period of stride for the ES only ($p<.001$). Finally, all three muscles displayed increased activity with higher walking velocities, although there was no significant interaction between velocity and group.[49] Thus, walking velocity results in increased muscle activity regardless of the presence or absence of CLBP.

The conclusion that ES activity is increased in individuals with LBP is further supported by a study by Lamoth et al.,[24] who compared thoracic (T12) and lumbar (L2 and L4) ES activity in healthy individuals to those with CLBP while walking at a range of speeds. Initial sEMG recordings were obtained as participants walked at their natural walking speed followed by assessment at a range of prescribed velocities. Unsurprisingly, the average comfortable walking velocity for the CLBP group was significantly lower than the control group ($p<.001$). As evidenced by Table 26, at the natural walking speed, the CLBP group demonstrated increased ES amplitudes compared to the control group. Aligning with the findings of van der Hulst et al.,[25,49] lumbar ES amplitudes were significantly greater in the CLBP group during both the ipsilateral (51%) and contralateral (68%) swing phases.[24] Additionally, average thoracic ES activity increased 48% in the ipsilateral swing phase only.[24] However, during the double stance phase, no significant effect of CLBP or velocity on lumbar ES activity was found (Table 27). Ultimately, analogous to conclusions made by van der Hulst et al.,[25,49] the researchers concluded lumbar ES activity is increased in participants with CLBP compared to controls.[24]

Table 27. Increase in ES activity in CLBP group compared to control at natural walking velocity

	Left T12	**Right T12**	**Left L2**	**Right L2**	**Left L4**	**Right L4**
Ipsilateral Swing	p=.02	p=.01	p=.03	p=.01	p<.01	p<.01
Contralateral Swing			p=.07*	p<.03	p=.02	p<.01

*Not significant

While in the previously described study van der Hulst et al.[49] conducted measurements at varying speeds, this analysis by Lamoth et al.[24] assessed a wider range of speeds (1.4 km/h to 7.0 km/h); therefore, these findings provide more thorough information regarding muscle activity at the full range of speeds pertinent to activities of daily living. For the assessment of various gait velocities, participants began walking at a speed of 1.4 km/h, and the speed was increased by 0.8 km/h until the participants reached their maximally attainable velocity. Parallel to the findings of van der Hulst et al.[49] who reported increased muscle activity at greater velocities, the researchers reported that in both groups, as walking velocity increased, the mean lumbar ES amplitude decreased during the swing phase up to a velocity of 4.6 km/h, followed by an increase in amplitude (p<.01).[24] In addition, the amplitudes for both lumbar ES measurements (L2 and L4) were significantly larger during the swing phase in the CLBP group compared to the control group (p<.05); however, there was no significant effect of velocity during double stance.[24]

Therefore, it can be concluded that gait velocity plays a role in ES activation; however, it does not appear to be a factor specific to individuals with LBP.

Furthermore, Lamoth et al.[24] analyzed variations of muscle activation patterns of the ES in individuals experiencing CLBP compared to a control group during treadmill walking at self-selected speeds as well as prescribed velocities.[24] The researchers found several differences between groups including smaller variability of the global pattern in the CLBP group compared to the control group for both the left and right lumbar ES at both the natural walking speed ($p<.01$) and the prescribed velocities ($p=.04$). Furthermore, at both the prescribed ($p=.03$) and natural walking ($p<.01$) velocities, the residual variability of the left and right lumbar ES was larger in the CLBP group compared to the control. In addition to the smaller contribution to the global pattern, the CLBP group displayed obvious deviations from the normal lumbar ES activity pattern. Based on these findings, lumbar ES activity is less coordinated in people with CLBP in comparison to healthy individuals.[24]

The final component analyzed in this study was the relationship between ES activation and measures of perceived disability. The researchers implemented the same measures used in the initial study by van der Hulst et al.[25] for pain, disability, and fear avoidance beliefs (VAS, RMDQ, and TSK, respectively).[24] The findings regarding these factors paralleled those of van der Hulst et al.,[25] indicating no correlation between observed changes in EMG variables and pain intensity, anticipated pain, disability, and fear-avoidance.[24]

In a follow-up study utilizing the same sample of participants, Lamoth et al.[50] confirmed their initial findings, indicating that individuals with LBP demonstrate less coordinated ES activity.[24,50] Moreover, they expanded upon their previous findings by examining lumbar ES activity patterns following perturbations in walking velocity.[50] Lumbar ES electrode placement replicated the prior study,[24] and measurements were conducted at six different walking velocities for 30 seconds each not allowing participants time to habituate to each new speed.[50] Assessment of global and residual patterns of ES activity revealed significant differences in activity between the control and CLBP group.[50] Significant effects based on results of ANOVAs for velocity and groups (control vs LBP) and post-hoc t-tests are presented in Table 28.[50] Similar to the previous study,[24] the CLBP group had a smaller contribution to the global pattern as well as greater variability of the residual pattern of ES activity at all velocities.[50] Participants with CLBP demonstrated less adaptability of the lumbar ES to changes in velocity, and a notable increase in variability of the residual pattern, primarily at higher velocities. Thus, similar to the initial study in which the researchers found decreased coordination of the lumbar ES in individuals with CLBP,[24] the researchers determined the CLBP group demonstrated decreased control of the lumbar ES when adapting to perturbations in walking velocity.[50]

Table 28. Significant effects of walking velocity and group (control vs CLBP) on the variability of the global and residual pattern of left and right lumbar erector spinae (LES) activity, and significant effects of post-hoc analyses[a]

Variability LES	**ANOVA**			**Post-hoc test**			
	Velocity	**Velocity x Group**	**Group**	**6.2 km/h**	**5.4 km/h**	**2.2 km/h**	**4.6 km/h**
Global pattern							
Left LES	p<.01	p=.03	p=.03	p=.02	p<.01		p=.01
Right LES	p<.01	p<.01	p<.01	p=.01	p<.01	p=.04	p<.01
Residual pattern							
Left LES	p<.01	p=.01	p=.02	p=.02	p<.01	p=.04	p=.01
Right LES	p<.01	p<.01	p<.01	p<.01	p<.01	p=.03	p<.01

[a]adapted from Lamoth et al.[50]

In an assessment of abdominal muscle activity during gait, Kim et al.[22] analyzed changes in activation of back and abdominal musculature between participants with and without LBP. Utilizing sEMG recordings of the RA, EO, and internal oblique (IO) normalized to sub-maximal voluntary isometric contraction (sub-MVIC), the researchers found the right internal oblique (IO) was the only muscle that demonstrated a significant difference in activation. Specifically, the

LBP group displayed a significant decrease in activity during the left swing (p=.046) and 2nd double support phase (p=.009). This finding opposes that of van der Hulst et al.,[49] who reported increased activity of the RA in participants with CLBP compared to the healthy control group. Furthermore, Kim et al.[22] separated LBP participants into two groups based on pain severity measured by VAS. Groups included low level pain (LLBP, VAS <5/10) and high level pain (HLBP, VAS≥5/10); however, no significant differences in muscle activity were noted between the HLBP and LLBP groups. Therefore, the authors concluded no significant difference in abdominal muscle activity based on pain intensity.[22]

Another notable component of this study was the relationship between muscle activity and measures of perceived disability.[22] Fear-avoidance beliefs were assessed using the Fear-Avoidance Beliefs Questionnaire (FABQ), pain intensity was measured via VAS, and disability was quantified using the modified Oswestry Disability Index (ODI) and the RMDQ.[22] Unsurprisingly, the HLBP group presented with significantly higher VAS (p<.001) and RMDQ scores compared to the LLBP group (p=.004). In opposition to previous findings,[24,25] relationships were noted between muscle activation and measures of perceived disability. The researchers reported disability via ODI was significantly correlated with left IO activity (p<.05), and fear-avoidance belief via FABQ was significantly correlated with right EO activation (p<.05).[22] However, because activation of the left IO and right EO were not associated with CLBP, this relationship is likely not indicative of back pain.

Echoing the methodology implemented by Kim et al.,[22] Pakzad et al.[23] investigated differences in muscle activity during walking in participants grouped by pain intensity (e.g. HLBP, LLBP, control). sEMG recordings were taken of the RA, EO, longissimus (ESL), iliocostalis (ESI), and multifidus (MF), and normalized to sub-MVIC.[23] A significant main effect of group was found for the MF bilaterally (right p=.016, left p=.026) and for the left RA (p=.016), with the HLBP group having significantly higher amplitudes compared to controls. The conclusion stating abdominal and back muscle activity is increased in individuals with LBP aligns with the results of several previously discussed studies.[24,25,49] Although significant differences were found between the HLBP and control groups, similar to the findings of Kim et al.[22] the researchers did not report any significant differences in EMG amplitude between the HLBP and LLBP groups.[23]

In addition to assessing the overall relationship between muscle activation and gait, Pakzad et al.[23] analyzed the four phases of stride. Significant interactions between group and phase of gait were noted in the bilateral EO (right p=.015, left p=.014) and ESI (right p=.033, left p=.048). Further analysis revealed elevated EO activation in the HLBP group during ipsilateral double support and contralateral swing. Conversely, the ESI demonstrated fewer clear changes in EMG amplitude but increased variability in EMG activation for the control and LLBP groups between phases of gait. As a result, the researchers suggested the interaction may be the result of reduced variability in muscle activation between phases of gait for the HLBP group. These data reinforce findings of the abovementioned studies,[22,24,25,49] suggesting that increased trunk muscle activity is associated with LBP.[23]

Similar to several of the previously discussed studies,[22,24,25] Pakzad et al.[23] examined the relationship between muscle activity and clinical measures of perceived disability. Measurements included the Pain Catastrophizing Scale (PCS), numeric pain rating scale (NPRS), ODI, and FABQ. Significant relationships were found between EMG amplitudes and PCS scores controlling for NPRS scores and gait speed in seven out of 10 muscles. The three exceptions were right ESL, right ESI, and left ESI. Although these specific clinical measures were unique to this study, the association between measures of perceived disability and muscle activation aligns with the findings of Kim et al.[22]; however, it opposes the findings of van der Hulst et al.[25] and Lamoth et al.[24] Based on these findings, the researchers concluded that activation of many trunk muscles during gait at self-selected velocities is higher in individuals with CLBP who demonstrate elevated PCS scores (e.g. HLBP group) compared to controls.[23]

Based on the existing body of literature regarding LBP and muscle activation during gait, it can be concluded that individuals with LBP demonstrate less coordinated and increased overall activity of the erector spinae compared to healthy individuals.[23–25,49,50] Additionally, individuals with LBP may display increased co-activation of the ES and RA compared to healthy controls.[49] Finally, it is unclear whether there is a relationship between muscle activation and clinical measures of perceived disability due to the conflicting conclusions of related studies.[22–25] Taken together, these findings suggest that back and abdominal muscle activation and control/coordination should be a consideration in individuals presenting with LBP.

2.6.3. Standing

In an effort to determine whether muscle co-activation is a factor in LBP development, Nelson-Wong and Callaghan[51] assessed co-activation of the gluteus medius (GM) in asymptomatic individuals completing a prolonged period of standing. Participants were required to have no history of LBP, and they performed simulated occupational tasks during two hours of standing in a confined area. Tasks included sorting and small object assembly, as well as a boredom period to assess the effect of distraction on pain. A 100 mm VAS was utilized to quantify pain levels throughout, and if participants reported changes in VAS greater than 10 mm during the two hour standing period, they were considered to be pain developers.[51] Eight different muscles were analyzed including the thoracic ES (T9), lumbar ES (L1), latissimus dorsi

(LD), RA, IR, EO, GM, and gluteus maximus (GMx). In addition, a standardized clinical assessment was performed including various strength and range of motion tests. The right GM was used as the reference muscle since it is the most distal of the selected muscles.[51] The goal of this methodology was to identify whether co-activation is predictive of, or a response to, LBP development.

The researchers determined that the presence of muscle co-activation during standing may be useful for early identification of at-risk individuals.[51] Based on the VAS measurements, the researchers reported 40% of participants developed LBP during the two hour standing period. Further, there was a significant interaction of time and group ($p<.001$). Based on the clinical assessment, the researchers indicated hip abduction strength may be a good predictor of LBP development (specificity of 0.85), as individuals who developed LBP (PD group) struggled to maintain the frontal plane position of the pelvis during active hip abduction in side-lying compared to those who did not develop pain (NPD group). In general, participants demonstrated similar activation patterns with trunk muscles activating prior to the right GM. Therefore, a primarily inferior-superior control method was demonstrated amongst both groups.[51]

As a whole, co-activation of the hip abductors and to a smaller degree the trunk flexor-extensors, were an indicator for potential development of LBP.[51] Analysis revealed significant time by group interactions for each of the trunk flexor-extensor combinations with the PD group displaying greater levels of muscle co-activation compared to the NPD group.[51] Furthermore, when global flexor-extensor co-activation was calculated, the significant time by group interaction remained ($p<.01$). Additionally, there was a time by group interaction for bilateral GM with the PD group having significantly higher amounts of bilateral GM co-activation during the first and last 30 min of standing ($p<.05$). In the period from 30-90 min, the PD group showed a decrease in trunk muscle co-activation with increasing VAS ratings while the NPD group displayed the opposite pattern. During this period, there was a strong negative correlation between VAS score and co-contraction index for bilateral GM and trunk flexor-extensor groups (r=-0.73 and r=-0.92, respectively). Moreover, the co-contraction indices for those muscle groups were negatively correlated (r=-0.39 for GM and r=-0.18 for trunk flexor-extensors), thus indicating different muscle co-activation patterns for the PD and NPD groups. Participants who developed pain demonstrated bilateral gluteus medius and trunk flexor-extensor muscle co-activation prior to reports of pain development indicating that co-activation is a potential cause of LBP rather than an adaptive response.[51]

In a similar assessment of muscle co-activation during standing, Marshall et al.[66] measured strength, endurance, and co-activation of the GM in asymptomatic individuals. Similar to the previously discussed study,[51] participants rated their pain on a 100 mm VAS throughout a two-hour standing period.[66] Additionally, participants completed four simulated occupational activities throughout the standing period including assembly of retractable pens, currency sorting, grocery store checkout, and card dealing.[66] Surface EMG electrodes were applied bilaterally to the GM, and participants' strength and endurance were tested before and after completion of the standing protocol. Strength was quantified by side-lying maximal isometric hip abduction, and bilateral side bridge endurance was measured via force transducer with concurrent EMG recordings.[66] Mirroring the aforementioned study,[51] patients were placed in the LBP group if they reported greater than a 10 mm increase in VAS score during the two-hour standing period.[66]

After reviewing VAS reports, the researchers found 71% of the previously asymptomatic participants developed LBP during the two-hour standing period,[66] a much larger proportion compared to the 40% reported by Nelson-Wong and Callaghan.[51] In agreement with reports of the abovementioned study,[51] there was a significant time by group interaction (p<.001).[66] Analysis of strength revealed no differences between groups before the standing protocol. However, after the two-hour standing period, hip abduction strength was significantly reduced for all participants (p=.003). This finding does not correspond to the findings of Nelson-Wong and Callaghan,[51] who found hip abduction strength may be good at predicting development of LBP due to its high specificity. Participants who did not develop pain demonstrated higher side-bridge endurance times both before and after the standing protocol (p<.001) while LBP group displayed an increased rate of fatigue for contralateral GM during the side-bridge test (p=.03).[66] Consistent with the findings of Nelson-Wong and Callaghan,[51] the researchers reported a significant between-groups difference for bilateral GM co-activation, with the LBP group demonstrating a greater degree of co-activation (p=.002).[66] Moreover, supporting the assertion that hip abduction strength can be an indicator of LBP development,[51] Marshall et al.[66] found side-bridge endurance and hip strength prior to the standing period were significantly associated with GM co-activation during standing (p=.005). Consequently, the researchers concluded that side-bridge endurance and GM co-activation may be useful for identifying individuals at risk for developing LBP.[66]

While the two previously discussed studies have assessed muscle activation and back pain during standing in the general population,[51,66] it should be considered that findings may differ in an athletic population. Bussey et al.[67] examined the effect of prolonged standing on GM co-activation and development of LBP in elite field hockey players. Participants with and without a history of LBP completed the ODI to assess severity of disability, and participants were excluded if they had an ODI score greater than 20%, which indicated the participant had too much pain/disability. Akin to the methodology described above,[51,66] hip strength was measured with a force transducer during a hip abduction test, and endurance was measured via side bridge hold; additionally, the researchers assessed hip abduction range of motion.[67] Surface EMG electrodes were placed bilaterally on the GM according to SENIAM guidelines,[102] and participants were instructed to stand on a force plate for 70 minutes. Aligning with previously implemented methodology,[51,66] a 100 mm VAS was used to measure pain, and participants who reported greater than a 10 mm increase in pain throughout the standing period were placed in the LBP group. VAS scores were reported at the beginning, end, and every 10 minutes throughout the 70 minutes session.

In total, 36% of participants developed LBP (PD group) during the prolonged standing period.[67] This proportion aligns with reports of Nelson-Wong et al.[51] who reported 40% of participants develop LBP; conversely, it is much less than the 71% reported by Marshall et al.[66] Of the 36% of participants in the PD group, 11 reported a history of LBP, while three did not. Baseline VAS scores and ODI scores were significantly higher in the PD group (p=.022 and p=.002, respectively). Additionally, the PD group demonstrated significantly decreased hip abduction range of motion compared to the NP group (p=.02). Similar to the findings of Marshall et al.,[66] the researchers did not find a significant effect of strength between groups[67]; however, this opposes the report that hip abduction strength is a good predictor of LBP development.[51] In contrast to the findings of the aforementioned study,[66] Bussey et al.[67] did not find a between group effect for GM endurance.

In order to assess the effect of history of LBP, the researchers examined the mean GM co-activation across time for all groups (PD with history, PD without history, NP with history, NP without history).[67] Interestingly, athletes with a history of LBP displayed slightly lower mean co-activation. Further, the researchers noted a significant effect of time on GM co-activation (p=.003)[67] with co-activation decreasing over time. As seen in Table 29, examination of group differences at each 10-minute time block showed significant differences between the PD and NP groups at several time periods.[67] Similar to previous findings,[51,66] when VAS scores were assessed, the researchers noted a significant time effect (p<.001) and a significant group by time interaction (p<.001) with the PD group displaying higher VAS scores at the 10 minute mark, which consistently increased throughout the standing period.[67] As a whole, the PD group experienced greater GM co-activation than the NP group; furthermore, participants with a history of LBP were more likely to develop pain throughout the standing period.

Table 29. Significant between group differences over time

Time (min)	**10**	**20**	**50**	**60**	**70**
p-value	0.027	0.008	0.013	0.009	0.012

The consensus within the literature regarding back pain and muscle activation during prolonged periods of standing is those who develop LBP demonstrate co-activation of the GM muscles[51,66,67]; therefore, GM co-activation during standing may help identify individuals at risk for developing LBP. Additionally, hip abductor strength and endurance may be helpful for identifying individuals at risk for developing LBP. While Nelson-Wong et al.[51] found hip abduction strength may be good at predicting development of LBP due to its high specificity, other researchers found that hip abduction strength was not a predictor of LBP.[66,67] Further, while one researcher suggested that lower side bridge endurance times may indicate an increased risk for developing LBP,[66] another did not find this relationship.[67] Overall, the data regarding hip abduction strength and endurance being a predictor for development of LBP is conflicting.

2.6.4. Predictive

LBP is a complex problem involving several factors, rendering prediction and prevention of LBP difficult. Based on conclusions drawn from previous studies, it is apparent muscle activity differs in individuals suffering from LBP compared to asymptomatic controls[23–25,49–51,66,67]; however, it is still unclear which risk factors remain most indicative of LBP development. Therefore, researchers have assessed several methods for predicting LBP, one of those being EMG.

In an investigation of asymptomatic individuals, researchers evaluated differences in trunk and hip muscle activation during a prolonged standing period to determine whether muscle activity patterns could be used to predict LBP.[52] The procedure required participants to stand in a confined area for two hours while completing four different simulated occupational tasks for 30 minutes each. Task order was randomized and included assembly of retractable pens, currency sorting, grocery store checkout, and card dealing. Surface EMG recordings of the lumbar ES, thoracic ES, RA, EO, and gluteus medius (GM) were collected and normalized to MVC. Participants rated their LBP on a 100mm VAS at the start, the end, and every 15 minutes throughout the standing period. VAS scores were collected by an independent examiner, and data were not shared until a blinded classification of participants into LBP and non-LBP groups was completed.[52]

Blind predictions were made using muscle coordination information to make predictions regarding which participants would develop LBP.[52] Cross-correlation analyses was used to assess muscle coordination, where R_{xy} represents the normalized cross-correlation of two signals. A highly positive correlation indicated two signals were acting together in phase, and a highly negative correlation indicated one signal was at a maximum and one was at a minimum. Upon initial examination, researchers noted drastically different patterns in R_{xy} values for left GM cross-correlated with right GM (R_{xy} – LGM – RGM) among participants. Therefore, participants were placed into the LBP or non-LBP category based on their R_{xy} – LGM – RGM values, with participants with positive R_{xy} values predicted to develop LBP, and those with negative R_{xy} values predicted as non-LBP. Finally, all VAS ratings were reviewed and predicted pain categories were compared with actual pain categories. The LBP group consisted of participants who reported a VAS rating greater than 20 mm at any point during the study, as well as an average rating greater than 10 mm. Overall, the researchers reported that 65% of participants developed high levels of back pain during the two-hour period of standing.[52]

As a whole, the researchers successfully predicted pain categories. In total, 74% of participants were placed in the correct group based upon the R_{xy} – LGM – RGM value, resulting in a sensitivity of 0.87 and a specificity of 0.50.[52] Review of VAS ratings revealed significant main effects of time (p=.000) and group (p=.001). Additionally, a significant interaction was noted between group and time (p=.000), indicating a difference between the LBP group and the non-LBP group VAS ratings over the two hours. Moreover, there were significant findings regarding co-activation of bilateral GM, and lumbar ES with EO (Table 29). Further assessment of co-activation of bilateral GM as well as lumbar ES/EO revealed no main effects of time or group when data for all participants were analyzed. However, analysis of only the 17 correctly predicted participants revealed a significant effect of co-activation and group. (Table 30).[52] Ultimately, participants who remained relatively asymptomatic throughout the standing period demonstrated synergistic, reciprocal activation of the bilateral GM muscles, whereas participants who developed LBP demonstrated co-activation of the bilateral GM muscles. Because this muscle activation pattern exists prior to the onset of pain, it may be a useful predictor for development of LBP. Additionally, it should be considered that co-activation may be a cause of pain rather than a response to it.[52]

Table 30. Co-activation of GM and lumbar ES/EO

All Participants (N=24)	
	Group
R_{xy} – LGM – RGM	P=.144
R_{xy} – LLES – LEO	P=.091
R_{xy} – RLES – REO	P=.123
Correctly Predicted Participants (N=17)	
R_{xy} – LGM – RGM	P=.002*
R_{xy} – LLES – LEO	P=.010*
R_{xy} – RLES – REO	P=.106

*significant

Akin to the aforementioned study, Heydari et al.[53] utilized EMG recordings to determine if they could be used as a prognostic indicator in LBP development. At the time of initial assessment, participants were assessed for symptoms of LBP via clinical assessment and subjective disability questionnaires and were classified into one of three groups: no-history, chronic, or past history. Surface EMG recordings of the ES were conducted while participants performed a 30-second isometric contraction at 2/3 of their determined MVC. Variables extracted from EMG data for analysis included initial mean frequency (IMF), median frequency slope (MF slope), and half-width (HW). In contrast to the methods of Nelson-Wong et al.,[52] the researchers analyzed changes in EMG measurements within subjects over time.[53] Two years later, participants self-identified as worse, better, or the same. Additionally, the same assessments were repeated, and work loss records for the two-year period were examined to determine if the change in EMG recordings over time could be used for prognosis purposes.[53]

Participants' subjective classification at follow-up paired with analysis of EMG variables indicated IMF, MF slope, and HW all have the ability to identify those at risk for developing LBP.[53] At the follow-up session, 72.4% of participants self-identified as unchanged, 12.4%

identified as better, and 15.2% identified as worse. IMF and MF slope were predictive of increased incidence of LBP in the no-history group. Participants with IMF values greater than 49 Hz had a relative risk of 5.8 (p=.014), representing a 5.8-fold increased risk of developing LBP compared to the rest of the population. Additionally, those with an MF slope less than -.2077 had a relative risk of 3.6 (p=.03). HW was associated with clinical changes over time, as mean HW increased for the worse group and decreased for the better group. The researchers determined HW could be used to distinguish those at increased risk for developing LBP. Of participants with no-history or past history of back pain, 32.2% had an initial HW of greater than 56 Hz, and the relative risk for back pain in this group was 2.7 (p=.05). Moreover, 31.7% of participants with no history of back pain had an initial HW greater than 56 Hz, with a relative risk for pack pain of 3.01 (p=.045) indicating a threefold greater risk of developing LBP. Based on these findings, the researchers concluded the examined EMG variables are capable of identifying individuals with greater likelihood of developing LBP.[53]

An additional component of interest was the predictive ability of EMG variables based on perceived disability measurements.[53] At the initial and follow-up assessments, participants completed the Low Back Outcome Score (LBOS), which was used to quantify disability. An initial HW greater than 56 Hz was observed in 31.7% of participants with no-history (RR=4.3, p=.075), and 37.5% of individuals with no-history or past history of LBP (RR=5.0, p=.04). These findings indicate when LBOS scores are used, HW is a superior predictor of LBP compared to self-rating data. Conversely, IMG and MF slope were not predictive when LBOS was used.[53] Taken as a whole, Heydari et al.[53] concluded sEMG of the lumbar ES can be implemented to identify a subgroup of individuals at increased risk for developing LBP.

Although the complexity of LBP makes it difficult to predict what factors may contribute to its development, these studies provide a foundation to be built upon regarding use of EMG as a predictive measure for LBP development. GM co-activation was successful at predicting LBP over 70% of the time.[52] Further, there is evidence that IMF, MF, and HW can be utilized in various populations as predictors of LBP development.[53] Taken together, the outcomes of these studies indicate EMG may be able to serve as a prognostic indicator for developing LBP.

2.6.5. Functional Activity

In order to assess muscle activity during functional movements, Santos et al.[47] analyzed differences in hip and trunk muscle activation during a kneeling to half-kneeling task in participants with CLBP compared to a control group. The task required participants to begin in a kneeling position with their knees pelvis width apart. Next, while maintaining an upright position of the trunk, participants moved to a half-kneeling position by flexing the right hip and bringing the right foot forward while maintaining the left knee on the ground. The task was completed when a stable, half-kneeling position was attained, with body weight distributed on the right knee and left foot. At the time of data collection, participants in the CLBP group were pain-free and the task did not induce pain. Surface EMG electrodes were placed bilaterally on the GM, IO, and lumbar ES at the level of L2, and EMG amplitudes were normalized with the average of the filtered values of muscle activity during the task.[47]

Participants in the CLBP group demonstrated different patterns of motor planning activity compared to the control group.[47] As indicated in Table 31, the control group showed higher peak amplitudes and earlier times of peak amplitude for the bilateral IO and GM compared to the CLBP group. Conversely, the CLBP group displayed higher peak amplitudes and earlier times of peak amplitude for bilateral lumbar ES muscles compared to the control group. In addition, the control group had increased activity (integrated linear envelope) of the right IO and bilateral GM, while the CLBP group demonstrated increased activity of the bilateral LES muscles (Table 31).[47] As a whole, participants with CLBP tend to recruit the lumbar ES muscles whereas the control group primarily utilized abdominal and hip muscles to complete the kneeling to half-kneeling task. Thus, it was concluded that the lumbopelvic control during the task differs between individuals with CLBP and asymptomatic controls.[47]

Table 31. Significant differences between groups for EMG parameters

Muscles	**Control**	**CLBP**	**Control**	**CLBP**	**Control**	**CLBP**
	Peak Amplitudes		**Time of Peak Amplitude**		**Integrated Linear Envelope**	
R IO	p=.001	--	p=.002	--	p<.021	--
L IO	p=.014	--	p=.026	--	--	--
R GM	p=.007	--	p=.001	--	p=.004	--
L GM	p<.001	--	p<.001	--	p=.001	--
R ES	--	p=.003	--	p=.003	--	p<.001
L ES	--	p<.001	--	p<.001	--	p<.001

Abbreviations: R, right; L, left

Similar to the goal of the previous study,[47] Ferguson et al.[48] conducted an investigation of muscle activation during manual material handling tasks in individuals with and without LBP. Temporal EMG components included start time, peak time, and duration of activity. Surface EMG electrodes were placed on the ES, LD, RA, EO, and IO. The lifting tasks utilized weights of 4.5 kg, 6.8 kg, 9.1 kg, and 11.4 kg, as these are considered weights for light duty; therefore, these are weight levels that employees with back injuries would likely be lifting upon returning to work. Additionally, lifting conditions started from five different origins including shoulder, waist, knee, waist-far, and knee-far, where the far conditions had a horizontal moment arm of 60 cm compared to 30 cm in the other conditions.

Overall, the researchers determined individuals with LBP experience increased muscle activity for greater lengths of time compared to asymptomatic controls.[48] Results of the mixed model are displayed in Table 32. Evaluation of EMG start time revealed the LBP group exhibited significantly different muscle activation start times compared to the control group, and these differences were influenced by lift region. Accordingly, the LBP group demonstrated significantly earlier activation in the shoulder and waist lifting regions compared to the control group. In contrast to the conclusions of Santos et al.[47] who reported earlier times of peak amplitude for the ES in the LBP group and for the IO and GM in the control group, Ferguson et al.[48] found no influence by group overall, although differences between groups were influenced by region of lift. Lastly, duration of EMG was longer in the LBP group than the control group, and in many muscles the difference was significantly influenced by region and asymmetry. In summary, comparable to the conclusions of Santos et al.,[47] the researchers found the LBP group demonstrated increase muscle activity in comparison to asymptomatic controls.[48]

Table 32. Results for temporal EMG parameters between groups (LBP vs Control)[a]

Effect	**P-values for mixed model**									
	R-LD	**L-LD**	**R- ES**	**L-ES**	**R-RA**	**L-RA**	**R-EO**	**L-EO**	**R-IO**	**L-IO**
Group	D		S D	S D			D	D		
Group x Region	P	P	P D	D	S P D	S P D	P	S P	P	S D
Group x Weight	D	D								
Group x Asymmetry		S D	S D	S D			P	P	S	
Group x Region x Asymmetry	P	S	S D							
Group x Weight x Asymmetry					P					

Abbreviations: D, significant difference in duration of activation; S, significant difference in start times; P, significant difference in peak times; R, right; L, left

[a]adapted from Ferguson et al.[48]

As a whole, it appears individuals experiencing back pain demonstrate different movement patterns compared to their asymptomatic counterparts during performance of functional tasks. The studies discussed demonstrate those with LBP display increased muscle activity as well as altered muscular control when completing practical activities such as kneeling and lifting.

2.7. Muscle Activation during Load Carriage

2.7.1. Introduction

Load carriage is defined as an external load carried by professionals as part of the demands associated with their occupation.[1,10] Long road marches are a substantial component of military training, and such marching often includes carrying loads consisting of weapons, equipment, body armor, and other protective gear and supplies.[1] Biomechanical factors associated with load carriage may have an impact on injury risk, and there are many factors to consider when conducting a biomechanical evaluation of load carriage.[2,29,36,37,103–105] Some factors include weight of the load, location of the load, and weight of the individual carrying the load.[103–106] Several studies have evaluated kinetic and kinematic effects of load carriage as well as other physiological measurements, including heart rate and VO_2, in the military population.[1,3–6,105,107] The body of literature using EMG to investigate changes in muscle activation during load carriage is relatively small, and interestingly the majority of this research is not focused on military personnel (Table 33).

Table 33. Analyses of muscle activation during load carriage

Author	Sample	Purpose	Muscles Tested	Conclusion
Lindner et al.[7]	37 German Air Force Soldiers (Age M=29, range 20-53)	Analyze lower extremity muscle activity with progressive addition of equipment	peroneus longus, gastrocnemius lateralis, gastrocnemius medialis, tibialis anterior, rectus femoris, biceps femoris	Changes in muscle activation were dependent on the weight of the equipment added.
Park et al.[8]	7 male military training university students	Investigate the effect of weight and distribution of weight on leg muscle activation	Rectus femoris, biceps femoris, tibialis anterior, medial gastrocnemius	Increasing loads, especially with uneven distribution of weight, should be avoided due to negative effects on balance and muscle function.
Silder et al.[3]	N=29 Males n=17 (Age 31±7) Females n=12 (Age 36±8)	Compare the effects of load carriage on muscle activation costs between men and women walking at a self-selected speed	Soleus, medial gastrocnemius, tibialis anterior, medial hamstrings, lateral hamstrings, vastus lateralis, rectus femoris	Men and women adopt similar gait adaptations when carrying loads determined by a percentage of body weight.
Simpson et al.[4]	15 female recreational hikers (Age 22.3±3.9)	Investigate the effect of prolonged load carriage on muscle activity of the lower extremity in female recreational hikers	Vastus lateralis, biceps femoris, semitendinosis, tibialis anterior, gastrocnemius	Loads greater than 30% of body weight should be avoided, as they result in vastus lateralis and biceps femoris co-activation.
Ghori & Luckwill[9]	N=18 Men n=14 Women n=4	Provide a better understanding of activity of muscles of the lower limb during load carriage in walking	Gluteus medius, tibialis anterior, gastrocnemius, vastus lateralis, medial hamstrings	Loads carried in the hands evoke significant prolongation of EMG activity in the lower extremity, while loads carried on the back significant shortened the swing phase and prolonged EMG activity of the lower extremity.
Bobet & Norman[6]	11 healthy males	Investigate the effects of two different load distributions on muscle activity	Erector spinae, upper trapezius	A high load placement (just above shoulder level) resulted in significantly greater levels of muscle activity compared to a lower placement (just below the mid-back).
Al-Khabbaz et al.[5]	19 male university students	Analyze trunk and lower extremity muscle activation while holding different backpacks in a standing position.	Erector spinae, rectus abdominis, vastus medialis, biceps femoris	Abdominal muscle activity increased progressively and disproportionably as the backpack weight increased, and 20% body weight caused the most significant muscular changes and should be avoided.

2.7.1.1. Investigations of Military Load Carriage

One military load carriage study was conducted using EMG to examine the effects of successive increases in load in a sample of 37 German Air Force Soldiers.[7] Dynamic EMGs of the tibialis anterior, peroneus longus, gastrocnemius (lateral and medial), rectus femoris, and biceps femoris were taken of the right leg, and data were collected in six different progressive load conditions. The first condition, referred to as the reference condition, consisted of shorts, standard combat boots, and socks (C1). The subsequent load conditions added a helmet (C2), carrying strap (C3), backpack (C4), weapon carried in front of the body (C5), or slung over the shoulder (C6).[7] All EMG recordings were normalized to the reference condition, and amount of muscle activity was determined by mean amplitude, peak, and area under the curve (AUC). The methodology used in this study is unique because the researchers assessed the changes in muscle activation with the progressive addition of uniform and equipment, thereby allowing them to pinpoint the specific causes for changes muscle activity.

Analysis of EMG data indicated muscle activity was impacted by the addition of equipment. As demonstrated by Table 34, the most significant increases in muscle activation were noted after the addition of the 15 kg backpack with the greatest increase observed in the rectus femoris.[7] The researchers' decision to assess the rectus femoris was based on its role in development of functional knee pain,[7] thus making this a clinically significant finding. It is also important to note no significant changes in muscle activity occurred in any muscle with the addition of the weapon (C5 and C6). Overall, lighter equipment such as the rifle, helmet, and carrying strap, resulted in small changes in EMG activity in comparison to heavier equipment, such as the backpack.

Table 34. Changes in muscle activity with progressively increasing loads[ab]

Condition	Measurement	TA	PL	GL	GM	RF	BF
Helmet (C2)	Mean	↓4%	NS	NS	NS	NS↓	NS
	Peak	NS	NS	NS	NS	NS↓	NS
	AUC	↓4.2%	NS	NS	NS	NS↓	NS
Carrying Strap (C3)	Mean	NS	NS	NS	NS	↑ (p=.023)	↑ (p=.001)
	Peak	NS	NS	NS	↑ (p<.05)	↑ (p<.05)	NS
	AUC	NS	NS	NS	NS	↑ (p<.05)	↑ (p=.002)
Backpack (C4)	Mean	↑16%	↑ (p<.001)	↑32% (p<.001)	↑24% (p<.001)	↑75% (p<.001)	↑ (p<.01)
	Peak	↑16%	↑ (p<.001)	↑ (p<.001)	↑ (p<.001)	↑ (p<.001)	↑ (p<.01)
	AUC	↑16%	↑ (p<.001)	↑ (p<.001)	↑ (p<.001)	↑76% (p<.001)	↑ (p<.05)

Abbreviations: NS, non-significant; TA, tibialis anterior; PL, peroneus longus; GL, lateral gastrocnemius; GM, medial gastrocnemius; RF, rectus femoris; BF, biceps femoris

[a]all values are in comparison to the reference condition (C1)

[a]dapted from Lindner et al.[7]

In a similar study utilizing progressive addition of loads, researchers investigated the effect of load weight and distribution on lower extremity muscle activation.[8] EMG recordings of the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius were completed in seven male military-training students, and seven load distributions were analyzed: 1) shorts only, 2) Outer Tactical Vest (OTV) weighing 9 kg, 3) 9 kg load attached to front left side of OTV, 4) 9 kg load attached to front right side of OTV, 5) 9 kg load evenly distributed to front right and left of OTV, 6) 18 kg evenly distributed between front and back of OTV, 7) 18 kg evenly distributed between the back right and left of the OTV.[8] In contrast to the aforementioned study,[7] the loads implemented in this methodology were distributed around the body, resulting in less impact on the center of mass.

Analysis of EMG recordings showed clear changes in muscle activation with the addition of loads in some lower extremity muscles. Peak EMG amplitude significantly increased with greater loads in the rectus femoris ($p<.001$) in order to maintain balance and in the medial gastrocnemius ($p=.01$) to increase propulsive force.[8] In contrast to results of the aforementioned study,[7] no significant effects were found for the tibialis anterior or biceps femoris.[8] The discrepancies in findings with regard to tibialis anterior and biceps femoris activity may be due to use of a vest compared to the backpack employed in the previous study. The vest creates a more even distribution of the load around the body resulting in fewer changes in muscle activation in comparison to a large load isolated to the back. Although the even distribution of the load may be more ideal for the individual carrying it, it does not accurately represent the demands placed on military personnel during load carriage activities, as they carry the majority of their weight in a rucksack carried on the back. The overall findings indicate that early muscle fatigue in the rectus femoris and medial gastrocnemius may occur with heavier loads as well as uneven distribution of loads, potentially leading to increased injury risk.

Overall, these studies presented similar evidence indicating addition of a load results in increased muscle activation in the lower extremities. Moreover, the findings of these studies suggest even distribution of the weight around the body should be encouraged in order to decrease stress on the muscles and, therefore, reduce risk of musculoskeletal injury[7,8]; however, this may not be a practical answer for military personnel carrying occupational loads.

2.7.1.2. Comparison between Sexes

Regardless of sex, military personnel are required to carry equipment, and with approximately 17% of active military personnel being female,[108] it is important to have an understanding of how loads may affect males and females differently. Many studies investigating biomechanics of load carriage have been conducted on an all-male population, neglecting the fact that findings in males may not be generalizable to females. Therefore, to address this research gap, Silder et al.[3] compared muscle activation between males and females carrying a load. Participants included 17 men and 12 women who completed four, five-minute walking trials under the following load carriage conditions: 1) body weight, 2) 10% of body weight, 3) 20% of body weight, and 4) 30% of body weight.[3] Researchers in this study utilized an adjustable weight vest for the load, resulting in less of a change in center-of-mass compared to carrying a backpack. However, use of a vest likely results in different amounts of activation of different muscles compared to effects seen when carrying a backpack. Surface EMG was used to measure muscle activation of the soleus, medial gastrocnemius, tibialis anterior, medial and lateral hamstrings, vastus medialis, vastus lateralis, and rectus femoris, and EMG data were normalized to the maximum low-pass filtered signal of the respective muscle activity for each subject during walking with no load.[3] This study offers valuable information regarding potential differences that may be present between males and females performing load carriage tasks.

EMG analysis indicated that muscle activity increased as weight was added to the load for many of the muscles evaluated. When a load was added, muscle activation significantly increased across the entire gait cycle for the soleus, gastrocnemius, lateral hamstrings, vastus medialis, and vastus lateralis ($p<.05$); additionally, activation of the rectus femoris significantly increased with added load, except during the stance phase ($p<.05$) (Figure 3).[3] These findings are consistent with those of the previously discussed military load carriage studies that also reported increased activation of the rectus femoris,[8] gastrocnemius, and biceps femoris with increased load.[7,8] Contrary to the result of Lindner et al.[7] who reported the addition of a 15 kg backpack resulted in a 16% increase in tibialis anterior muscle activity, the tibialis anterior was the only muscle that did not show a significant change with added load.[3] However, this finding aligns with those of Park et al.[8] who did not report a significant change in tibialis anterior activation with increasing loads, which suggests the use of a weight vest has less of an impact of tibialis anterior activation compared to a backpack. Moreover, the researchers found no significant differences in muscle activation between genders.[3] The outcomes of this investigation indicate that when carrying a load that is adjusted based on a percentage of body weight, men and women develop similar gait adaptations. In addition, the results of this study align with those of the previously discussed studies demonstrating that muscle activation of the lower extremity increases with greater loads,[3,7,8] and the impact of loads differs with the use of a weight vest compared to a backpack.[3,7,8]

2.7.1.3. Effects of Distance

An additional component of load carriage that may impact muscle activity and injury risk is the distance the load is carried. Using a sample of 15 female recreational hikers, researchers assessed load carriage utilizing a percentage of body weight to determined load and investigated the effect of increasing load and distance traveled on lower limb muscle activity.[4] Four different load conditions were evaluated including 0% body weight as the control, 20% of body weight, 30% of body weight, and 40% of body weight carried in a backpack. Data were collected at each of four distances (0 km, 2 km, 4 km, and 8 km) and load conditions were counterbalanced.[4] Surface EMG was used to asses muscle activation of the vastus lateralis, biceps femoris, semitendinosus, tibialis anterior, and gastrocnemius muscles while walking an 8 km load carriage circuit at a self-selected pace. Burst duration was used to evaluate muscle activation, while mean power frequency (MPF) was used to evaluate muscle fatigue.[4] The investigation of the effect of distance traveled on muscle activation is unique to this study, as the majority of the literature regarding muscle activation during load carriage is focused specifically on changes that occur due to increases in load weight rather than longer distances traveled.

In alignment with the findings of previously discussed studies,[3,7] greater activation of several muscles was found with increasing loads (Table 35).[4] Specifically, when carrying 40% of body weight, the biceps femoris demonstrated a significantly longer burst duration compared to the other three load conditions (p=.004). It should be recognized that in this study,[4] loads with a greater percentage of body weight were assessed compared to those analyzed by Silder et al.[3] Additionally, activity of the vastus lateralis (p=.005) and gluteus medius (p=.001) were significantly greater in the 20%, 30%, and 40% of body weight conditions compared to the 0% body weight condition. Increased activity of the vastus lateralis during load carriage with a greater percentage of body weight is supported in the literature with other researchers reporting a statistically significant increase in activation of the vastus lateralis with the addition of a load.[3] No main effects of load were noted for MPF, thus signifying lack of significant fatigue. The significant changes in vastus lateralis and biceps femoris co-activation in the 40% of body weight condition suggest carrying loads as heavy as 40% body weight may modify loading of the knee joint. Furthermore, evidence suggests co-activation may be a predisposing factor to development of back pain.[49,51,52,66] Thus, it may be beneficial to limit loads to 30% of body weight in order to decrease changes in muscle activation and reduce risk of musculoskeletal injury.[4]

Table 35. Mean muscle activity variables during the four load conditions[a]

Muscle	Measurement	0% BW	20% BW	30% BW	40% BW
Tibialis Anterior	Burst Duration (ms)	391	279	386	380
	Mean Power Frequency (%)	103.2	99.5	101.5	102.7
Gluteus Medius	Burst Duration (ms)	374	381	398	404
	Mean Power Frequency (%)	102.2	106.2	104.4	104.9
Vastus Lateralis	Burst Duration (ms)	297	293	305	319
	Mean Power Frequency (%)	102.2	106.1	107.5	109.7
Semitendinosus	Burst Duration (ms)	253	258	257	264
	Mean Power Frequency (%)	106.4	105.7	106.4	101.5
Biceps Femoris	Burst Duration (ms)	263	279 [c]	281 [c]	309 [b]
	Mean Power Frequency (%)	107.1	104.9	100.4	103.2

[a]adapted from Simpson et al.[4]
[b]p≤.05 compared to 0% BW
[c]p≤.05 compared to 40% BW

When data were analyzed for distance effects, significant effects were seen for multiple muscles and conditions, and these data are presented in Table 36. The vastus lateralis displayed a significant effect for burst duration (p=.026) representing a significantly shorter burst duration at the 8 km distance compared to 0 km. Similarly, the gluteus medius (p=.01), vastus lateralis (p=.006), and semitendinosus (p=.027) all displayed a smaller burst at 2 km, 4 km, and 8 km compared to 0 km. Shorter burst duration at greater distances means the activity of the muscle decreases over distance, thereby potentially signifying fatigue. Finally, MPF for the biceps femoris was significantly higher at 4 km and 8 km compared to 0 km (p=.007), and the MPF for the tibialis anterior was significantly lower at 8 km compared to 4 km (p=.014).[4] The fatigue of the tibialis anterior at farther distances suggests that the function of the muscle may be compromised during longer bouts of load carriage. The all-female population makes this study unique because as previously mentioned, most load carriage studies utilize males only. Although the female cohort sets this study apart, it may impede the ability to generalize the results to a male population; however, the findings of Silder et al.[3] indicate that males and females adopt similar gait adaptations to load carriage.[16] Ultimately, the researchers concluded the increased activity of the vastus lateralis, semitendinosus, and medial gastrocnemius with greater loads was due to the body's attempt to maintain stability of the lower limb, whereas the significant changes in vastus lateralis and biceps femoris co-activation with loads over 40% of body weight indicate loads of this magnitude likely alter knee joint loading, possibly resulting in increased injury risk.

Table 36. Mean muscle activity variables at the four walking distances[a]

Muscle	Measurement	0 km	2 km	4 km	8 km
Tibialis Anterior	Burst Duration (ms)	371	351	352	353
	Mean Power Frequency (%)	101.1	102.8	104.1	100.8 [c]
Gluteus Medius	Burst Duration (ms)	386	387	391	391
	Mean Power Frequency (%)	102.2	104.2	105.5	105.4
Vastus Lateralis	Burst Duration (ms)	319	300	302	294 [b]
	Mean Power Frequency (%)	105.7	107.4	107.1	109.3
Semitendinosus	Burst Duration (ms)	274	252	254	245
	Mean Power Frequency (%)	99.5	105.1	107.4	109.1
Biceps Femoris	Burst Duration (ms)	279	280	283	276
	Mean Power Frequency (%)	98.9	102.9	105.6 [b]	107.9 [b]

[a]adapted from Simpson et al.[4]
[b]p≤.05 compared to 0 km distance
[c] p≤.05 compared to 4 km distance

2.7.1.4. Comparison of Load Placement

Another important consideration regarding muscle activation during load carriage is the placement/location of the load. As previously discussed, loads placed on the back (such as in a backpack) may result in differences in muscle activation compared to loads evenly distributed around the body (such as with the use of a weight vest). In an investigation of lower extremity muscle activity, researchers evaluated loads carried on the back and in the hands.[9] Eighteen participants (14 men and four women) were placed into two different groups based on load location (hands vs. back). Similar to previously discussed studies,[3,4] load weights were determined utilizing percentage of body weight.[9] Surface EMG was used to measure activation of muscles of the lower extremity on the left side.[9]

In the hand load group (n = 12), weights of 10%, 15%, and 20% of body weight were examined. Muscle activation was measured of the gluteus medius, tibialis anterior, gastrocnemius, vastus lateralis, and semimembranosus/semitendinosus, and loads were carried on both the ipsilateral and contralateral sides.[9] Analysis revealed significant prolongation of EMG activity in several muscles. In alignment with findings for load carried on the back,[4] the researchers reported contralateral carrying of 15% and 20% body weight loads resulted in statistically significant prolongation of EMG activity of the gluteus medius (p<.05).[9] Comparable to assessments of loads carried with a weight vest,[3,8] the tibialis anterior showed no significant changes with any loads carried in the hands. The gastrocnemius showed prolonged activity with 10%, 15%, and 20% loads carried on the ipsilateral side (p<.05), as well as with a 20% load carried on the contralateral side (p<.05). This appears to be consistent throughout the literature, as results of previous studies assessing the gastrocnemius have indicated increased activity with the addition of a load.[3,4,7,8] Significant prolongation of activity of the vastus lateralis and was found at 15% and 20% ipsilateral loads (p<.05), which is similar to reports of other researchers who investigated loads carried on the back[4] as well as with a weight vest.[3] Finally, prolongation of semitendinosus/semimembranosus activity was also found at 15% and 20% ipsilateral loads (p<.05). Although the evaluation of the effects of loads carried in the hands is unique, it does not strongly relate to military load carriage. The evaluation of the loads carried on the back is more related to the present population of interest.

The back load group (n=6) carried loads of 10%, 20%, 30%, 40%, and 50% of their body weight, and activity of the vastus lateralis and semimembranosus/semitendinosus were measured. The researchers reported significant prolongation of EMG activity in the vastus lateralis at loads of 20%, 30%, 40%, and 50% of body weight (p<.05), while no changes were seen for the semimembranosus/semitendinosus.[9] The increased activity of the vastus lateralis with added load aligns with the findings of Simpson et al.[4] who also reported a significant increase in vastus lateralis activity with loads of 20% to 40% of the participants' body weight. The use of the medial hamstrings alone seems to be uncommon in the existing literature; all of the previously discussed studies utilized the lateral hamstring (biceps femoris), or a combination of both medial and lateral hamstrings, to assess activation of this muscle group.[3,4,7,8] There appears to be inconsistencies within the literature with regard to increases in activation of the hamstring muscle group with the addition of a load. While several researchers reported increased activity of the biceps femoris when a load was added,[3,4,7] the findings of this study align with those of Park et al.[8] who noted no significant effects of load carriage in the biceps femoris.[9]

Overall, these results show that loads up to 20% of body weight carried in the hands induced significant prolongation of activity of the ipsilateral gastrocnemius, vastus lateralis, and semimembranosus, as well as the contralateral gluteus medius. Moreover, loads up to 50% of body weight carried on the back prolong activity of the vastus lateralis only. Thus, loads carried in the hands appear to cause greater changes in muscle activity compared to those carried on the back; however, fewer muscles were assessed for loads carried on the back, so this is likely not a just comparison.

In a different investigation of load placement, researchers focused specifically on loads placed on the back but in varying locations. Additionally, back musculature was evaluated as opposed to muscles of the lower extremity. Participants included 11 healthy males who carried a 19.5 kg load at a speed of 5.6 km per hour over a 90 m course.[6] The load was carried in a backpack at either the level of the xiphoid process (low), or the level of the ear lobe (high). Surface EMG of the erector spinae and upper trapezius muscles were evaluated over four strides per subject per load placement. In an effort to normalize activity of the upper trapezius across load placements and subjects, arm position was standardized to bent elbows and hands at chest level with thumbs under backpack straps if a load was present.

EMG means for the erector spinae for both the low (59%) and high (86%) placements indicated that the addition of the load decreased activity of the erector spinae in comparison to unloaded walking. EMG means for the trapezius revealed that the low load placement resulted in marginally lower activation than unloaded walking (92%), while the high load placement resulted in slightly greater activation compared to unloaded walking (108%).[6] Interestingly, adding a load resulted in less work being done by the erector spinae muscles compared to unloaded walking. Investigation of the effect of load placement on muscle activation revealed that EMG means for the low load placement were significantly lower than for the high load placement ($p<.05$), consequently indicating that carrying the load higher on the back results in greater stress on the muscles.[6] As a result, it may be beneficial to suggest that loads be carried closer to the level of the xiphoid process in order to avoid unnecessary stress on the core musculature.

2.7.1.5. Effects of Loads in Standing

The effect of load carriage on muscle activation during gait may differ from the effect during stationary standing. The methodology of this study may be important pertaining to military personnel, as they may spend extended periods of time standing while carrying occupational loads. Therefore, researchers investigated the relationship between load carriage and trunk muscle activation in standing rather than during ambulation.[5] Participants included 19 male university students who were required to stand erect with extended knees and head facing forward in four different load conditions: unloaded, 10% of body weight load, 15% of body weight load, and 20% of body weight load. All loads were carried in a regular, non-framed backpack. Surface EMG of the erector spinae, rectus abdominis, vastus medialis, and biceps femoris were evaluated in each load condition.

Changes in muscle activation were noted for some muscles, while others demonstrated no significant change with the addition of a load. When evaluating the erector spinae, no significant changes in activity were found with the addition of a load with activity ranging from 15.96% to 16.85% on the right side, and 17.5% to 19% on the right side. This finding is in opposition to the findings of Bobet and Norman[6] who reported a sizable decrease in erector spinae activity with the addition of a load, specifically a load placed lower on the back, at the level of the xiphoid process. When analyzing the rectus abdominis, researchers found significant increases in activity between each load condition ($p<.05$). The average right RA activities were 3.1%, 3.98%, 5.37%, and 6.84% in unloaded, 10%, 15%, and 20% BW conditions, respectively. Similarly, the average left RA activities were 2.96%, 3.41%, 4.58%, and 5.42% for BW, 10%, 15%, and 20% BW conditions, respectively. No significant changes were noted between different load conditions in the vastus medialis and biceps femoris muscles.[5] This differs from the findings of Silder et al.[3] who reported significant increases in activity of both, the vastus medialis and lateral hamstring, with the addition of a load. Furthermore, it differs from the reports of other researchers who described a significant increase in biceps femoris activity with the addition of greater loads.[4,7] The crucial takeaway from this study is that in standing, the activity of the rectus abdominis progressively increases as load carried on the back increases. Therefore, the heavier loads, in this case 20% of body weight, cause the most substantial muscular and postural changes and, therefore, should be avoided. Although there are some discrepancies between the results of this study compared to many of the previously discussed studies, it is important to consider that this study was conducted while standing as opposed to during ambulation.

2.8. Conclusion

As a whole, the research supports the concept that lower physical fitness is an indicator of injury risk. In particular, decreased cardiovascular fitness is associated with increased risk for sustaining a musculoskeletal injury.[14–16,19–21] A commonly reported mechanism of injury in military personnel is road marches while carrying additional loads. More specifically, loads exceeding 25% of the individual's body weight appear to increase the risk for musculoskeletal injury.[37] Additionally, the most commonly reported injury locations are the lower extremity and back.[2,30,31,36]

Analyses of muscle activity during load carriage activity have generally concluded greater carrying loads result in greater muscle activation in the lower extremity, which increases as loads increase.[7,8] It has also been established that the weight of equipment impacts the activity of trunk muscles; however, the change and degree of change is not well understood.[5,6] It is important to recognize the inconsistencies in methodologies, which make it difficult to draw firm conclusions. While some researchers chose to utilize military load carriage systems or other packs carried on the back, others used weight vests that distribute the weight around the body more evenly. Furthermore, some researchers used set weights for all participants, while others utilized various percentages of body weight. Due to these inconsistences, it is difficult to make determinations regarding best practices for military load carriage, as military load carriage systems have not been widely studied, and methods utilizing weight vests and percentages of body weight are not widely generalizable to the military population. Thus, more research is needed investigating the relationship between muscle activation and load carriage specific to military equipment and the military population.

3. METHODOLOGY

3.1. Investigation 1: An Analysis of Muscle Activity during Load Carriage in Army ROTC Cadets

3.1.1. Purpose of the Study

The purpose of this study was to explore a possible relationship between back pain and muscle activity measured via surface electromyography of the lower back, abdominal, and leg musculature during military load carriage. A secondary purpose was to compare muscle activation patterns to past and current patient-reported back pain to determine whether activity of these muscles during load carriage can be used as a predictive model for military personnel. There is a relatively small body of literature devoted to muscle activation during load carriage with even fewer studies specific to the military population. Furthermore, the available research in this realm is focused on muscles of the lower extremity, thereby neglecting key musculature of the core.

Since load carriage is a frequently reported mechanism of injury, accounting for approximately 34% of all injuries in the Army population,[2] it is important for athletic trainers to be educated on specific causes of injury, predisposing factors for injury, and prevention of load carriage related injuries. We anticipate that the results of this study can be used by athletic trainers in the military setting to treat the root cause of injuries associated with load carriage as well as prevent injuries from occurring based on early recognition of muscular pathomechanics. The research was designed to answer the following questions:

Q1: What are the differences in muscle activation in the core and lower extremity of Army ROTC cadets walking with and without a 35 lb. load carried on the back?

Q2: What is the relationship between the presence of back pain and muscle activation of the lower extremity and core?

Q3: To what extent do muscle activation patterns predict the development of low back pain?

3.1.2. Participants

Prior to participant recruitment, this study was approved by the Institutional Review Board at North Dakota State University. Participants included a total of 27 Army ROTC Cadets (Age 20.89±1.78, M=20, F=7) from the brigade associated with the mid-sized university. Recruitment of participants occurred through an informational meeting held during Army ROTC Lab as well as recruitment email via the cadet list serve. Inclusion criteria required participants to be enrolled in Military Science courses and a member of the Army ROTC. Therefore, participants had experience with the type of load carriage task they were asked to perform. Exclusion criteria included cadets with any injury or general medical illness that prevented completion of the load carriage protocol.

3.1.3. Instrumentation

Prior to initiation of data collection, study procedures were explained and participants read and signed an informed consent acknowledging they understood the study procedures and consented to participate. After providing consent, basic demographic information including biological sex and age were collected, and height (m), weight (kg), and subsequent body mass index (kg/m^2) were measured and documented.

3.1.3.1. Back Pain Disability Questionnaire

A questionnaire (modified-MBQ) developed by the researchers was used to assess participants' self-reported back pain and self-perceived level of disability. The nine item questionnaire was constructed base on the Modified Oswestry Low Back Pain Disability Questionnaire and with the use of the article "Preliminary Validation of the Military Low Back Pain Questionnaire" by Roy et al.[109] Based on a Likert-type scale with six responses, presented in order of least pain and disability (equal to a score of zero) to most pain and disability (equal to a score of 5), participants indicated their capacity to perform various activities of daily living (ADLs) as well as Army/occupation specific tasks. Scores were calculated as follows:

$$\frac{total\ score}{45} \times 100$$

3.1.3.2. Muscle Surface Electromyography

Muscle sensor surface electromyography (sEMG) electrodes (Red Dot 2560 monitoring electrodes, 3M Healthcare, London, Ontario, Canada) were placed on the right rectus abdominis, erector spinae, gluteus medius, gluteus maximus, rectus femoris, and biceps femoris muscles to measure sEMG during walking. Skin in locations of electrode placement was prepared by trimming hair when necessary and cleaning the skin with alcohol. Two electrodes were placed on each of the aforementioned muscles with a 4.0 cm interelectrode distance. Electrode placement for all muscles was determined according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines,[110] with the exception of the rectus abdominis, which was placed in accordance with the methodology cited by Silva et al.[111] Specific descriptions of electrode placement can be found in Table 37. After electrode application, electrode locations were marked so placement was consistent on the second day of participation. Data were collected using the sEMG MP150 machine (Biopac Systems Inc., Goleta, CA) and saved under the participant's randomly assigned number.

Table 37. Electrode Placement Descriptions

Muscle	Electrode Placement
Rectus Abdominis	Just below the midpoint between the umbilicus and xiphoid process, 3 cm lateral from the midline[111]
Erector Spinae	One finger width medial from the line from the PSIS to the lowest point of the lower rib at the level of L2, oriented in the direction of the line between the PSIS and the lower rib
Gluteus Medius	Midway between the iliac crest and the greater trochanter oriented in the direction of the muscle fibers
Gluteus Maximus	Midway on the line between the sacral vertebrae and greater trochanter oriented in the direction of the PSIS to the middle of the posterior aspect of the thigh
Rectus Femoris	Midway on the line from the ASIS to the superior to the superior border of the patella oriented in the direction of the muscle fibers
Biceps Femoris	Midway on the line between the ischial tuberosity and the lateral epicondyle of the tibia oriented in the direction of the muscle fibers

Abbreviations: PSIS, posterior superior iliac spine; ASIS, anterior superior iliac spinae

3.1.4. Procedures

This repeated measures experimental study was conducted in the human performance laboratory at a mid-sized research university. Two different load conditions were tested over two separate days separated by 24-48 hours. Load conditions were randomized and counterbalanced to mitigate effects of fatigue. Both protocols included a five kilometer (3.1 mile) walk on a treadmill (Trackmaster TMX425C Full Vision, Inc., Newton, KS) at a speed of three miles per hour. One session was completed with the addition of a 35-lb. load carried in a traditional, framed rucksack while the other included no load. The speed and load weight were selected based on requirements for successful completion of cadet summer training.[112] The distance was selected due to a lack of existing information regarding changes in muscle activation over time during load carriage.

On the first day of data collection, participants provided informed consent and researchers collected the abovementioned demographic information. Next, participants completed the previously described back pain disability questionnaire. The questionnaire was filled out twice; once indicating the cadets’ current level of pain, and the second time indicating how they felt on average over the last year.

Following completion of documentation, the skin was prepared and sEMG electrodes were applied. Functional, sEMG data were obtained of the gluteus medius, gluteus maximus, erector spinae, rectus femoris, rectus abdominis, and biceps femoris muscles as described above. After electrode application, electrode locations were marked so placement was consistent on the second day of participation.

Following electrode application, in order to normalize the data, maximal voluntary isometric contractions (MVIC) were performed against manual resistance for each of the six muscles being analyzed. Manual muscle tests (MMTs) to attain MVIC for each muscle were performed by a certified athletic trainer (ATC), and the same ATC performed all MMTs to diminish the change for violations of inter-rater reliability. After completion of the normalization protocol, participants completed the first five-kilometer walk with the randomly assigned load condition.

On the second day of data collection, the same skin preparation procedures were utilized and electrodes were placed in the marked locations from day one. Participants then completed the same MVIC normalization protocol followed by the final five-kilometer walk with the remaining randomly assigned load condition.

3.1.5. Data Analysis

All sEMG signals were band-pass filtered (50-450 Hz) using digital infinite impulse response filtering. Then, the root mean square value of the entire signal was computed using the Biopac Acknowledge 4.0 software. Mean sEMG amplitude observed during the five kilometer walking task was then normalized to mean amplitude achieved during the MVIC performed on that same day.

3.1.6. Statistical Analysis

All statistical analyses were completed via IBM® SPSS statistics software version 25.0 (IBM®, Armonk, New York). Independent variables include load condition and time. Dependent variables include scores on the modified-MBQ and muscle activity. It was hypothesized that the primary variables affecting muscle activation would be self-reported pain, load condition, and time. Therefore, six two-way repeated measures ANOVA models (one for each muscle) were estimated with load and pain as independent factors. Point biserial correlations were used to test the association between the presence of back pain and muscle activation of the lower extremity and core. Additionally, point biserial correlations were used to test the association between biological sex and muscle activity as well as the relationship between body weight and muscle activity. Lastly, an independent samples t-test was used to assess differences in MMBQ scores between males and females.

3.2. Investigation 2: A Comparison of ACFT Scores, Back Pain, & Muscle Activity in Army ROTC Cadets

3.2.1. Purpose of the Study

The primary purpose of this study was to explore a possible relationship between fitness of cadets, presence of back pain, and muscle activation patterns. A secondary goal of this research is to examine relationships between kinesiophobia, self-reported pain, and performance on the Army Combat Fitness Test (ACFT). There is a large body of literature pertaining to the relationship between fitness and injury incidence using the Army Physical Fitness Test (APFT). However, since the transition to the ACFT is being implemented across the Army, there is currently no information regarding potential relationships using this new, functional fitness assessment. Therefore, this research was designed to answer the following questions:

Q1: What is the relationship between muscle activation in the core and lower extremity of Army ROTC cadets and performance on the ACFT?

Q2: What is the relationship between self-reported back pain during performance of ACFT skills in Army ROTC cadets?

Q3: What is the relationship between kinesiophobia and performance on the ACFT in Army ROTC cadets?

3.2.2. Participants

Prior to participant recruitment, this study was approved by the Institutional Review Board at North Dakota State University. Participants included a total of 21 Army ROTC Cadets (Age 21.29±1.82, M=15, F=6) from the brigade associated with the mid-sized university. Inclusion criteria required participants to be enrolled in Military Science courses and a member of the Army ROTC. Additionally, participation in a previous study titled "An Analysis of Muscle Activity during Load Carriage in Army ROTC Cadets" was required. The design of the two studies allowed for further analysis of muscle activation and back pain data related to Army-specific physical requirements. Exclusion criteria included cadets with any injury or general medical illness that prevented completion of the ACFT, or failure to complete any portion of the ACFT.

3.2.3. Instrumentation

Prior to initiation of data collection, study procedures were explained and participants read a study information sheet detailing the purposes and procedures. Participants acknowledged they understood the study procedures and consented to participation.

3.2.3.1. Tampa Scale for Kinesiophobia

The Tampa Scale for Kinesiophobia (TSK) is frequently utilized as a clinical tool to quantify pain-related fear of movement in individuals with back pain.[113] Kinesiophobia is defined as a state where an individual experiences fear of movement and activity as a result of a feeling of susceptibility to painful injury or re-injury.[113,114] The 17-item questionnaire uses a four-point, Likert-type scale to quantify participants' level of apprehension pertaining to suffering an injury/re-injury during activity.

3.2.3.2. Visual Analog Scale

A traditional visual analog scale (VAS) with associated numbers from zero to ten was utilized to assess back pain at specific time points during participation in the ACFT skills. Intensity of back pain is commonly assessed with a VAS, numerical rating scale, or other disability scoring systems.[115] On the specific scale utilized for this study, a score of zero was equivalent to no pain, five indicated moderate pain, and a score of ten indicated the worst pain possible.

3.2.4. Procedures

This observational and survey study was conducted in the indoor track facility at a mid-sized research university. After consenting to participate in this study, cadets filled out the TSK prior to initiating any physical activity. Following completion of the TSK, participants participated in the Army Combat Fitness Test (ACFT). This test consists of six different components assessing various aspects of functional fitness. The six events include 1) three repetition maximum deadlift, 2) standing power throw, 3) hand release push-up, 4) sprint-drag-carry, 5) leg tuck, and 6) two-mile run. Soldiers must complete all six events in the listed order in 70 minutes or less.[27]

Prior to completing the three repetition maximum deadlift, participants indicated their current level of pain on a VAS. Immediately following completion of the deadlift event, cadets once again scored their current level of pain on the VAS. Similarly, when participants got to the last event, the two-mile run, they indicated their current level of pain on a VAS immediately before initiating the run. Additionally, immediately following completion of the two-mile run the cadets again indicated their current pain level. Additionally, performance on all six events of the ACFT was recorded. These data included weight lifted (deadlift), distance thrown (standing power throw), repetitions performed (hand release push-ups and leg tuck), and time needed to complete the task (sprint-drag-carry and two-mile run). Lastly, after completing the ACFT in its entirety, participants completed the TSK again indicating their level of kinesiophobia upon completion of the fitness assessment.

In addition to the kinesiophobia, pain scale, and fitness data collected during the ACFT, data from a prior study was utilized in the analysis to assess a variety of relationships. These data included demographic information (biological sex, height, weight, and age), scores from a back pain disability questionnaire, and sEMG data from six different muscles of the lower extremity and core collected during walking with and without load carriage.

3.2.5. Statistical Analysis

All statistical analyses were completed via IBM® SPSS statistics software version 25.0 (IBM®, Armonk, New York). Dependent variables included activity of the RF, BF, ES, RA, GM, and GMx. Independent variables included performance on each component of the ACFT (weight lifted, repetitions performed, time to complete), scores on the TSK, MMBQ, and VAS's. Biological sex was included as a covariate. Regression was used to model the ability of ACFT scores, MMBQ scores, TSK scores, and VAS scores to predict mean muscle amplitude of six muscles of the lower extremity and core during completion of a submaximal load carriage task. Independent samples *t*-tests were used to assess significant differences in ACFT performance between males and females. Paired samples *t*-tests were used to assess changes in pain between pre- and post-MDL, pre- and post-2MR, and to assess changes in pain and kinesiophobia from start and end of the ACFT.

4. AN ANALYSIS OF MUSCLE ACTIVITY DURING LOAD CARRIAGE IN ARMY ROTC CADETS

4.1. Abstract

Context: Every year approximately 3,300 Army Reserve Officer Training Corps (ROTC) cadets attend advanced training camp where they are required to complete a 12-mile foot march carrying a 35-pound load in under 4 hours. During load carriage tasks, the physiological cost of carrying the load increases as the weight of the load increases, resulting in increased injury risk. Although researchers have found the spine is the most commonly injured area during load carriage activities, little is known about the effects of loads on back and core muscle activity and how that translates to back injuries and subsequent pain, as existing research focuses on muscle activity of the lower extremity. **Purpose:** The objective of this study was to analyze changes in muscle activity during load carriage in Army Reserve Officer Training Corps (ROTC) cadets and how current or history of low back pain (LBP) relates to changes in muscle activation. **Methods:** This randomized and counterbalanced experiment included a sample of 30 Army ROTC cadets (age 21±1.82 years). Participants completed a 5-kilometer walk on a treadmill at a speed of 3 mph, with and without a 35-pound load carried in a traditional rucksack. Surface electromyography data were obtained of the rectus femoris (RF), rectus abdominis (RA), gluteus medius (GM), gluteus maximus (GMx), erector spinae (ES), and biceps femoris (BF). Participants reported current and history of LBP using a military-specific version of the Oswestry Low Back Pain Disability Questionnaire. Independent variables included load condition and time. Dependent variables included back pain and mean muscle activation. Six repeated measures ANOVA models were estimated with time and load as independent factors. **Results:** Muscle activation for all muscles declined significantly over time (p<.001). Amplitude of RF (*p*=.014), GM (*p*<.001), and GMx (*p*=.007) significantly increased in the load carriage condition. Cadets who reported pain had greater average muscle activation; however, only the RF showed a significant association (*p*=.01). Significant correlations were found between body weight and activity of the BF in the load and no-load condition (*p*=.012 and *p*=.017, respectively) as well as between biological sex and activity of GMx in both the load and no-load condition (*p*=.008 and *p*=.048, respectively). **Conclusions:** The addition of a load resulted in increased muscle activation, and increased muscle activation also appears to be associated with pain. Thus, individuals displaying muscle activity at greater percentages of their MVC should consider adopting a core strengthening program prior to embarking on foot marches with load carriage.

4.2. Introduction

The physical demands associated with military training, such as completing occupational tasks while carrying heavy loads, place soldiers at high risk for sustaining musculoskeletal injuries. Long foot marches are a substantial component of military training, and such marching often includes carrying loads consisting of weapons, equipment, body armor, and other protective gear and supplies.[1,2] Injuries associated with load carriage represent approximately 34% all injuries in the Army population,[2] and the spine has been identified as the leading injury site. In fact, one study evaluating load carriage injuries in the Australian Army found the back was the leading injury location accounting for 23% of all injuries.[2]

There are numerous factors that can be associated with the development of back pain, some of which include amplitudes and patterns of muscle activity. While there is an abundance of literature concentrated on kinetic effects of load carriage as well as other physiological measurements including heart rate and VO_2,[10,103,104,106,116–118] the body of research investigating changes in muscle activation during load carriage is relatively small. Moreover, military-specific studies of this type are even more scarce.[7,8] One of the primary limitations of existing analyses is limiting the scope of the study to changes in lower extremity musculature and neglecting the changes that may occur in muscles of the core.[3,4,7,8]

Previous studies investigating the association between back pain and activity of core musculature have suggested increased activity of the erector spinae and rectus abdominis muscles is associated with low back pain (LBP).[23–25,49] However, as previously stated, much of the current research pertaining to muscle activation during load carriage focuses on the lower extremity and disregards core musculature. Additionally, due to the stabilizing role of the gluteus medius (GM) during gait, there is reason to believe this muscle plays an important role in the development of low back pain (LBP). Researchers have reported increased co-activation of the GM during prolonged periods of standing in individuals with LBP.[51,66,67] However, it is unknown whether this co-activation is causative of or an adaptation to LBP.

One understudied, yet important subset of the Army population, is Reserve Officers' Training Corps (ROTC) cadets. It has been documented that load carriage accounts for approximately 23% of injuries in the Reserve Officers' Training Corps (ROTC) population. Similar to the results reported of the Australian Army, the low back is the most commonly reported injury location.[119] Despite the matriculation of ROTC cadets into the US Army, there is minimal information regarding causes of pain resulting from load carriage in this population. Therefore, exploring causative factors related to LBP in cadets is important for mitigating future injuries.

With well over 250 Army ROTC programs in United States, ROTC is currently the largest commissioning source for U.S. Army officers.[120] As a prerequisite for commissioning, cadets are required to pass advanced training camp, which is a 31-day training event designed to assess cadets' proficiency in basic officer leadership tasks.[112] Two key components of advanced camp are land navigation and foot marches, both of which are often completed while carrying an external load.[112] One specific requirement for successful completion of advanced camp is finishing a 6-mile foot march in two-hours while carrying a 35 lb. rucksack.[112] The weight and time are predetermined, regardless of biological sex, age, or weight of cadets.

Based on the lack of research on the cadet population, as well as the need to identify trainees at risk for developing LBP, the aim of the present study was twofold. First, to explore a possible relationship between back pain and muscle activity measured via surface electromyography of the lower back, abdominal, and leg musculature during military load carriage. Second, to compare muscle activation patterns to self-reported past and current back pain to determine whether activity of these muscles can be used as a predictive model for developing back pain. Therefore, this study aimed to assess how back pain relates to muscular adaptations in the lower extremity, pelvis, and core of Army ROTC cadets during load carriage over a prolonged distance.

4.3. Methods

4.3.1. Participants

The university's institutional review board approved this repeated measures experimental study prior to participant recruitment. Participants included 30 Army ROTC Cadets; however, four sets of data were dismissed due to EMG failures. Thus, the final study sample included 26 cadets (Age 20.96±1.78, M=19, F=7) from one brigade associated with a mid-sized university. Inclusion criteria required participants to be enrolled in Military Science courses and a member of the Army ROTC. Therefore, participants had experience with the type of load carriage task required in this study. Exclusion criteria included cadets with any injury or general medical illness that prevented completion of the load carriage protocol.

4.3.2. Measures

The Modified Oswestry Low Back Pain Disability Questionnaire (M-ODI) is one of the most frequently used questionnaires to assess disability related to LBP due to its proven validity and reliability.[109] However, this questionnaire is less useful in the military population because it does not adequately represent the physical demands required to complete occupational tasks. Due to these deficiencies, researchers have developed a questionnaire based on the M-ODI that contains similar questions and also adds components that are more relevant to the military population. This questionnaire, the Military Low Back Pain Questionnaire (MBQ), has undergone preliminary validation and was found to have good concurrent validity and more sensitive to change in the military population.[109] The MBQ itself is not accessible at this point in time due to government regulations. Therefore, a modified version of MBQ (MMBQ) was created by the researchers of the current study from information provided in an article on the preliminary validation of the MBQ.[109] The MMBQ can be found in Appendix B.

4.3.3. Protocol

Two different conditions were tested over two separate days (separated by 24-48 hours). Conditions were randomized and counterbalanced to mitigate effects of fatigue. Both protocols included a 5-km (3.1 miles) walk on a treadmill (Trackmaster TMX425C Full Vision, Inc., Newton, KS) at a speed of three miles per hour. One session was completed with the addition of a 35-lb. load carried in a traditional, framed rucksack. The remaining condition did not include a load. The speed and load weight were selected based on minimum requirements for successful completion of cadet summer training.[112] The researchers recognize the potential limitation of the use of a treadmill. However, existing research comparing muscle activity during treadmill and overground walking lacks methodological consistency and results vary among studies.[121] While it has been hypothesized that treadmill walking requires decreased propulsive forces, specifically of the hamstring muscles, the evidence for this theory is conflicting. While some researchers have noted decreased activity of the hamstring muscles during parts of the gait cycle during treadmill walking,[122–124] others have reported no significant difference between treadmill and overground conditions.[125,126] In one study, researchers even reported treadmill walking resulted in greater lower extremity muscle activation compared to overground walking.[127] Due to the demonstrated lack of consistency in findings, it is difficult to determine whether a clinically relevant difference exists between treadmill and overground walking.

On the first day of data collection, participants provided informed consent, and researchers collected demographic information including age, biological sex, height and weight, and calculated body mass index (BMI). Next, participants were asked to complete the MMBQ with two separate sets of instructions. Participants were instructed to consider his/her current level of pain followed by instructions to consider pain he/she has experienced within the last year.

Following completion of documentation, the skin was prepared and surface electromyography (sEMG) electrodes (Red Dot 2560 monitoring electrodes, 3M Healthcare, London, Ontario, Canada) were applied. Skin preparatation consisted of trimming hair when necessary and cleaning the skin with alcohol. Surface EMG electrodes were placed on the gluteus medius (GM), gluteus maximus (GMx), erector spinae (ES), rectus femoris (RF), rectus abdominis (RA), and biceps femoris (BF) muscles. Electrode placement for five of the six muscles were determined based on the SENIAM (Surface Electromyography for the Non-

Invasive Assessment of Muscles) guidelines.[110] The electrodes for the rectus abdominis were placed in accordance with the methodology cited by Silva et al.[111] After electrode application, electrode locations were marked on the participants' skin so placement was consistent on the second day of participation. Data were collected and stored using the sEMG MP150 system (Biopac Systems Inc., Goleta, CA).

Following electrode application, maximal voluntary isometric contractions (MVIC) were performed against manual resistance for each of the six muscles being analyzed. The MVIC values were collected to provide a value for normalization of the EMG data. After completion of the normalization protocol, participants completed the first 5-km walk with the randomly assigned load condition.

On the second day of data collection, the same skin preparation procedures were utilized and electrodes were placed in the marked locations from day one. Next, the same MVIC normalization protocols were conducted prior to performance of the final 5-km walk with the remaining randomly assigned load condition.

4.3.4. Data Analysis

All sEMG signals were band-pass filtered (50-450 Hz) using digital infinite impulse response filtering. Then, the root mean square value of the entire signal was computed using the Biopac Acknowledge 4.0 software. Data collected during the 1-hour walking task were divided into four, 15-minute segments. Mean sEMG amplitude observed during each 15-minute segment, as well as over the entire 5-km walking task, was then normalized to mean amplitude achieved during the MVIC.

4.3.5. Statistical Analysis

All statistical analyses were completed via IBM® SPSS statistics software version 25.0 (IBM®, Armonk, New York). Independent variables included load condition and time. Dependent variables included scores on the MMBQ and muscle activity. It was hypothesized that the primary variables affecting muscle activation would be self-reported pain, load condition, and time. Therefore, six repeated measures ANOVA models (one for each muscle) were estimated with load and pain as independent factors. Point biserial correlations were used to test the association between the presence of back pain and muscle activation, and between weight and muscle activation. Lastly, an independent samples *t*-test was conducted with biological sex as the independent variable and score on the MMBQ as the dependent variable.

4.4. Results

EMG data for four of the 30 participants were dropped due to excess artifact impeding the EMG signal. GMx data in the load carriage condition were dropped for one female participant due to excess artifact. Therefore, 26 participants were included in the final analysis, and GMx data during load carriage for 25 were included. It was hypothesized that the primary variables affecting muscle activation would be load condition and time. Additionally, biological sex was considered as a potential covariate; however, results of a *t*-test assessing differences in back pain, determined by MMBQ score, revealed no significant difference between males and females (*t*[24]=-.686, *p*=.499). Because there is no evidence of substantial differences by biological sex, the variable is not included as a factor in other analyses. Descriptive statistics for scores on the MMBQ at the time of data collection are presented in Table 38.

Table 38. MMBQ scores

	N	**Mean ± SD**
All	26	3.333 ± 4.959
Male	19	2.924 ± 4.569
Female	7	4.444 ± 6.153
Cadets who reported pain	13	6.667 ± 5.212
Cadets who reported no pain	13	0

4.4.1. Load and Time Effects

To examine the effects of load condition and time on muscle activation, six two-way repeated measures ANOVA models (one for each muscle) were estimated with time and load as independent factors. Correlation analysis was conducted to explore the relationship between reported pain and muscle activation. In almost all cases, Mauchly's test indicated concerns regarding sphericity, so the reported degrees of freedom and p-values for all ANOVA results use the Greenhouse-Geisser correction. Table 39 displays the average muscle activation across all participants for the six muscle groups in 15-minute segments for the load and no-load conditions. The repeated measures ANOVAs revealed significant effects for both load and time (Table 40). Bonferroni's pairwise comparisons for changes in muscle activity between the four time quartiles are presented in Table 41.

Table 39. Average normalized muscle activation (%) by measurement time*

Time	**No Load**						**Load Carriage**					
	RF	**RA**	**GM**	**GMx**	**ES**	**BF**	**RF**	**RA**	**GM**	**GMx**	**ES**	**BF**
Q1	0.318	0.182	0.213	0.177	0.200	0.615	0.813	0.518	0.892	0.956	0.566	0.709
Q2	0.265	0.193	0.197	0.154	0.199	0.519	0.231	0.150	0.241	0.199	0.072	0.381
Q3	0.226	0.108	0.175	0.131	0.166	0.432	0.178	0.067	0.202	0.176	0.071	0.298
Q4	0.195	0.095	0.149	0.123	0.170	0.384	0.159	0.047	0.208	0.174	0.068	0.257

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF

*All values are normalized to MVIC and equivalent to a percentage

Table 40. Repeated measures ANOVA for each muscle examined

	RF	**RA**	**GM**	**GMx**	**ES**	**BF**
Load	*p*=.015*	*p*=.236	*p*<.001*	*p*=.007*	*p*=.886	*p*=.345
Time	*p*<.001*	*p*<.001*	*p*<.001*	*p*<.001*	*p*<.001*	*p*<.001*

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF
*significant at α=.05

Table 41. Change in muscle activity over time by quartile**

Muscle		**Q1↔Q2**	**Q1↔Q3**	**Q1↔Q4**	**Q2↔Q3**	**Q2↔Q4**	**Q3↔Q4**
RF	Difference	.317*	.363*	.388*	.046*	.071*	.025*
	Significance	*p*<.001	*p*<.001	*p*<.001	*p*<.001	*p*<.001	*p*<.001
RA	Difference	.178	.263*	.279*	.084	.100	.016
	Significance	*p*=.211	*p*<.001	*p*<.001	*p*=.710	*p=.742*	*p*=1.00
GM	Difference	.334*	.364*	.374*	.031*	.040	.010
	Significance	*p*<.001	*p*<.001	*p*<.001	*p*=.010	*p*=.205	*p*=1.00
GMx	Difference	.390*	.413*	.418*	.023	.028	.005
	Significance	*p*<.001	*p*<.001	*p*<.001	*p*=.323	*p*=1.00	*p*=1.00
ES	Difference	.248*	.265*	.264*	.017	.016	.001
	Significance	*p*<.001	*p*<.001	*p*<.001	*p*=.543	*p*=1.00	*p*=1.00
BF	Difference	.212*	.297*	.342*	.085*	.130*	.045*
	Significance	*p*=.002	*p*<.001	*p*<.001	*p*=.009	*p*=.003	*p*=.002

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF
**All differences are absolute values of mean differences between time quartiles
* significant at α=.05

For RF, load condition was statistically significant (F[1, 25]=6.87, p=.015, η_P^2=.216) demonstrating a statistically significant increase in muscle activity in the load condition compared to the no load condition. Additionally, the analysis revealed a significant decrease in RF activity over time (F[1.094, 27.359]=5.15, p<.001, η_P^2=.736). The interaction was also statistically significant (Wilks' Λ=11.206, p<.001). As will be the case for all statistically significant interaction terms, the cause is a substantial decrease in muscle activation in the load condition between the first and second measurements.

For RA, although load condition was not significant (F[1, 25]=1.474, p=.236, η_P^2=.056), an overall trend in increased muscle activity was noted in the load carriage condition compared to the no-load condition (Table 39). Time was statistically significant with a large effect size (F[1.325, 33.121]=12.188, p=.001, η_P^2=.328) with the RA showing a significant decrease in mean muscle activity over time. The interaction effect was also statistically significant (Wilks' Λ=9.367, p<.001).

For GM, mean muscle activity was significantly greater in load condition (F[1, 25]=30.284, p<.001, η_P^2=.548) and decreased significantly over time (F[1.139, 28.474]=34.583, p<.001, η_P^2=.580). The interaction effect was also statistically significant (Wilks' Λ=12.152, p<.001) due to the large decrease in the load condition between the first two measurements.

Similarly, both load condition (F[1, 24]=8.819, p=.007, η_P^2=.269) and time (F[1.065, 25.561]=47.212, p<.001, η_P^2=.663) were significant for GMx with increased mean muscle activity in the load condition and significant decreases in activity over time. The interaction effect was also statistically significant (Wilks' Λ=13.868, p<.001) due to the sizable decrease between the first and second time quartiles in the load condition.

The ES demonstrated an increase in mean muscle activity in the load carriage condition compared to the no-load condition, however this increase was not significant and had a small effect size (F[1, 25]=0.021, p=.886, η_P^2=.001). For ES, time was statistically significant with a large effect size (F[1.533, 38.321]=122.838, p<.001, η_P^2=.831) with activity decreasing over time. The interaction effect was also statistically significant (Wilks' Λ=38.829, p<.001) due to the substantial drop for the load condition between the first two measurements.

Last, for BF, mean muscle activity in the no-load condition was actually greater than that of the load carriage condition (Table 39), but this difference was not statistically significant with a small effect size (F[1, 25]=0.926, p=.345, η_P^2=.036). For time, there was a statistically significant decrease in mean muscle activity over the four time periods with a large effect size (F[1.64, 40.94]=31.494, p<.001, η_P^2=0.557). While the interaction effect is not statistically significant (*p*=.184), there was a noticeable decline in muscle activation for the load condition from the first to the second period.

4.4.2. Pain

Table 42 presents the average muscle activation aggregated by the two factors of load and pain condition using a yes/no value for pain (yes=MMBQ>0, no=MMBQ=0). For GM and GMx, the greatest average activation was in the load carriage condition of those with reported pain. Meanwhile, for RF, RA, ES, and BF the greatest average activation occurred in the no load condition for participants with reported pain. Participants with reported pain also had greater average activation in all cases.

Table 42. Average muscle activation by load and pain conditions

Load	Pain	RF	RA	GM	GMx	ES	BF
Yes	No	0.195	0.057	0.204	0.237	0.062	0.263
Yes	Yes	0.270	0.123	0.272	0.749	0.081	0.466
No	No	0.231	0.113	0.176	0.136	0.087	0.453
No	Yes	0.272	0.175	0.190	0.157	0.283	0.525

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF

Point biserial correlations were used to test the association between severity of back pain (based on overall MMBQ score) and muscle activation. Assessment of this relationship in the no-load condition revealed no significant associations. However, when the relationship was assessed in the load carriage condition, a significant association was found for the rectus abdominis (*r*[25]=.499, *p*=.01), suggesting a positive correlation between MMBQ scores and activity of the rectus abdominis when a load is added. Additionally, the ES demonstrated an association with pain in the load carriage condition, which was significant at the 10% level (*r*[25]=.334, *p*=.096). No other significant associations were found (Table 43).

Table 43. MMBQ & Muscle Activity

Muscle	**Condition**	**R**	***p*-value**
RF	Load	.268	.186
	No-load	-.012	.952
RA	Load	.499	.010*
	No-load	.143	.485
GM	Load	.046	.823
	No-load	.282	.162
GMx	Load	.078	.711
	No-load	.254	.211
ES	Load	.334	.096**
	No-load	-.010	.963
BF	Load	.302	.134
	No-load	-.028	.894

*significant at α=.05
**significant at α=.10

4.4.3. Demographics

Additionally, point biserial correlations were used to assess the relationship between body weight and muscle activation. These analyses revealed a statistically significant association between mean biceps femoris activity and weight in both the load (*r*[25]=.483, *p*=.012) and no-load (*r*[25]=.465, *p*=.017) conditions. An association was also noted between weight and RA activity in the no-load condition, which was significant at the 10% level (*r*[25]=.358, *p*=.073). No other significant associations were found (Table 44).

Table 44. Weight & Muscle Activity

Muscle	**Condition**	**R**	***p*-value**
RF	Load	.220	.280
	No-load	.009	.965
RA	Load	.023	.910
	No-load	.358	.073**
GM	Load	-.146	.478
	No-load	-.221	.278
GMx	Load	-.196	.348
	No-load	-.283	.161
ES	Load	-.325	.106
	No-load	.189	.355
BF	Load	.483	.012*
	No-load	.465	.017*

*significant at α=.05
**significant at α=.10

Last, to analyze the association between biological sex and mean activity of each of the six muscles, point biserial correlation coefficients were used. For this analysis a positive correlation indicates females activated more, while a negative correlation indicates males activated more. These analyses, in both the load carriage and no-load conditions, revealed a significant positive correlation for gluteus maximus (no load *r*[25]=.391, *p*=.048; load carriage *r*[24]=.516, *p*=.008). Thus indicating females demonstrated significantly greater GMx activity. No other significant associations were found (Table 45).

Table 45. Sex & Muscle Activity

Muscle	**Condition**	**R**	***p*-value**
RF	Load	-.083	.688
	No-load	-.206	.313
RA	Load	.088	.667
	No-load	.020	.924
GM	Load	.132	.520
	No-load	.224	.270
GMx	Load	.516	.008*
	No-load	.391	.048*
ES	Load	.319	.112
	No-load	-.065	.754
BF	Load	-.313	.119
	No-load	-.278	.168

*significant at α=.05

4.5. Discussion

The physical demands associated with military training place soldiers at risk for sustaining musculoskeletal injuries. One major facet of Army training is road marching while carrying an external load. In an analysis of injuries associated with load carriage, researchers found the spine accounted for approximately 31% of injuries.[30] Due to the large volume of back injuries sustained during load carriage, there is a need to increase the amount of available data related to potential causes of back pain in the military population.

Existing research in these areas is lacking as it is 1) focused solely on muscles of the lower extremity[3,4,7,8]; 2) conducted over short distances[3,5–9]; or 3) assesses back pain during standing[51,66,67] or unloaded walking[23–25,49,50] but not during load carriage. Therefore, this study expanded upon the existing research by increasing the distance walked, assessing muscles of the lower extremity, pelvis, and core, as well as incorporating a back pain assessment. We noted significant changes in muscle activity in response to both load and walking time/distance. Additionally, significant load x time interactions were identified, which may be explained by the notable decrease in mean activity between Q1 and Q2 in the load carriage condition (Table 39). Lastly, all muscles displayed an association between reported pain and mean amplitude of the EMG signal (Table 41).

4.5.1. Load Effects

4.5.1.1. Lower Extremity

Two of the six muscles examined in the present study are lower extremity muscles with important functional roles. First, the RF has multiple contributions to the gait cycle, acting eccentrically during the load response phase and assisting with hip flexion during the pre-swing and initial-swing phases. As a result of the muscle's involvement in the gait cycle, it has been consistently included in evaluations of muscle activity during load carriage.[3,7,8] Paralleling findings of existing research,[3,7,8] we noted a significant increase in mean RF activity when the 35-lb. load was added. Akin to the methods of the current study, Lindner et al.[7] utilized a military load carriage system including a 15-kg (33-lb.) framed rucksack and reported a significant increase in RF activity during gait when the pack was added. This increase in RF activity can likely be attributed to an increased force generated by the muscle to support the added weight and increase propulsive forces during loaded walking.[8]

In contrast to the consistency of outcomes related to the reaction of the RF to added loads, findings regarding the BF are not as straight forward. Some researchers have reported a significant increase in BF activity with an added load,[3,4,7] while others have reported no significant change.[5,8] Interestingly, the BF displayed a decrease in activity with the addition of the load, although this decrease was not statistically significant. The BF, which is the lateral muscle of the hamstring group, has an important role in performing hip extension and knee flexion during gait.[128] During hip extension, delayed firing of the gluteus maximus, which is common in individuals with LBP,[128] results in earlier activation of the hamstrings to compensate for the lack of gluteal functioning.[129,130] This compensatory mechanism increases the risk for various injuries, including the development of LBP.[129] Surprisingly, only 50% of the cadets participating in this study indicated they were experiencing back pain, and even fewer reported back pain associated with load carriage (~23%). Therefore, it is possible that this decrease in hamstring activity is the result of properly functioning gluteal muscles, as both the GM and GMx displayed significant increases in activity with the addition of a load.

4.5.1.2. Pelvic Muscles

Examination of the GM and GMx revealed that the additional load resulted in significantly increased mean activity of both muscles. Although the GM has not been extensively analyzed during load carriage,[9] it functions as a primary hip stabilizer during gait. The GM is the main hip abductor and helps maintain elevation of the non-weight-bearing hip to allow clearance for the swinging leg during walking, thereby making it an essential contributor to "normal" gait.[131–133] Dysfunction of this muscle can result in dropping of the pelvis to the contralateral side during walking.[131,132] The pathomechanics resulting from weakness or dysfunction of the GM have been associated with the presence of LBP.[51,66,67]

Like the GM, information regarding the response of the GMx to load carriage is lacking. Our results suggest activity of the GMx is significantly impacted by the addition of a load carried on the back. While not a major contributor to normal walking, the GMx is a producer of powerful hip extension.[133] It has an important function in activities such as running, sprinting, and jumping.[133] Since ambulation while carrying a load requires greater propulsive forces of the lower extremity compared to unloaded walking, it is likely that loaded walking requires more use of the GMx. Due to the important role of the GMx in hip extension, there is a need for more information regarding its function in load carriage as there is evidence that delayed onset of the GMx is associated with LBP.[129]

4.5.1.3. Core Muscles

Although not statistically significant, the RA and ES demonstrated an increase in activity in the load carriage condition during the Q1 time period, which subsequently decreased, displaying a lower mean amplitude in the load carriage condition for the remainder of the walking protocol (Q2-Q4). Similarly, researchers who analyzed ES activity during loaded gait with two different load placements (mid-back, high back) revealed a decrease in activity when loads were added compared to unloaded walking. Moreover, the decrease in ES activation was significant for the mid-back placement compared to the high placement, suggesting placing loads in the mid-back may help decrease the strain placed on the ES.[6]

While most analyses of loaded walking do not address core musculature, one study evaluated activation of back and abdominal muscles during stationary standing.[5] Although it is difficult to compare a static assessment to a dynamic load carriage task, the results of this study suggest a possible relationship between back and abdominal muscular response to loads. The researchers reported a significant increase in RA activity when the load was added, but no significant change in ES activity.[5] This may be due to the load being isolated to the back resulting in increased RA activity to counterbalance the load, while the back muscles do not need to activate to the same degree. In contrast, in the current study there was no notable difference between activation of back vs abdominal musculature, which does not support the hypothesis of increased RA activity to counterbalance the load. It is important to note that load carriage studies evaluating back and core musculature are limited; therefore, more data is needed to determine to accurately determine the effects of load carriage on these muscles.

4.5.2. Effects of Time

An important aspect of road marching that is not adequately assessed within the existing body of literature is how muscle activity changes over time while carrying a load. Several researchers have analyzed muscular adaptations to load carriage over short distances ranging from a few stride cycles to five minutes of walking[3,5–9]; however, there is minimal data available regarding changes in muscle activity over time/distance.[4] The lack of information available makes it difficult to determine if time/distance walked is a significant factor impacting how muscles adapt to added loads. Based on this research gap, in the present study, cadets completed a 5-km walk while controlling the speed set to 3 mph.

We discovered a significant time effect for mean EMG activity with all six muscles (RF, RA, GM, GMx, ES, and BF) displaying decreased activity over time. The mean amplitude of the EMG signal generally has a linear association with the magnitude of muscle force produced,[134] and an inverse relationship with fatigue.[135] Therefore, the decrease in amplitude displayed over the walking period is suggestive of decreased force produced over time and an associated lack of fatigue.

Similar to our findings, in an analysis of hikers walking an eight kilometer course, Simpson et al.[4] reported significantly decreased integrated EMG at 2 km, 4 km, and 8 km compared to 0 km in several muscles of the lower extremity. Although these two studies differ in the muscles analyzed, the finding of decreased muscle activity over time aligns with our outcomes.[4] We hypothesize that participants with high fitness levels volunteered to complete the activity with a relatively low level of difficulty. Although the 5-km and 8-km walks demonstrate substantial increases in distance compared to much of the existing research, these lengths are still relatively short in terms of the distance participating individuals are likely used to walking with a load. The three miles required for our testing procedure is drastically less physically taxing than the 12-mile road march the participating cadets are trained to complete. Due to the load carriage specific training our sample of cadets complete and the associated high level of physical fitness, our protocol was likely not extensive to produce a fatigue effect in this particular sample.

4.5.3. Relationship between Back Pain and Muscle Activity

Analysis of the association between back pain and muscle activation revealed a statistically significant correlation between MMBQ scores and RA activity in the load carriage condition. Additionally, an association between MMBQ scores and ES activity was noted in the load carriage condition, which was significant at the 10% level. Conversion of back pain results to a ‘yes/no’ format revealed increased mean EMG amplitude for all muscles examined in individuals reporting LBP in both the load and no-load conditions (Table 41). One limitation of the current study was recruitment efforts did not specifically target individuals with LBP; therefore, the level of pain reported was relatively low even when removing scores of those who reported an overall score of zero on the MMBQ (mean MMBQ score of individuals reporting pain was 6.667 out of a possible total of 45). A larger sample of individuals reporting greater levels of LBP may provide additional associations not present in this sample. Existing research related to muscle activity and back pain does not include a load carriage condition; however, our findings are consistent with existing data regarding the ES and RA.

Individuals with LBP demonstrate increased overall activity of the ES[23–25,49,50] and RA[23,49] during gait compared to healthy, asymptomatic individuals. In agreement with these findings, we noted cadets who reported experiencing LBP displayed greater activity of both the ES and RA compared to those who reported no pain. A potential explanation for this finding is the concept of muscle guarding, meaning individuals with LBP may not allow the muscles of the core to relax sufficiently. While the role of the ES in muscle guarding has been widely documented,[23–25,49,50] there is less information available regarding the role of the RA.[23,49] Van der Hulst et al.[50] was one of the first to include abdominal musculature in an evaluation of the muscle guarding hypothesis during gait. The researchers found that core muscle activity increased significantly during walking, especially at greater speeds, in individuals with LBP compared to pain-free controls.[50] Similarly, our results support the notion that the abdominal muscles have a signficaint role in the muscle guarding response to LBP, as our analysis revealed the RA had statistically signficant relationship to LBP. Based on our findings in conjunction with exisitng research, it is likely the noted increase in muscle activity in cadets with LBP is the result of muscle guarding.

4.6. Conclusion

This study is unique among load carriage research as it is one of few to incorporate muscles of the pelvis and core as well as determine effects over a prolonged distance. Further, the inclusion of a back pain/disability questionnaire adds a new component that has not previously been considered. Cadets demonstrated increased activity of lower extremity, pelvis, and core musculature when a load was added and displayed a significant decrease in mean EMG amplitude over time for all muscles examined. Additionally, we noted an association between presence of pain and muscle activity for all muscles, although results of the correlational analysis revealed significance for the RA only. These findings support the conclusion that added loads result in increased muscle activity of the lower extremity and expand upon previous findings by demonstrating that pelvic and core muscle activity is also impacted by added loads. Lastly, the association between back pain and muscle activity provides a promising starting point for further investigation.

Road marching while carrying a load is a standard occupational task for military personnel. Soldiers are often expected to carry heavy loads over long distances, which often results in development of back pain. The findings of this study suggest several muscles of the lower extremity are pelvis are significantly affected by the addition of a load. Moreover, there appears to be an association between the presence of pain and muscle activity during load carriage. Based on these associations, soldiers muscle activity should be evaluated proactively to augment strength and conditioning procedures.

5. A COMPARISON OF ACFT SCORES, BACK PAIN, & MUSCLE ACTIVITY IN ARMY ROTC CADETS

5.1. Abstract

Context: Existing research has demonstrated an association between physical fitness measured by APFT performance and future injury risk. Additionally, low back pain (LBP) is among the most reported musculoskeletal injuries in the Army. As the Army transitions to the Army Combat Fitness Test (ACFT), there is a need for information relating to performance on the test and injury risk. **Purpose:** The primary objective of this research was to analyze a possible relationship between performance on the ACFT and LBP, muscle activity, and kinesiophobia in Army Reserve Officer Training Corps (ROTC) cadets. **Methods:** 21 Army ROTC cadets completed a 5-kilometer walk with a 35-pound load. Electromyography (EMG) data were obtained of the rectus femoris (RF), rectus abdominis (RA), gluteus medius (GM), gluteus maximus (GMx), erector spinae (ES), and biceps femoris (BF), and a military-specific questionnaire was used to assess LBP. Additionally, cadets completed the six-event ACFT (3 repetition maximum deadlift [MDL], standing power throw [SPT], hand release push-ups [HRP], sprint-drag-carry [SDC], leg tuck [LTK], and 2-mile run [2MR]), the Tampa Scale of Kinesiophobia (TSK) pre and post ACFT, and visual analog scales (VAS) pre and post MDL and 2MR. Regression was used to model the ability of ACFT, MMBQ, TSK, and VAS scores to predict muscle activity. Independent samples *t*-tests were used to assess for differences in ACFT performance between sexes. Paired samples *t*-tests were used to assess changes in pain throughout the ACFT. **Results:** Results of the regression revealed significant predictive value for the GM (*p*=.007). Comparison between males and females revealed males performed significantly better on all components of the ACFT except the 2MR. Last, significant increases in self-reported pain were noted from pre- to post-ACFT ($p<.001$). **Conclusion:** Significant increases in pain and fear of movement suggest there is a need for training that is more specific to the movements included in the ACFT. Additionally, differences in ACFT performance suggest females are unlikely to qualify for jobs classified as "heavy" based on the current scoring system.

5.2. Introduction

The Army Physical Fitness Test (APFT) has been the gold standard for measuring United States Army soldiers' physical readiness since 1980.[136] The APFT is a three-event assessment that evaluates muscular and aerobic endurance with two-minutes of push-ups, two-minutes of sit-ups, and a two-mile run. The components of the APFT do not encompass aspects of functional fitness, which are crucial for injury prevention and ensuring soldiers are prepared to complete physically demanding occupational tasks. Measurements of power, strength, and anaerobic endurance have been neglected since the inception of the APFT over 40 years ago.

Presently, the US Army is in the process of phasing out the APFT. Concurrently, a new test, the Army Combat Fitness Test (ACFT), is being introduced across the Army. In contrast to the APFT, the six-event ACFT is a functional fitness assessment designed to test soldiers' upper and lower body strength, grip strength, upper and lower body explosive power, flexibility, dynamic balance, upper body muscular endurance, anaerobic capacity, and aerobic endurance.[137] This new fitness assessment is a more accurate representation of the physical demands of military service, and it more closely replicates tasks soldiers must be prepared to perform as compared to the APFT.[138]

Since the APFT was employed for over four decades, the test and how it can be used to assess injury risk has been extensively researched.[14,15,20,21,32,119,136,139,140] Investigations pertaining to the relationship between APFT performance and injury incidence demonstrate steadfast support of the inverse association between cardiovascular fitness and injury.[14–16,19–21] It is clear from the abundance of research on this topic that lower cardiovascular fitness, as measured by the two-mile run, is associated with increased risk for sustaining a musculoskeletal injury.[14–16,19–21] In contrast, the measures of muscular endurance (push-ups and sit-ups) included in the APFT do not demonstrate the same strong, consistent association with injury risk.[14–21] Findings of preliminary research reveal inconsistencies when comparing performance data between the APFT and ACFT.[141,142] As a result, it cannot be concluded definitively that the fitness and injury relationships established based on the APFT directly translate to the ACFT. Furthermore, review of existing analyses of injury incidence in relation to APFT performance reveal a clear trend of high rates of injuries to the lower extremity and spine with fewer injuries involving the upper extremity.[2,30,31,36] Therefore, these body regions require a specific focus to determine the cause of injuries as well as methods for preventing future injuries.

Researchers have reported that back injuries are among the leading reported injuries in Army personnel, accounting for approximately 23% of all injuries.[2] However, while the APFT is has been effective for predicting those at risk for sustaining lower extremity injuries,[16,20,21] it has not successfully identified fitness-related explanations for such high rates. There are numerous factors that can be associated with the onset of back injuries, some of which include pathological muscle activity, self-reported pain, and perceived disability. Analyses using electromyography to assess core muscle function have consistently revealed increased activity of the erector spinae and rectus abdominis muscles in those with low back pain.[23–25,49] Pain and perceived disability are frequently quantified though measures such as the Tampa Scale of Kinesiophobia (TSK) and visual analog scales (VAS).[22–25,113,115,143] Due to conflicting results of studies evaluating these measures in individuals with LBP, it is unclear whether there is a relationship between muscle activation and clinical measures of perceived disability.[22–25] Attaining further information related to how the previously described muscular changes may relate to VAS and TSK outcomes could provide valuable information pertaining to the development of LBP in the Army population. Moreover, drawing a connection between ACFT performance, pain and disability measurements, and muscle activity could create an opportunity to identify solders at risk for sustaining back injuries based on performance on specific components of the ACFT.

Recognition of these relationships creates an opportunity for early identification and intervention, thereby decreasing soldier attrition secondary to musculoskeletal injuries. While the ACFT is clearly a more comprehensive assessment of the physical demands placed on soldiers, several unknowns remain. Therefore, the purpose of this study was three-fold. First, to explore how back pain relates to ACFT performance; second, to assess a possible relationship between muscle activity and ACFT performance; and lastly, to identify a possible relationship between kinesiophobia and performance on the ACFT.

5.3. Methods

5.3.1. Participants

Prior to participant recruitment, this observational and survey study was approved by the Institutional Review Board at North Dakota State University. Participants included a total of 21 Army ROTC Cadets (Age 21.29±1.82 years; M=15, F=6) from one brigade associated with a mid-sized university. Inclusion criteria required participants to be enrolled in a Military Science course. Additionally, participation in a prior study, “An Analysis of Muscle Activity during Load Carriage in Army ROTC Cadets,” was required. The design of the two studies allowed for further analysis of muscle activation and back pain data related to Army-specific physical requirements. Exclusion criteria included cadets with any injury or general medical illness that prevented completion of the ACFT or failure to complete any portion of the ACFT.

5.3.2. Measures

This study utilized EMG data obtained during a prior study session. EMG data were collected during a 5-kilometer loaded walking protocol in which cadets walked at a set speed of three miles per hour while carrying a 35-lb. load in a traditional, framed rucksack. Mean EMG amplitude over the entire one-hour walking protocol was normalized to maximal isometric contraction (MVC). The normalized mean amplitude was used as the muscle activation value in the analyses for the present study.

Two separate subjective measures of pain and pain-related fear of movement were used. The Tampa Scale for Kinesiophobia (TSK) is used in rehabilitation to quantify pain-related fear of movement in individuals with back pain.[113] The TSK has been proven to have high levels of validity and reliability.[113] Therefore, it was selected for use in this study to determine cadets' fear of movement and how their pain-related fear of movement changed after completing physical activity (Appendix D).

Additionally, a Visual Analog Scale (VAS) was implemented to assess pain. The VAS is proven to be a reliable and valid measure of pain intensity.[143] Based on its frequent use in research, a 10-point VAS (Appendix C) was employed to quantify current pain levels immediately before and after completion of selected activities.

5.3.3. Protocol

After consenting to participate in this study, cadets completed the TSK prior to initiating any physical activity. Following completion of the TSK, participants participated in the Army Combat Fitness Test (ACFT) with the rest of the cadets in the brigade. This test consists of six different components assessing various aspects of functional fitness. The six events include 1) three-repetition maximum deadlift (MDL), 2) standing power throw (SPT), 3) hand release push-up (HRP), 4) sprint-drag-carry (SDC), 5) leg tuck (LTK), and 6) two-mile run (2MR). The six events are completed in the listed order and must be completed in 70 minutes or less.[27]

Immediately before and after completing the MDL, participants indicated their current level of pain on the 10-point VAS. Similarly, directly before and after the 2MR, the last event of the ACFT, cadets again indicated their current level of pain on the VAS. Lastly, after completing the ACFT in its entirety, participants filled out the TSK again indicating their level of kinesiophobia upon completion of the fitness assessment.

In addition to the subjectively reported pain and kinesiophobia data, objective measurements of fitness were recorded. The collected values included performance on all six events of the ACFT. These data consisted of weight lifted (MDL), distance thrown (SPT), repetitions performed (HRP and LTK), and time needed to complete the task (SDC and 2MR).

Furthermore, data from a prior study was utilized in the analysis to assess a variety of relationships. These data included demographic information (biological sex, height, weight, and age), scores from a back pain disability questionnaire, and sEMG data from six different muscles of the lower extremity and core (rectus femoris [RF], biceps femoris [BF], erector spinae [ES], rectus abdominis [RA], gluteus medius [GM], and gluteus maximus [GMx]) collected during walking with a 35-lb. load.

5.3.4. Statistical Analysis

All statistical analyses were completed via IBM® SPSS statistics software version 25.0 (IBM®, Armonk, New York). Dependent variables included activity of the RF, BF, ES, RA, GM, and GMx. Independent variables included performance on each component of the ACFT (weight lifted, repetitions performed, time to complete), scores on the TSK, MMBQ, and VAS's. Biological sex was included as a covariate. Regression was used to model the ability of ACFT scores, MMBQ scores, TSK scores, and VAS scores to predict mean muscle amplitude of six muscles of the lower extremity and core during completion of a submaximal load carriage task. Independent samples *t*-tests were used to assess significant differences in ACFT performance between males and females. Paired samples *t*-tests were used to assess changes in pain between pre- and post-MDL, pre- and post-2MR, and to assess changes in pain and kinesiophobia from start and end of the ACFT.

5.4. Results

5.4.1. Muscle Activity Predicted by Pain, Kinesiophobia, and ACFT Performance

Six multiple linear regression analyses were calculated to develop a model for predicting muscle activity (one for each of the six muscles assessed). Dependent variables included mean muscle activity during a one-hour load carriage protocol for the rectus femoris (RF), rectus abdominis (RA), gluteus medius (GM), gluteus maximus (GMx), erector spinae (ES), and biceps femoris (BF). Independent predictors included MMBQ score for current pain, post-ACFT TSK score, post-event VAS score when applicable (MDL and 2MR), and ACFT performance including 3-Repetition Maximum Deadlift (MDL), Standing Power Throw (SPT), Hand-Release Push-Ups (HRP), Sprint-Drag-Carry (SDC), Leg Tuck (LTK), and 2-Mile Run (2MR). A significant regression equation was found for the GM, while there were no predictive qualities for the remaining five muscles. Demographic information is displayed in Table 46 and descriptive statistics for all variables are displayed in Table 47. Results of each overall model are presented in Table 48.

Table 46. Demographic Information

Variable	Mean	Standard Deviation
Age (years) (N=20)	21.35	1.84
Male (n=15)	21.13	2.07
Female (n=5)	22.00	0.71
BMI (kg/m^2) (N=20)	25.53	2.63
Male (n=15)	25.83	2.83
Female (n=5)	24.75	2.16

Table 47. Descriptive statistics for ACFT performance, muscle activity, and pain

Variable	Mean	Standard Deviation	Male (M±SD)	Female (M±SD)
MDL (lbs.)	242.00	66.70	260.67±67.03	186±13.42
Pre-MDL VAS	0.75	1.12	0.8±1.08	0.6±1.34
Post-MDL VAS	1.35	1.57	1.33±1.68	1.4±1.34
SPT (meters)	8.93	1.93	9.66±1.55	6.72±1.09
HRP (repetitions)	38.45	7.40	40.67±6.92	31.8±4.32
SDC (seconds)	102.65	18.18	96.07±10.91	122.4±22.46
LTK (repetitions)	10.35	5.83	12.73±4.40	3.2±2.77
2MR (minutes)	16.32	1.93	15.92±1.56	17.53±2.57
Pre-2MR VAS	2.30	2.18	2.67±2.32	1.2±1.3
Post-2MR VAS	4.30	2.89	4.4±3.0	4±2.83
Pre-ACFT TSK	30.00	4.30	30.47±4.76	28.6±2.3
Post-ACFT TSK	31.40	6.46	32.47±6.94	28.2±3.56
MMBQ	3.33	5.37	3.41±5.03	3.11±6.96
RF (mV)	0.196	0.192	0.207±0.211	0.165±0.133
RA (mV)	0.086	0.172	0.088±0.197	0.083±0.073
GM (mV)	0.249	0.182	0.251±0.187	0.244±0.187
GMx (mV)	0.214	0.274	0.131±0.149	0.466±0.418
ES (mV)	0.072	0.033	0.070±0.032	0.078±0.040
BF (mV)	0.349	0.372	0.406±0.412	0.180±0.133

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF; 3-Repetition Maximum Deadlift, MDL; Standing Power Throw, SPT; Hand-Release Push-Ups, HRP; Sprint-Drag-Carry, SDC; Leg Tuck, LTK; 2-Mile Run, 2MR; Tampa Scale of Kinesiophobia, TSK; Visual analogue scale, VAS; modified military back pain questionnaire, MMBQ; Army Combat Fitness Test, ACFT

Table 48. Results of the overall model for each muscle

Dependent Variable	Significance (*p*-value)	R^2
RF	.177	0.677
RA	.264	0.631
GM*	.007	0.866
GMx	.206	0.661
ES	.131	0.706
BF	.123	0.712

Abbreviations: rectus femoris, RF; rectus abdominis, RA; gluteus medius, GM; gluteus maximus, GMx; erector spinae, ES; biceps femoris, BF

*significant at α=.05

The multiple regression model to predict activity of the GM was significant. The results of the regression indicate that the model explained 86.6% of the variance and that the model was a significant predictor of mean amplitude of the muscle during completion of a submaximal load carriage task (*F*[10,9]=5.832, *p*=.007). SPT, SDC, LTK, and 2MR performance contributed significantly to the model, while MDL, HRP, VAS scores, TSK scores, and MMBQ scores did not (Table 49).

Table 49. Individual coefficients for the gluteus medius

	Predictor variable	**Unstandardized beta coefficient**	**Significance (*p*-value)**
GM	MMBQ	-.007	.228
	TSK	.010	.103
	Post-MDL VAS	.023	.315
	Post-2MR VAS	.002	.905
	MDL	-.001	.280
	SPT*	-.085	.006
	HRP	-.009	.242
	SDC*	-.011	.003
	LTK*	.021	.013
	2MR*	.094	.002

Abbreviations: gluteus medius, GM; 3-Repetition Maximum Deadlift, MDL: Standing Power Throw, SPT; Hand Release Push-ups, HRP; Sprint-Drag-Carry, SDC; Leg Tuck, LTK; 2-Mile Run, 2MR; Tampa Scale of Kinesiophobia, TSK; Visual analogue scale, VAS; modified military back pain questionnaire, MMBQ
*significant at α=.05

5.4.2. ACFT Performance & Biological Sex

Independent samples *t*-tests assessed using raw performance data revealed significant differences in ACFT performance between males and females at the 5% level for the MDL, SPT, HRP, and LTK. A difference was noted at the 10% level for the SDC. No significant difference was found for the 2MR. When the comparison was assessed using scored data, MDL, SPT, and HRP were significant at the 5% level, while SDC and LTK were significant at the 10% level. There was still no significant difference for 2MR performance. Additionally, a significant difference was noted between males and females for total score. All significant differences involved males outperforming females (Table 50).

Table 50. Difference in ACFT performance by biological sex

Event	Biological Sex	Mean ± SD	Significance
		Raw Data	
MDL*	Male	260.67±67.03	*p*=.001
	Female	186±13.42	
SPT*	Male	9.66±1.55	*p*=.001
	Female	6.72±1.09	
HRP*	Male	40.67±6.92	*p*=.016
	Female	31.8±4.32	
SDC**	Male	96.07±10.91	*p*=.057
	Female	122.4±22.46	
LTK*	Male	12.73±4.40	*p*<.001
	Female	3.2±2.77	
2MR	Male	15.92±1.56	*p*=.106
	Female	17.53±2.57	
		Scored Data	
MDL*	Male	82.8±14.26	*p*=.001
	Female	66.4±3.13	
SPT*	Male	81.13±9.76	*p*=.003
	Female	65.6±3.91	
HRP*	Male	80.87±6.40	*p*=.011
	Female	72.2±3.56	
SDC**	Male	96.07±4.40	*p*=.074
	Female	80.2±15.71	
LTK**	Male	85.4±8.96	*p*=.079
	Female	53.6±30.41	
2MR	Male	72.8±31.12	*p*=.979
	Female	73.2±16.38	
Total*	Male	500.07±42.16	*P*=.001
	Female	411.2±50.44	

Abbreviations: 3-Repetition Maximum Deadlift, MDL: Standing Power Throw, SPT; Hand Release Push-ups, HRP; Sprint-Drag-Carry, SDC; Leg Tuck, LTK; 2-Mile Run, 2MR
*significant at α=.05
**significant at α=.10

5.4.3. Pain & Kinesiophobia

Finally, results of the paired samples *t*-test revealed significant increases in pain from pre- to post-MDL (*t*[19]=-2.698, *p*=.014), pre- to post-2MR (*t*[19]=-4.873, *p*<.001), and pre- to post-ACFT (*t*[19]=-5.262, *p*<.001). At the 10% level, there was a significant increase in TSK scores from pre- to post-ACFT (*t*[19]=-1.889, *p*=.074).

5.5. Discussion

Musculoskeletal injuries are a leading cause of medical encounters within the military population[13,14] and many of these injuries involve the spine.[20,21] Moreover, researchers have demonstrated that soldiers with lower physical fitness levels are at greater risk for sustaining musculoskeletal injuries[14–21] with the strongest predictor being poor cardiovascular fitness measured by the two-mile run component of the APFT.[14–16,19–21] The body of research examining the relationship between injury incidence and performance on the APFT is extensive.[14–21] However, due to the novelty of the ACFT, there is a lack of knowledge regarding the utility of the test for assessing injury risk.

This study is unique, as it is among the first to use the ACFT to evaluate the relationship between muscle activity, back pain, and performance on each component of the test. This study builds upon the available information by including an EMG analysis of lower extremity and core musculature during loaded walking and how those values relate to ACFT performance. Further expanding on existing data, we included measures of self-reported pain and fear of movement to assess how these factors influence functional performance. We found significant relationships between various components of the ACFT and activity of the GM, while there were no strong predictive qualities for the remaining five muscles.

5.5.1. Muscle Activity

Our analysis revealed that increased GM activity during load carriage was associated with better performance on the SDC and LTK and decreased performance on the SPT and 2MR. First, decreased performance on the SPT was associated with increased GM activity during completion of a loaded walking task. Increased muscle activity values indicate the muscle is working at a greater percentage of its maximum ability, or MVC. The SPT is designed to assess upper and lower body explosive power and dynamic balance.[27] The event requires activation of the GM, primarily to assist with maintaining balance; however, the primary lower extremity contributor to the SPT task should be the GMx, as it is a producer of powerful hip extension.[133] Powerful hip extension is required as the soldier squats and explosively extends the knees and hips to throw the ball overhead. If the GMx is not firing appropriately, the GM may be working harder to compensate for the lack of GMx activity, thereby resulting in a less effective method for producing the movement.

Similarly, increased GM activity during the load carriage task was associated with longer 2MR times, indicating poorer performance. During running, the GM acts to provide stability and prevent dropping of the non-weight-bearing hip.[131–133] GM contractions at a greater percentage of MVC during load carriage may be explained by the onset of fatigue taking place by the time cadets reached the end of the load carriage task. Increased EMG amplitude in combination with decreased mean power frequency is generally associated with fatigue.[134,135] A fatigue effect would explain the increased GM amplitude, as the muscle is working at a greater percentage of its capacity. The 2MR is the last of six components and it requires use of the GM throughout, similar to a prolonged road march. Thus, our results suggest that cadets who begin to display increased GM amplitude during a prolonged load carriage task are likely to have poorer performance on the 2MR event.

We also noted significant associations between increased GM activity during load carriage and decreased SDC time, indicating better performance. The SDC event requires activation of the GM similar to the SPT and 2MR. The GM should contract to maintain balance during quick turns, to provide stability during the 50-m lateral shuffle, and prevent dropping of the non-weight-bearing hip during running.[131–133] GM weakness is a relatively common issue, which is often associated with the presence of LBP.[144,145] The association between increased activity of the GM during load carriage and improved performance on the SDC may suggest that cadets who are able to activate their GM perform better on the SDC.

Last, we noted an association between increased GM activity during load carriage and more LTK repetitions. The GM is not a major contributor to the LTK task. As a result, this association is likely a coincidence and not clinically relevant. Although it is unclear what the exact nature of the relationship is between GM activity and ACFT performance, we do know there is a significant association between these two factors. The GM is a major pelvic stabilizer and has an important role in gait and other weight bearing activities.[131–133]

5.5.2. Biological Sex

One aspect of the ACFT that has been a source of concern is the scoring system. While scoring of the APFT was adjusted to account for difference of age and biological sex, the ACFT is age and gender neutral.[27] Instead, scoring requirements are based on military occupational specialty (MOS). Jobs are classified into one of three categories: heavy, significant, or moderate. Although the current scoring system is subject to change by the time the ACFT is officially implemented, the current scoring system maxes out at a score of 600, and the minimum to pass is a total of 360 (≥60 per event). Jobs classified as heavy require a score of at least 70 on each event, jobs categorized as significant require a minimum score of 65 per event, while moderate jobs require a score of at least 60 on each event (Table 51).[27]

Table 51. ACFT Performance Requirements by MOS*

Event	Raw Performance	Score
MDL (pounds)	180	70
	160	65
	140	60
SPT (meters)	8.5	70
	6.5	65
	4.6	60
HRP (repetitions)	30	70
	20	65
	10	60
SDC (minutes: seconds)	2:09	70
	2:45	65
	3:35	60
LTK (repetitions)	5	70
	3	65
	1	60
2MR (minutes: seconds)	18:00	70
	19:00	65
	21:07	60

*Adapted from ACFT Field Testing Manual[27]

Unsurprisingly, our results demonstrate that males outperform females on every component of the ACFT, and this difference is statistically significant on every event except the 2MR. Furthermore, based on the performance of our sample of cadets, it is unlikely that many females will have the physical capacity to qualify for jobs classified as heavy, and many would also struggle to qualify for jobs in the significant category. The primary events preventing females from meeting the scoring requirements for heavy are the MDL, SPT, and LTK with LTK scores being by far the lowest.

The MDL, SPT, and LTK events are all different measures of muscular strength and power.[27] Compared to males, females naturally possess less muscle mass, and as a result, they have less strength and produce less power.[146] Furthermore, research has demonstrated that males are consistently able to perform heavier deadlifts compared to their female counterparts due to males larger muscle mass and the associated strength and power production abilities.[147] Existing research suggests these sex-related differences in strength and power can be attributed to various muscle properties such as differences in muscle cross sectional area and the size of higher-threshold motor units.[146]

5.5.3. Pain and Kinesiophobia

Our findings revealed no significant associations between muscle activity and TSK or VAS scores. There is evidence that muscle guarding of the RA and ES, which involves increased muscle activity, is associated with the presence of LBP.[23–25,49,50] Therefore, we anticipated cadets reporting increased pain and kinesiophobia would also demonstrate increased muscle activity. However, our findings do not support this concept. In prior studies, researchers have utilized various measures of perceived disability, including the TSK and VAS scales, with evaluations of muscle activity in patients experiencing LBP.[22–25] Based on the outcomes of these studies, no consistent association exists between muscle activity and self-perceived disability measurements,[22–25] which aligns with the findings of the present study. Furthermore, in a study of TSK efficacy, researchers documented a lack of association between TSK scores and rehabilitation outcomes, functional abilities, and pain,[113] which may explain the lack of association with muscle activity we identified.

Although self-reported pain and fear of movement were not significantly associated with muscle activity, we did note statistically significant increases in these measurements from pre- to post-activity. This increase in both VAS and TSK scores over the duration of the ACFT indicates the activities involved in the ACFT elicited substantial LBP in many of our cadets. In a previous study, researchers determined high TSK scores indicated patient belief that painful activities would cause injury, decrease function, and increase suffering.[148] Therefore, our findings may suggest a need for more ACFT-specific training to reduce the associated increases in pain and kinesiophobia.

5.6. Conclusion

This study is one of the first to assess relationships between back pain and performance on the ACFT. Due to the novelty of the ACFT, research utilizing the test is minimal. There are mixed findings within preliminary research examining how performance on the APFT translates to performance on the ACFT. Thus, it cannot be assumed that findings pertaining to injury risk based on the APFT can be translated to the ACFT. Furthermore, there are documented muscular adaptations that are consistently associated with the presence of LBP. Therefore, the inclusion of an EMG analysis adds a unique component to this study to build upon existing knowledge.

While the exact nature of the association is unclear, there is a significant relationship between performance on various components of the ACFT and activity of the GM. Additionally, the significant difference in performance between male and female cadets is one of the key findings of the current study due to the current scoring system and the potential for changes to occur prior to the official implementation of the ACFT. Based on the current scoring system, the majority of females will be limited in their MOS options. Additionally, significant increases in self-reported pain were noted from pre- to post-MDL, pre- to post-2MR, as well as pre-MDL to post-2MR (start to finish of the ACFT). Furthermore, TSK scores increased from pre- to post-ACFT. These findings related to self-reported pain and fear of movement suggest the movements required during the ACFT cause drastic increases in pain and kinesiophobia, which may point to a need for improved training methods specific to the ACFT.

Furthermore, the significant association between ACFT performance and GM activity warrants further research, as GM weakness has been associated with the presence of LBP. In sum, our findings suggest additional assessment of the efficacy of ACFT training is needed to ensure soldiers are prepared for high-energy producing movements. Perhaps of the greatest concern is the need to re-evaluate performance requirements based on the physiological differences between males and females resulting in significant performance disparities.

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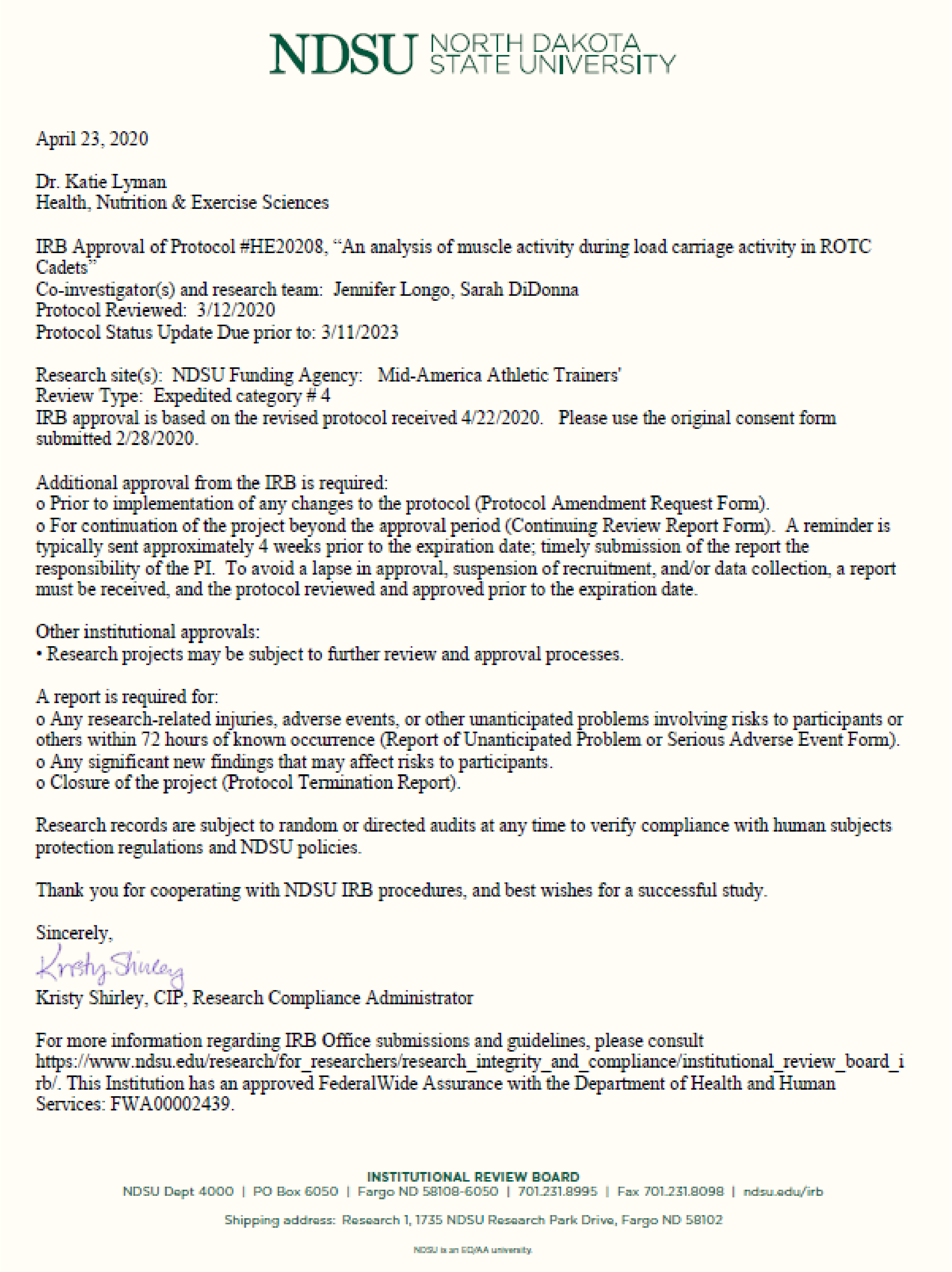
APPENDIX A. IRB APPROVAL #HE20208



NDSU NORTH DAKOTA STATE UNIVERSITY

April 23, 2020

Dr. Katie Lyman
Health, Nutrition & Exercise Sciences

IRB Approval of Protocol #HE20208, "An analysis of muscle activity during load carriage activity in ROTC Cadets"
Co-investigator(s) and research team: Jennifer Longo, Sarah DiDonna
Protocol Reviewed: 3/12/2020
Protocol Status Update Due prior to: 3/11/2023

Research site(s): NDSU Funding Agency: Mid-America Athletic Trainers'
Review Type: Expedited category # 4
IRB approval is based on the revised protocol received 4/22/2020. Please use the original consent form submitted 2/28/2020.

Additional approval from the IRB is required:
o Prior to implementation of any changes to the protocol (Protocol Amendment Request Form).
o For continuation of the project beyond the approval period (Continuing Review Report Form). A reminder is typically sent approximately 4 weeks prior to the expiration date; timely submission of the report the responsibility of the PI. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

Other institutional approvals:
• Research projects may be subject to further review and approval processes.

A report is required for:
o Any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
o Any significant new findings that may affect risks to participants.
o Closure of the project (Protocol Termination Report).

Research records are subject to random or directed audits at any time to verify compliance with human subjects protection regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,
Kristy Shirley
Kristy Shirley, CIP, Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult https://www.ndsu.edu/research/for_researchers/research_integrity_and_compliance/institutional_review_board_irb/. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

INSTITUTIONAL REVIEW BOARD
NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo ND 58102

NDSU is an EO/AA university.

APPENDIX B. BACK PAIN QUESTIONNAIRE

Instructions: Please answer every question by placing a mark in the **one** box that best describes your condition over the past year. We realize you may feel that two of the statements may describe your condition, but **please mark only the box that most closely describes your condition.**

Pain Intensity

☐ I can tolerate the pain I have without having to use pain medication.
☐ The pain is bad, but I can manage without having to take pain medication.
☐ Pain medication provides me with complete relief from pain.
☐ Pain medication provides me with moderate relief from pain.
☐ Pain medication provides me with little relief from pain.
☐ Pain medication has no effect on my pain.

Lifting

☐ I can lift heavy weights without increased pain.
☐ I can lift heavy weights, but it causes increased pain.
☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if the weights are conveniently positioned (e.g., on a table).
☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned.
☐ I can lift only very light weights.
☐ I cannot lift or carry anything at all.

Walking

☐ Pain does not prevent me from walking any distance.
☐ Pain prevents me from walking more than 1 mile. (1 mile = 1.6 km).
☐ Pain prevents me from walking more than 1/2 mile.
☐ Pain prevents me from walking more than 1/4 mile.
☐ I can walk only with crutches or a cane.
☐ I am in bed most of the time and have to crawl to the toilet.

Sitting

☐ I can sit in any chair as long as I like.
☐ I can only sit in my favorite chair as long as I like.
☐ Pain prevents me from sitting for more than 1 hour.
☐ Pain prevents me from sitting for more than 1/2 hour.
☐ Pain prevents me from sitting for more than 10 minutes.
☐ Pain prevents me from sitting at all.

Standing

- ☐ I can stand as long as I want without increased pain while wearing body armor and a helmet.
- ☐ I can stand as long as I want while wearing body armor and a helmet, but it increases my pain.
- ☐ Pain prevents me from standing for more than 1 hour while wearing body armor and a helmet.
- ☐ Pain prevents me from standing for more than 1/2 hour while wearing body armor and a helmet.
- ☐ Pain prevents me from standing for more than 10 minutes while wearing body armor and a helmet.
- ☐ Pain prevents me from standing at all while wearing body armor and a helmet.

Sleeping

- ☐ Pain does not prevent me from sleeping well.
- ☐ I can sleep well only by using pain medication.
- ☐ Even when I take medication, I sleep less than 6 hours.
- ☐ Even when I take medication, I sleep less than 4 hours.
- ☐ Even when I take medication, I sleep less than 2 hours.
- ☐ Pain prevents me from sleeping at all.

Traveling

- ☐ I can travel anywhere in a military vehicle while wearing body armor and a helmet without increased pain.
- ☐ I can travel anywhere in a military vehicle while wearing body armor and a helmet, but it increases my pain.
- ☐ My pain restricts my travel over 2 hours in a military vehicle while wearing body armor and a helmet.
- ☐ My pain restricts my travel over 1 hour in a military vehicle while wearing body armor and a helmet.
- ☐ My pain restricts my travel to short necessary journeys under 1/2 hour in a military vehicle while wearing body armor and a helmet.
- ☐ My pain prevents all travel except for visits to the physician / therapist or hospital.

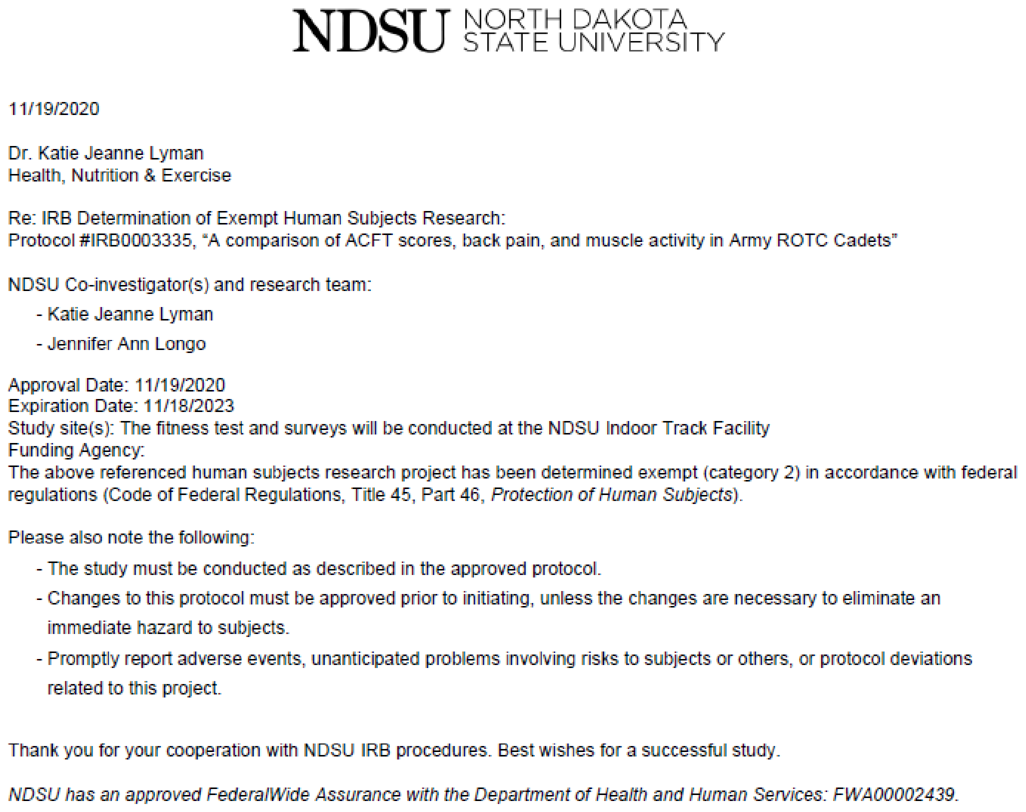
Employment

- ☐ My normal job activities do not cause pain.
- ☐ My normal job activities increase my pain, but I can still perform all that is required of me.
- ☐ I can perform most of my job duties, but pain prevents me from performing more physically stressful activities (e.g., lifting, running, load carriage).
- ☐ Pain prevents me from doing anything but light duties.
- ☐ Pain prevents me from doing even light duties.
- ☐ Pain prevents me from performing any job.

Load Carriage

- ☐ Pain does not prevent me from walking while wearing all necessary equipment (e.g., armored vest, helmet, backpack, etc.).
- ☐ Pain does not prevent me from walking while wearing all necessary equipment, but it increases my pain.
- ☐ Pain prevents me from walking while wearing equipment for more than 2 hours.
- ☐ Pain prevents me from walking while wearing equipment for more than 1 hour.
- ☐ Pain prevents me from walking while wearing equipment for more than ½ hour.
- ☐ Because of my pain I cannot walk while wearing equipment.

APPENDIX C. IRB APPROVAL #IRB0003335



NDSU NORTH DAKOTA STATE UNIVERSITY

11/19/2020

Dr. Katie Jeanne Lyman
Health, Nutrition & Exercise

Re: IRB Determination of Exempt Human Subjects Research:
Protocol #IRB0003335, "A comparison of ACFT scores, back pain, and muscle activity in Army ROTC Cadets"

NDSU Co-investigator(s) and research team:

- Katie Jeanne Lyman
- Jennifer Ann Longo

Approval Date: 11/19/2020
Expiration Date: 11/18/2023
Study site(s): The fitness test and surveys will be conducted at the NDSU Indoor Track Facility
Funding Agency:
The above referenced human subjects research project has been determined exempt (category 2) in accordance with federal regulations (Code of Federal Regulations, Title 45, Part 46, *Protection of Human Subjects*).

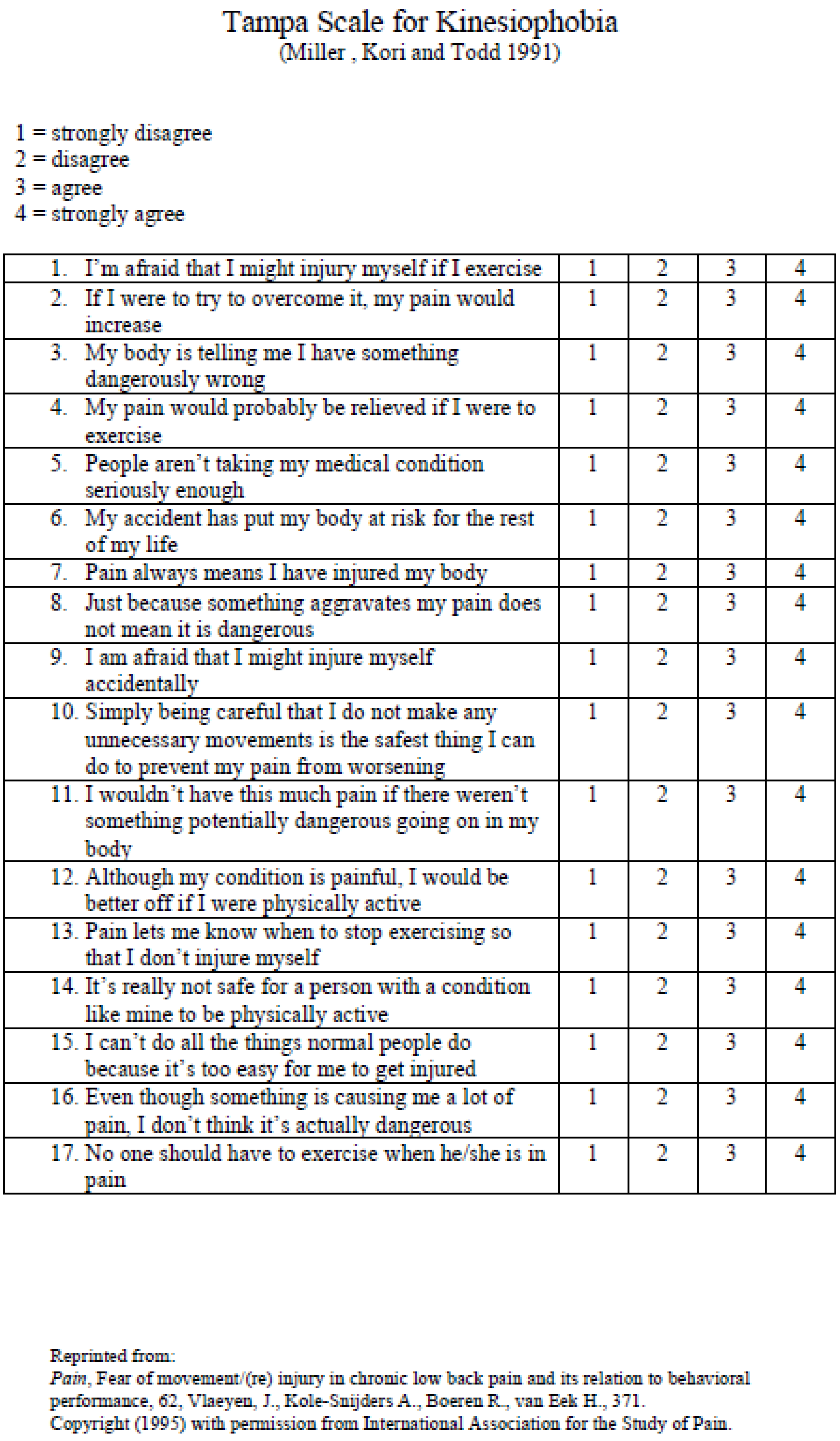
Please also note the following:

- The study must be conducted as described in the approved protocol.
- Changes to this protocol must be approved prior to initiating, unless the changes are necessary to eliminate an immediate hazard to subjects.
- Promptly report adverse events, unanticipated problems involving risks to subjects or others, or protocol deviations related to this project.

Thank you for your cooperation with NDSU IRB procedures. Best wishes for a successful study.

NDSU has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

APPENDIX D. TAMPA SCALE FOR KINESIOPHOBIA



Tampa Scale for Kinesiophobia

(Miller , Kori and Todd 1991)

1 = strongly disagree
2 = disagree
3 = agree
4 = strongly agree

1. I'm afraid that I might injury myself if I exercise	1	2	3	4
2. If I were to try to overcome it, my pain would increase	1	2	3	4
3. My body is telling me I have something dangerously wrong	1	2	3	4
4. My pain would probably be relieved if I were to exercise	1	2	3	4
5. People aren't taking my medical condition seriously enough	1	2	3	4
6. My accident has put my body at risk for the rest of my life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13. Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17. No one should have to exercise when he/she is in pain	1	2	3	4

Reprinted from:
Pain, Fear of movement/(re) injury in chronic low back pain and its relation to behavioral performance, 62, Vlaeyen, J., Kole-Snijders A., Boeren R., van Eek H., 371.
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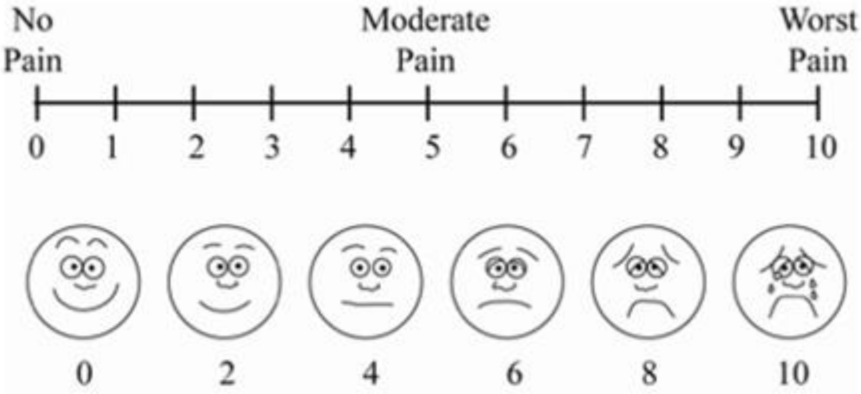
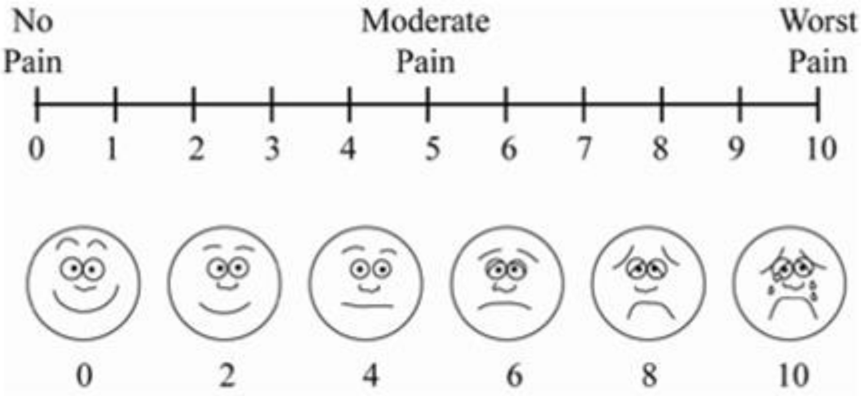
APPENDIX E. VISUAL ANALOG SCALE

DEADLIFT

PRE

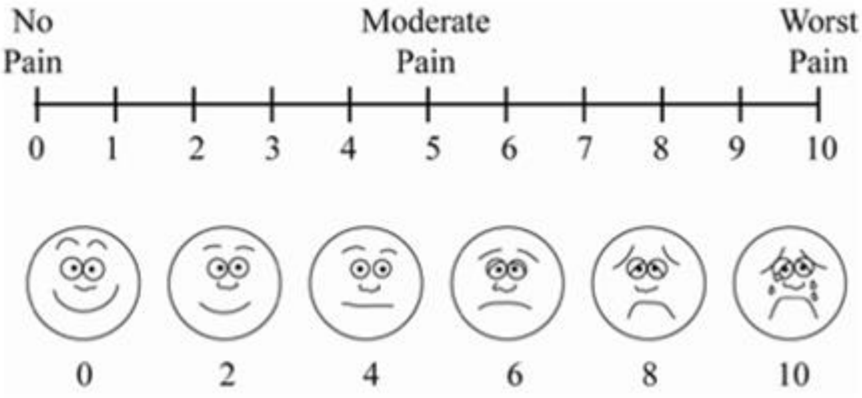


POST



2-MILE RUN

PRE



POST