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BODY ARMOR INDUCED CHANGES IN THE TRUNK MECHANCIAL AND NEUROMUSCULAR BEHAVIOR

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BODY ARMOR INDUCED CHANGES IN THE TRUNK MECHANCIAL AND NEUROMUSCULAR BEHAVIOR

THESIS

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

By

Rebecca Leigh Tromp

Lexington, Kentucky

Director: Dr. Babak Bazrgari, Professor of Biomedical Engineering

Lexington, Kentucky

2015

ABSTRACT OF THESIS

BODY ARMOR INDUCED CHANGES IN TRUNK MECHANICAL AND NEUROMUSCUALR BEHAVIOR

While military body armor is used among warfighters for protection on and off the battlefield, it has been suggested to impede performance and act as a risk factor for the development of musculoskeletal disorders, especially low back pain. Apart from personal suffering, low back pain in soldiers is a great economic burden on the US economy. The objective of this study was to quantify the changes in trunk mechanical and neuromuscular behavior following prolonged exposure to body armor compared to exposure without. A crossover study design was used where 12 sex-balanced participants completed a series of tests before and after 45 minutes of treadmill walking with and without body armor. The tests included range of motion, isometric trunk tests, sudden perturbations, and stress relaxation. As a whole, exposure duration considered in this study resulted in no significant differences in performance between armor and no armor conditions. However, comparing the effects of body armor among the sex-differentiated groups showed a body armor -induced increase in range of trunk motion in the sagittal plane among females ($p = 0.0018$) and a decrease in pelvic range of motion in the transverse plane among both males (p=0.025) and females (p=0.004).

KEYWORDS: military body armor, trunk range of motion, isometric trunk testing, stress-relaxation

Rebecca Tromp

March 13, 2015

BODY ARMOR INDUCED CHANGES IN THE TRUNK MECHANICAL AND NEUROMUSCULAR BEHAVIOR

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Chapter 1: Introduction

Musculoskeletal disorders among the U.S. military are extremely common. Musculoskeletal disorders (MSDs) are even prevalent among non-deployed active duty service members with a reported annual rate of 628 per 1000 persons [1]. The warfighter's load carriage system and protective equipment (LCSPE) has been identified as a risk factor for MSDs [2]. There have been many examples throughout history in which heavy loads not only resulted in MSDs, but also resulted in reduced performance, and even unnecessary deaths [3]. This is an important consideration given the training and mission requirements or limited transportation assets of some types of units (i.e. U.S. Army Light Infantry). Service members must often depend on their physical capabilities to move individual equipment. The magnitude and distribution of a LCSPE over the warfighter's back and extremities impacts the physical and physiological demands of the interactions between the warfighters and their operating environment and will therefore influence warfighter's performance, fatigability, and risk of MSDs.

Body armor is a large component of the warfighter's LCSPE. Soldiers worldwide wear body armor (BA) for protection on and off the battlefield. This body armor is typically worn for long periods of time and during many different types of physical activity [4]. Body armor alone can account for up to 30% of the load that is carried by a soldier. Improvements in weaponry, surveillance, communications, and personal protective equipment have added to that load; however, these improvements have only partially been compensated for by using enhanced strategies to safely and effectively manage these loads [5]. Due to the weight of the body armor, negative effects are often seen, both physiologically and psychologically [4]. Recent improvements in ballistic protection of body armor had increased soldier survivability, but had decreased mobility and endurance [5]. Wearing body armor has also been proven to increase perceived exertion, energy cost of walking, vertical ground reaction forces, and loading rate [5].

Among MSDs, low back pain (LBP) is the most common musculoskeletal disorder in deployed soldiers [6]. Approximately 6% of all medical visits in the US Armed Forces are for low back pain [6]. Heavy loads can be a risk factor for back injuries [5]. This could be due to the heavier loads leading to changes in trunk angles, stressing the back muscles, or because heavier loads do not move in synchrony with the trunk, causing cyclic stress of the back muscles, ligaments, and spine [5]. The large numbers of soldiers that sustain LBP lead to great reductions in the capacity to conduct wartime operations [6]. These LBP injuries result in a great economic burden on the US tax payers via medical evacuations, treatment, disability payments, and training of replacement personnel, which adds up to billions of dollars [6]. To control these adverse effects from the weight of the body armor, it first requires an understanding of the underlying mechanisms that link carrying body armor with an increased risk of back injuries.

The objective of this study has been to contribute to our understanding of the underlying mechanism(s) responsible for linking body armor and the high occurrence of LBP via quantification of body armor induced changes in trunk mechanical and neuromuscular behaviors. In the following sections, a literature review including body armor history, types of injuries endured by soldiers, and previous research is presented (Chapter 2). A conceptual model is presented in the same chapter that has been used to formulate our working hypotheses. Chapter 2 ends by statement of specific aims to be completed in this thesis in order to test our hypotheses and achieve our objective. This is followed by an in-depth explanation of the study protocols (Chapter 3). A detailed review of the results obtained from these experimental sessions can be found in Chapter 4 and a discussion about these results follows in Chapter 5. Chapter 6 concludes this thesis by discussing the new directions future works in this area of study could take. The outcomes of this study will quantify the effects of body armor on the trunk's neuromuscular and mechanical behaviors and could also enhance our understanding of body armor's effect on a warfighter's performance. These results will serve as a guide for future studies aiming to minimize the negative effect of body armor on military personnel.

Chapter 2: Background

2.1 History

The negative effects of load carriage and body armor are not a recent development. As far back as around 800 BC, heavy loads carried by Assyrian soldiers reduced their mobility and led them to experiment continually with their shields in order to lighten their loads [7]. Around 400 BC, the long marches of Cyrus' army resulted in many stress fractures, torn ligaments, muscle damage, blisters, and abrasions [8]. Before the 18th century, foot soldiers rarely carried more than 15 kg while on the march, but loads have significantly increased since then [9]. Their extra equipment was often carried by supplementary transportation such as assistants, horses, carts, etc. [9]. This auxiliary transportation was de-emphasized after the 18th century, adding to the load of the individual soldier by carrying their own loads [9]. During World War I, tactics of war were claimed to be altered due to the heavy loading of the foot soldiers [10]. Midst WWII, during the D-Day landings, American troops were so overburdened that their loads contributed to a number of deaths by drowning [10]. Since then, the estimated load mass carried by each soldier has increased dramatically, thus increasing the potential for injuries and even deaths among war fighters.

The average combat loads for army soldiers in Afghanistan in 2003 can be seen below (Fig. 2.1). The average fighting load contained a bayonet, weapon, clothing, helmet, body armor, load-bearing equipment, and a reduced load of ammunition [11]. The average approach march load includes the fighting load items as well as a basic load of ammunition, a small assault pack, and a lightly loaded rucksack or poncho roll [11]. The average emergency approach load contains the entire approach march load in addition to a much larger rucksack [11]. These numbers take into account that soldiers in 2003 in Afghanistan wore lighter-weight body armor, yet today, BA is generally heavier, as much as twice that worn in 2003 [11].

Table 2.1 Average Combat Loads for Army Soldiers in Afghanistan, 2003

	Average Fighting Load		Average Approach March Load		Average Emergency Approach Load	
Duty Positions	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight
Rifleman	63	36	96	55	127	71
Squad automatic rifleman	79	45	111	63	140	80
60mm mortar gunner	64	38	108	64	143	87

Notes: SOURCE: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April–May 2003," Ft. Leavenworth, Kan.: U.S. Army Center for Army Lessons Learned, 2003.

Body armor today is heavy and represents a large portion of the load carried by soldiers. The weight of a full-up torso body armor set ranges anywhere from 27 to 38 pounds, for small to extra-large sizes, respectively [11]. Studies have shown that soldiers wearing body armor exhibited a reduction in performance during function field tests, reduction in cardiovascular performance, balance, and strength, as well as an increase in physiological fatigue [11].

2.2 Injuries

It is well known that load carriage tasks frequently place increased stress on the muscles and skeleton of the carrier [10]. These increased stresses are considered abnormal mechanics and can lead to musculoskeletal injuries (MSDs). These injuries can in turn reduce the amount of manpower and impacts on force generation and force sustainment [10]. As an example, a 2008 survey discovered that approximately 80 percent of US Army soldiers on modified work plans (because of a musculoskeletal injury) were unable to undertake load carriage activities, while

73 percent were unable to even carry a rucksack [10]. Additionally, if an individual doesn't sustain an injury during load carriage, it expected that the loads carried will reduce their mobility [12]. One study found that the time taken to complete a 10-km march increased by 22.5 minutes (23% increase) when load were increased from 18 kg to 36 kg [13]. This decrease in mobility can lead to an increased likelihood of falling or tripping, which can be life-threatening to a soldier [10]. Figure 2.2 shows the significant impact on performance of a soldier due to heavy loads. For a rifleman, with a load of 95 pounds (43 kg) (actual total load today), compared to 50 pounds (23 kg) (goal total load), his marching distance over eight hours reduces by 35 percent (from approximately 17 to 11 miles) [11].

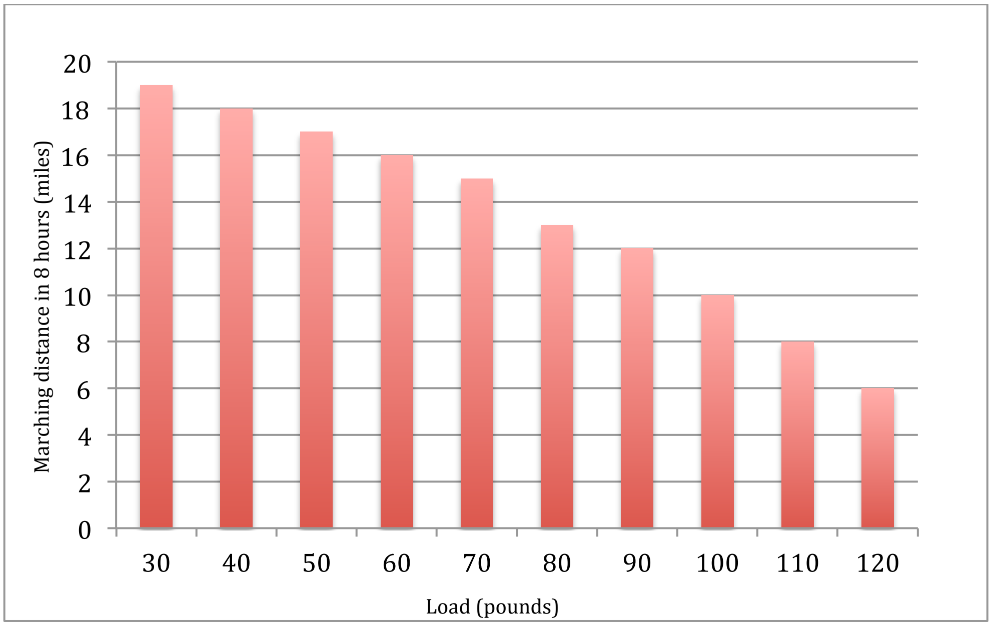

Figure 2.1: Marching distance capabilities vs. load carried by soldiers. SOURCE: Unpublished findings from a 1988 Army study by R. F. Goldman

In regards to the type of injury, and accounting for both primary and secondary diagnoses, 82% of all MSDs in non-deployed active duty service members are classified as inflammation/pain (overuse), followed by joint derangements (15%) and stress fractures (2%) affecting mainly knee/lower leg (22%), lumbar spine (20%) and ankle/foot (13%) [1]. In studies on deployed soldiers, the lower back is the one of the most commonly injured region of the body and the leading cause for non-battle injury medical evaluations (~17%) [6]. In one study, 50% of the soldiers who were unable to complete a strenuous 20-km walk reported back problems [5]. In another study where military personnel completed a 20-km march with a 46 kg load, it was found that lower back injuries were second most common only to blisters [14]. However, unlike blister sufferers, individuals with lower back injuries were unable to complete the activity [14].

2.3 Previous Research

There have been numerous previous studies on the effects of load carriage, mainly focusing on energy cost, gait changes, and effects on mobility. Studies have also been conducted that have investigated the effects of military load carriage on a soldier's performance. Through multiple studies, it has been found that load carriage significantly impedes sprint performance, obstacle course runs, army crawling, upper body strength exercises, grenade throwing, shooting ability, and many other factors [4].

One study conducted at US Army Natick Soldier Research, Development and Engineering Center looked at the metabolic costs as well as gait biomechanics during load carriage [15]. Since it is widely accepted that carrying heavy loads for prolonged periods of time can lead to injury, these researchers looked into using a prototype of a lower body exoskeleton (EXO) that could assist the load carrier to bear the load [15]. The EXO consisted of a hip structure with a back plate (where the rucksack was to be attached), tubular leg struts extending from the hips and paralleling the lateral surfaces of the wearer's legs, and semi-rigid foot plates (containing sensors that monitored contact with the ground) [15]. Their results revealed that the EXO significantly raised metabolic costs and carrying heavy loads with the EXO prototype was not metabolically sustainable for extended periods of time due to the prototype's mass, distribution on the body, and design elements that altered the user's gait patterns [15].

While body armor is a part of the military load carriage, there have been limited studies that focus on body armor alone. One study by Ricciardi et al looked at the effects of body armor on metabolic demands such as energy cost and physiological fatigue [16]. It was found that wearing body armor causes a significant negative impact on physiology and performance. They found significant increases in energy cost, reductions in physical work performance capabilities, and increases in fatigue [16]. A second study by Dempsey et al at the University of Otago looked at the impact of body armor and equipment on mobility. Two experimental sessions were conducted, with and without body armor, where multiple mobility tasks were completed. Their results demonstrated a significant decrease in performance during all tasks, where participants were off-balance longer; slower to complete the acceleration, grapple and mobility tasks; and had greater physiological cost [17]. However, this study looked at stab resistant body armor for police personnel only. A third study looked at the physiological, biomechanical, and performance of 11 enlisted Army men with and without body armor [11]. Their results demonstrated that performance during maximal-effort tasks (five continuous 30-m rushes, five minutes of repetitive lifting of 20.5-kg box, and an obstacle course run) were poorer when body armor was worn [11]. They also found significant changes in gait biomechanics and increases in metabolic costs when wearing body armor compared to not wearing body armor [11]. While these few studies have demonstrated the negative effects associated with carrying body armor, the underlying mechanism(s) responsible for these effects are still unclear. Due to the high prevalence of low back pain among soldiers, one of the goals of this study has been to understand the underlying mechanism(s) responsible for high occurrence of LBP. This study focuses on the mechanical and neuromuscular behavioral changes in the human trunk.

2.4 Conceptual Model

We used a conceptual model (Figure 2.3) where it was suggested that abnormal mechanics of the spinal column could result in lower back pain through stimulation of embedded nociceptors within the spinal column [3]. Abnormal mechanics includes stress and strain distributions among components of the spinal column beyond their biomechanical/physiological thresholds. When individuals perform a task, the mechanical loads experienced by their lower back tissues are the result of the interaction between the task demand and internal tissues responses (active and passive mechanical responses) to spine equilibrium and stability demands. Disturbance and recovery of the active and passive mechanical responses depends on the level and duration of exposure [18].

Body armor can affect risk of MSDs and the warfighter's performance via its influence on the demand of a task/mission and mechanical behaviors of musculoskeletal system. It is widely accepted that the added weight of the body armor increases the physical demands of a task performed. The weight of the body armor can alter both the active and passive mechanical behaviors of the tissue through its effects on inertial properties of body segments. Persistent influences of such biomechanical effects over prolonged operations will further affect mechanical behaviors of the system. These effects can be seen in viscoelastic changes in the tissue, alterations in muscle force generation capacity, and changes in muscle spindle sensitivity [19] [20] [21]. Mass and volume of the body armor will also affect mechanical demands of the task through their impact on change of inertial properties of body segments.

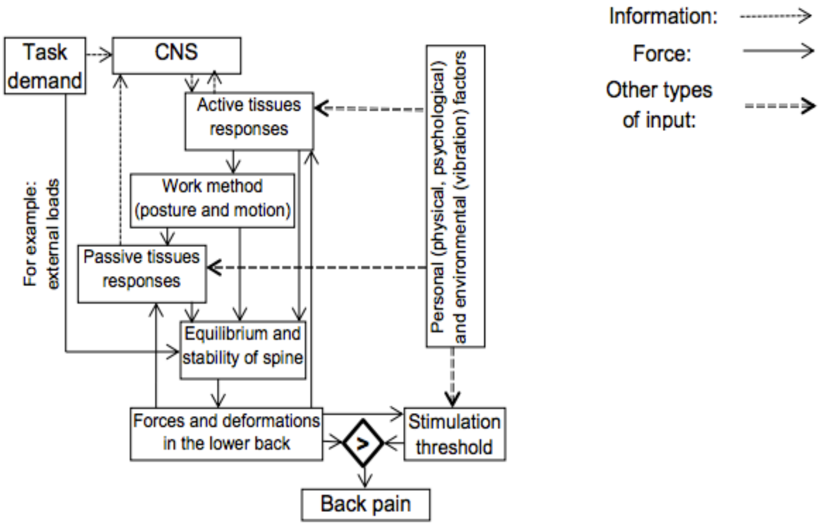

Figure 2.2: Conceptual Model

2.5 Specific Aims

The present study is a portion of a larger, broad-spectrum project designed to assess the effects of military body armor on a warfighter's performance and risk of MSDs. Another study in this project conducted thus far included quantifying the effect of BA-induced changes in several aspects of the lower back and knee mechanics during basic tasks involving extreme sagittal plane flexion.

The main goal of the present study was to understand the underlying mechanisms that link carrying body armor and low back pain. In order to do this, we needed to quantify the changes in trunk mechanical and neuromuscular behavior following prolonged exposure to military body armor compared to prolonged exposure with no body armor. This was an explorative study, implying that the exact outcome was unknown; however, it was hypothesized that changes in mechanical properties of the trunk that could adversely affect spine mechanics would be seen. Particularly, it was hypothesized that body armor induced changes in our outcome measures would be consistent with the negative effects on performance as well as the increased risks of MSDs.

Chapter 3: Methods

In this chapter, the details of the experimental data collection as well as the analyses conducted for the range of motion tests, isometric trunk tests, and stress relaxation test are presented. Additionally, a description of the sample population, study protocol, and body armor are exhibited.

3.1 Participants

Fourteen highly recreationally active (18-35 year old) individuals participated in this study after completing a consenting procedure approved by the University of Kentucky Institutional Review Board. Participants included eight males with mean (SD) age, height, and weight of 26.33 (2.81) years, 183.63 (5.93) cm, and 98.2 (14.28) kg, respectively, and six females with mean (SD) age, height, and weight of 23.0 (4.19) years, 170.13 (8.87) cm, and 60.31 (10.91) kg, respectively. Participant recruitment was done via distribution of study flyer on University of Kentucky websites, as well as in the Veterans Resource Center on the University of Kentucky campus. Subjects needed to be healthy, with no signs or symptoms of lower extremity or trunk injury, have no history of lower extremity or trunk surgery that could impede their range of motion, and not use an assisted ambulatory device or have other mobility impairments. They need to be pain free and not have any allergies to adhesives used to attach measurement instruments to their body. This study was approved by the University of Kentucky Institutional Review Board and all participants provided written informed consent prior to participation.

3.2 Study Design

The study took place in the Human Musculoskeletal Biomechanics Laboratory (HMBL) and the Biodynamics Laboratory at the University of Kentucky. The study included two data collection sessions, each lasting approximately three hours. The order of which session the participants wore the body armor (BA) or no body armor (NBA) was randomized and counter-balanced. During each session, participants completed a variety of test (range of motion, perturbations, stress relaxation, etc.) before (pre-exposure) and after (post-exposure) 45 minutes of treadmill walking (exposure). Therefore, each test was completed four times by each participant (session 1: before and after exposure, and session 2: before and after exposure).

3.3 Experimental Procedures

Upon first contact of the interested participants, a confirmation of the stated inclusion/exclusion criteria on the flyer was requested (Appendix A.1). Participants who met the advertised criteria were provided an electronic copy of the consent form to help familiarize them with the procedures of the study (Appendix A.2). If they decided to continue with the study, they were then invited to the laboratory in order to be consented after thoroughly familiarizing them with the experimental procedure. Participants were told to wear athletic clothing (i.e. shorts, t-shirt, tennis shoes, etc.) and were encouraged to bring a water bottle and an iPod for the treadmill portion of the study if they desired. Upon arrival to the HMB lab, the principal investigator thoroughly went through the informed consent document with the subject. After having a chance to review the consent form, participants had the opportunity to talk about procedures, risks, and the voluntary nature of the protocol with the principal investigator. Once informed consent was obtained, a copy of the signed consent form was provided for them upon request.

3.3.1 Screening

After written consent was obtained, the participant underwent the screening process. Screening involved verification of participants' physical fitness as well as lack of any of the above described exclusion criteria. To be considered physically fit for this study, participants had to score a minimum of a 5 on the Tegner scale (Appendix A.3), a self-evaluation of physical fitness [22]. Additionally, subjects were asked to self-report any symptoms they were currently experiencing or have experienced by completing the PAR-Q & You form (Appendix A.4) [23]. These forms were used to ensure participants were able to complete vigorous physical activity without the need for medical supervision. If participants met the criteria from the two screening forms, measurements of the participant's blood pressure, oxygen saturation, height, and weight were then obtained.

3.3.2 Instrumentation

Participants were initially instrumented to collect activity of select trunk muscles and motion of several body parts. A Delsys (Delsys Inc., Natick, MA) electromyography (EMG) system was used to measure trunk muscles activity during data collection. To attach EMG electrodes, the subject's shirt was either removed or rolled up and secured with clips and the electrodes were placed using double sided tape. The locations of the electrodes were sanitized and cleaned with alcohol swabs and any hairs were removed with a disposable razor. Nine surface electrodes were used on each participant to collect EMG activity of four back (i.e., left and right erector spinae at the L1 and L3 spinal levels) and four abdominal (i.e., left and right rectus abdominus and external oblique) muscles and one for ground. EMG electrodes were attached according to earlier studies (Larivière, 2009) and included eight DELSYS DE-2.1 EMG electrodes (for back and abdominal muscles) and one DermaSport reference electrode (for the ground). Electrodes used to measure back muscles activity were attached one and two inches to left and right of the midline at respectively the L1 and L3 levels (Fig 3.1). On the abdomen, two electrodes were placed on the left and right external obliques, in line with the navel, and two other electrodes were placed on the left and right rectus abdominus muscles, approximately one inch outward and two inches above the navel (Fig 3.2). The ground electrode was placed on the left elbow of the participant.

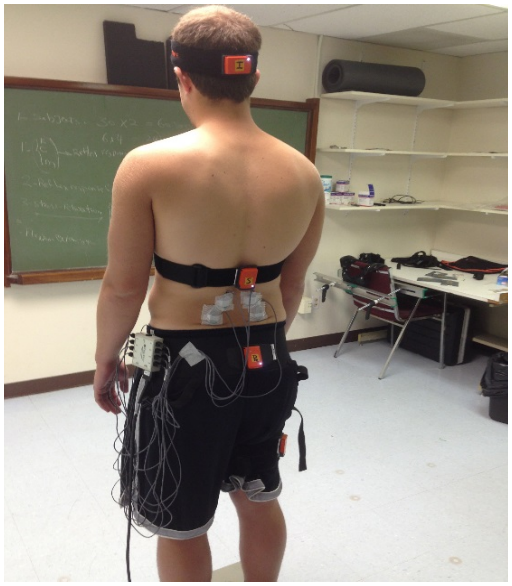

Figure 3.1: Electrode placement on participant's back

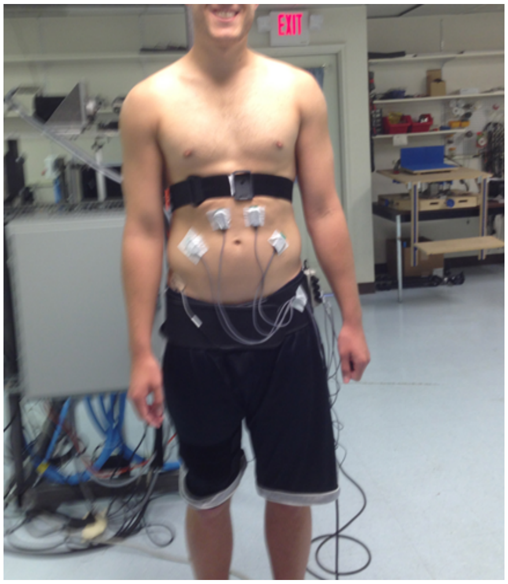

Figure 3.2: Electrode placement on participant's abdomen

Once all of the electrodes were placed and connected to the amplifier and A/D card, their proper placement was tested using an in-house "EMG check" MATLab program while the participant was asked to complete various flexion/extension exercises. The electrodes readings were used to visually determine whether electrode placement provide a proper signal to noise ratio. If a poor signal to noise ratio was observed in an electrode, its location was slightly altered and EMG-check tests were repeated. This procedure was repeated until a subjectively acceptable signal to noise ratio was achieved in all electrodes reading. After the best electrode location was chosen and noted, all of the electrode's locations were marked using a pen for future placement and existing attached electrodes were secured with medical tape.

A tri-axial Inertial Motion Senor (Xsens, Culver City, CA) system was also used to measure motion of participants' head, thorax, pelvis, and upper and lower legs. Xsens accelerometers were attached to different body part using five straps with accelerometer clasps including: 1) on the head with the accelerometer clasp in the center of the back of the head, 2) on the participant's back with the accelerometer clasp at the location of T10 on the spine, 3) on the participant's pelvis with the clasp on the back side, centered and in line with the spine at the location of S1, 4) on the participant's right thigh with the clasp on the lateral side, approximately half way between the knee and hip joints, and 5) on the right ankle, again, with the accelerometer clasp on the lateral side. The height from the ground to the top of all of the accelerometers were measured and recorded to ensure similar placement in subsequent sessions. After instrumentation, participant completed the pre-exposure tests that included: 1) Range of motion test, 2) Maximum voluntary isometric trunk test, 3) perturbation test, and 4) stress-relaxation test.

3.3.3 Range of Motion Tests

Three different sets of range of motion tests were performed: 1) flexion/extension, 2) left and right lateral bending, and 3) left and right axial twisting. For the flexion/extension test, the participant was instructed to stand on a force platform (AMTI, Watertown, MA) in an upright position for five seconds then bend forward at the waist, slowly, until they reached their maximum, comfortable flexed posture, but careful not to stretch past this position. Once they reached that position, the participant stayed flexed for five seconds, and then returned slowly to an upright posture. This sequence was repeated another two times during the measurement. While still on the force platform, the lateral bending test was completed, beginning similarly, by standing in an upright position for five seconds and then bending laterally to their maximum comfortable posture on their left side. Without pausing in the bent position, the participant then returned to an upright posture and stood idle for another five seconds. The participant repeated the lateral bend on their right side, and then returned back to an upright, standing position. For the axial twisting test, similarly to the previous two tests, the participant began by standing in an upright position for five seconds, then twisted their trunk to the left to their maximum ability and then proceed to return to a normal, upright position. They waited in the starting position for another five seconds and then repeated the twist to the right side, and ended back the neutral starting position. During all of the tests, the researcher was using a clock and counting a loud to keep consistent time for each subject.

After all three range-of-motion tests were completed, all accelerometers and straps were removed and the participant received a ten-minute break. During the break, participants were allowed to sit and rest. The subject's blood pressure and oxygen saturation were measure and recorded again during this time.

3.3.4 Maximum Voluntary Isometric Trunk Testing

A custom made metal frame that is also used for perturbation tests was used to complete maximum voluntary isometric trunk testing. Participants were instructed to stand on an adjustable platform inside the frame and were then secured at the pelvis by a strap to isolate their trunk motion from their lower body. They were then connected to an AC synchronous brushless servomotor (Kollmorgen, Radford, VA) using a rigid harness-rod assembly. The servomotor had a peak torque of 26.5 Nm (235 lb-in) and a max speed of 1740 RPM. The height of servomotor platform and the length of connecting rod between the harness and servomotor were adjusted so each participant's posture was a neutral standing posture and connecting rod was completely in a horizontal direction (verified by a level). Prior to subject standing on the platform, the height of platform was also adjusted such that the platform's center of rotation aligned with the L5/S1 joint. The harness that connect participant to testing frame was required to be tight. As such, using feedbacks from participants, the harness was tightened such that it was difficult to take a deep breath; however, it was still possible to breathe easily.

For the isometric trunk testing, the subjects were instructed to make their maximum extension effort against the harness-rod assembly following a start command from the researcher. They were required to achieve their maximum effort gradually and hold it for approximately five seconds and then relax. The isometric trunk testing was repeated again; with a thirty second break for the subject in between trials. During these tests the subject's effort was measured using both an in-line load cell (Interface SM2000, Scottsdale, AZ) located on the connecting rod of the harness-rod assembly and EMG of back muscles.

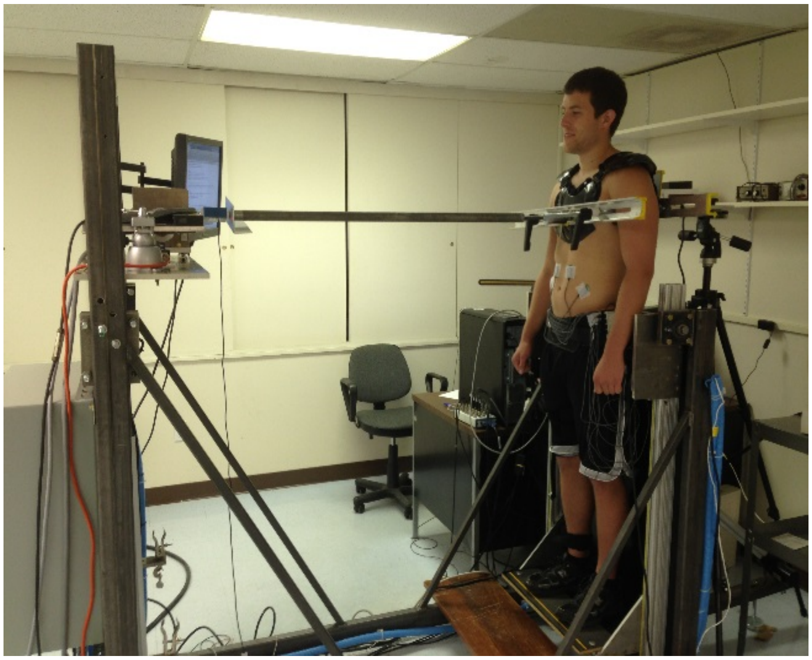

Figure 3.3: Subject in harness and perturbation device

3.3.5 Perturbation Test

The perturbation tests were conducted in the same setup as maximum voluntary isometric trunk testing. During these tests, a pseudorandom series (n=19) of anterior-posterior position perturbation (±5 mm), generated by the servomotor and transferred using the harness-rod assembly, were applied to participants. The duration of each perturbation was set to 28 ms (anterior) and 44 ms (posterior) to be shorter than latency of trunk muscles reflexive response hence allowing us to separate the reflexive and intrinsic response of the trunk to the applied perturbations. Each participant completed four position perturbation tests, while holding an extension effort using visual biofeedback. Extension efforts included 10% and 20% of their recorded maximum extension effort during maximum voluntary isometric trunk tests. Each level of effort was repeated using feedbacks from 1) average back muscle activities and 2) in-line load cell on the harness-rod assembly. Each perturbation test took one-minute, and thirty seconds of rest was provided between tests. The four perturbation sets were in a predetermined, randomly generated order to prevent any learning effect.

The perturbation system had six safety features including a limit switch on top of the motor platform that will cut all power to the perturbation device if the motor rotates over 70 degrees past it's normal position, therefore generating an anterior-posterior displacement of the trunk larger than one inch. The second is a handheld pendant switch (McMaster-Carr), controlled by the participant that will cut all power to the device if it is released during testing. The third safety feature is a mushroom emergency stop button (Consolidated Electrical Distributors) located on the device frame on right hand side of the participant, primarily for the experimenter to cut power to the device if necessary. The fourth feature is an "On/Off" switch located on the right edge of the anterior side of the frame, right below the mounted monitor, controlling power to the whole device. The fifth safety feature is another "On/Off" switch located on the outside of the electrical box, again, controlling power to the entire device. The last safety feature is a manual emergency stop control in the computer program that can stop power to the motor if necessary.

During the participant’s first session, a practice set of perturbations was given to allow the participant to become familiar with the perturbations. For each test, participants were asked to hold down the pendant switch and were told if at any time they felt uncomfortable or wanted to prematurely end the perturbation set, releasing the button would stop the motor. After the button was pressed, the lock pin for the servomotor was released, hence allowing the transfer of servomotor-generated motions to participants. Participants were instructed to pull against the rigid frame to maintain the desired force/EMG (either 10% or 20%). After this level was reached and maintained, the perturbations began and the participant’s objective was to maintain that level to the best of their ability throughout the entire perturbation set. Once the set was over, the lock pin was placed back in the device and they were instructed to release the pendant switch.

This procedure was repeated for all four perturbation tests. The resulting kinematics were measured using two high-accuracy laser displacement sensors (Optex-FA, West Des Moines, IA), one at the T8 level and the other targeting the load cell. The driving force during the perturbations was measured using the in-line load cell located next to the motor.

3.3.6 Stress Relaxation Test

Stress-relaxation tests were also conducted in the same frame used for maximum voluntary isometric trunk testing and perturbation tests. Data from the accelerometers during the range of motion tests in the sagittal plane (i.e. flexion/extension tests) were used to calculate the participant's maximum flexion angle of their trunk. During the stress-relaxation test, participant's lower back was passively stretched in the sagittal plane by raising their legs and rotating their lower limbs around L5/S1. Rotating lower limbs around L5/S1 would cause passive stretch of the back tissues, hence pulling back participants trunk. Since the participant's trunk was fixed with the harness-rod assembly, passive stretching of lower back tissues was reflected in the readings of the in-line load cell on the harness-rod assembly. During stress-relaxation tests, the participant's legs/pelvis were raised, using an actuator, to achieve a flexion in their lower back that was 70 percent of their maximum lumbar flexion angle, obtained during range of motion tests in the sagittal plane (Fig 3.4). This posture was maintained for approximately four minutes, during which trunk resistance (via load cell) and lower limbs kinematics (via an IMU) were measured. Subjects were instructed to minimize the activity of their back muscles using biofeedback (of EMG). Since the trunk was kept upright, muscle activity and hence active muscle stiffness was minimized; thus, measured resistance represents primary passive trunk resistance.

Once the stress-relaxation test was completed, the subject was removed from the perturbation device and unhooked from the EMG amplifier. The harness was loosened and removed and the subject was then stripped of the electrodes and shirt clips before the treadmill portion of the study (i.e., exposure).

Figure 3.4: Participant's legs were raised to 70 percent of their maximum flexion angle of their trunk for stress relaxation portion of experiment and remained in that position for four minutes.

3.3.7 Exposure

Each participant then completed a walking protocol with or without body armor that took place in the Biodynamics Laboratory, next door to the HMB lab. For the walking protocol, participants were asked to walk on a treadmill for 45 minute at a speed of 1.65 m/s., to simulate a military foot march [25].

On days when the participant was using the body armor, the Biodynamics Laboratory had restricted access to only those who successfully completed the necessary International Traffic in Arms Regulations (ITAR) training. ITAR regulations dictate that information and material pertaining to defense and military related technologies may only be shared with U.S. Persons unless authorization from the Department of State is received or a special exemption is used. The ceramic plates donated for use in this study came from a U.S. Defense contractor. The material has very strict handling and control requirements. Therefore, only United States citizens or green card authorized individuals were eligible to be included in this study.

The body armor used in this study consisted of a military issued vest with ceramic plates (~13 lbs). One single size of BA (i.e., size Small vest) was used for all participants. While it was known that this would not be the size that every participant would actually be issued normally, everyone was placed in the same size vest for consistency purposes. The remaining portions of the provided armor were made in-house using metal plates and consisted of two upper arm plates (~3 lbs/each arm) and two thigh plates (~4 lbs/each leg) to simulate extremity body armor.

On the armor days, the participant was placed in the military body armor before they began their treadmill walk (taking approximately 10 minutes). After the body armor was secure, the participant began their treadmill walk for 45 minutes at a speed of 1.65 m/s. If it was the participant's non-armor day, they could immediately start on the treadmill.

3.3.8 Post Exposure Measurement

Following the end of walking protocol, the participant was stripped of the body armor (if an armor day) and brought back to the HMB lab. All of the body armor was cleaned using a disinfectant spray after each participant's use. Immediately after returning to the lab, the exact same pre-exposure experiments were repeated. The electrodes were placed in their original position by using the marks placed during the pre-exposure portion. Their placement was checked again and after, they were secured with medical tape. The accelerometers were placed again and the heights were measured to ensure similar placement as the first session. All accelerometers were adjusted to be ±0.5 cm of the original height recorded in the pre-exposure session.

The three range-of-motion tests were completed. Again, the accelerometers and accelerometer straps were removed and the subject received a ten-minute break. Following the break, the participant was placed back in the harness and secured back in the perturbation device. Maximum voluntary isometric tests, perturbations, and stress-relaxation tests were repeated. Once all of the tests were completed, the participant was removed from the harness and the electrodes and shirt clips were stripped off. After the necessary payment paperwork was completed, the participant was free to go.

3.4 Data Analysis

All data collected was processed using in-house MATLab programs (MathWorks, Natick, MA).

3.4.1 Range of Motion Tests

Kinematics data were collected using lightweight 3D human motion trackers (Xsens, Culver City, CA). These data were sampled at 50 Hz and processed using the provided MT Manager program as well as our in house MATLab program. These programs were used to determine the trunk angles (thoracic, pelvic, and lumbar) during the three range-of-motion tests (flexion/extension, lateral bending, and axial twisting) in the three different planes (sagittal, frontal, and transverse). For each motion, the maximum thoracic rotation on the plane of motion and time point it occurred was determined first. That time point was then used to determine the rotations of pelvis and lumbar in the same plane (Figure 3.5). Any coupled motion in the other two planes was also determined at the same time point. This was achieved by obtaining the thorax, pelvis, and lumbar rotation in the two planes other than main plane of motion. Preliminary analyses of range of motion tests indicated very little coupled motion in the frontal and transverse planes during the flexion/extension test in the sagittal plane. Therefore, coupled motions for the range of motion tests in the sagittal plane were not further investigated. However, the range of motion tests in the other two planes demonstrated considerable coupled out of plane motion that was recorded for subsequent statistical analyses. Since there were three repetitions of range of motion tests in the sagittal plane, the reported maximum thorax rotation and corresponding pelvic and lumbar rotation for statistical analyses were the averages of the maximums from the three repetitions.

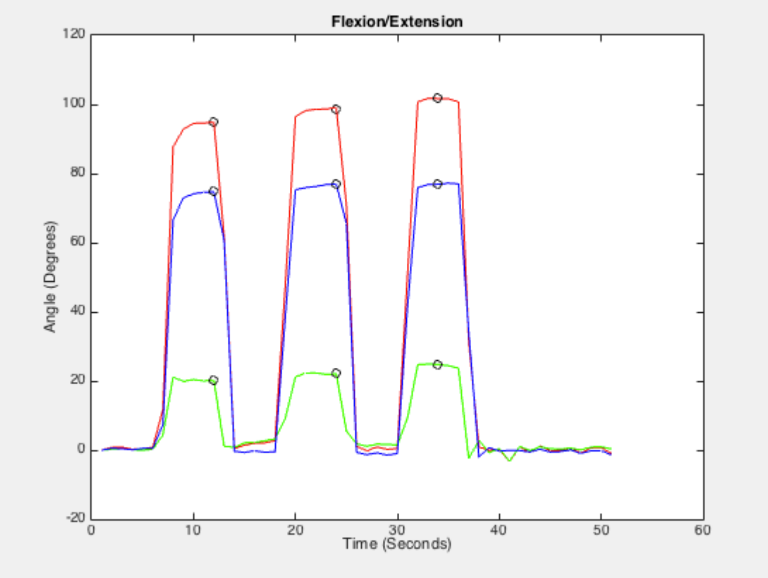

Figure 3.5: MATLab output graph of the range of motion test in the sagittal plane. (Red = Thoracic, Blue = Lumbar, Green = Pelvic).

3.4.2 Maximum Voluntary Isometric Tests

The maximum value of recorded force by the in-line load cell as well as the maximum value of recorded average EMG of four back muscles during these tests were calculated and then averaged for subsequent statistical analyses. Prior to obtaining the maximum average EMG of the four back muscles (LL3, RL3, LL4, RL4), collected raw EMG data from each channel was pre-amplified (x1000) near the collection site, band-pass filtered using a Butterworth filter (30-300 Hz), amplified and then converted to RMS in hardware. Then the signal was squared and a low-pass filter was used to create the linear envelope (cutoff frequency of 25 Hz). These readings where then graphed (Fig. 3.6), displaying lines at the 10 and 20 percent values, and the maximum values, obtained graphically, were recorded.

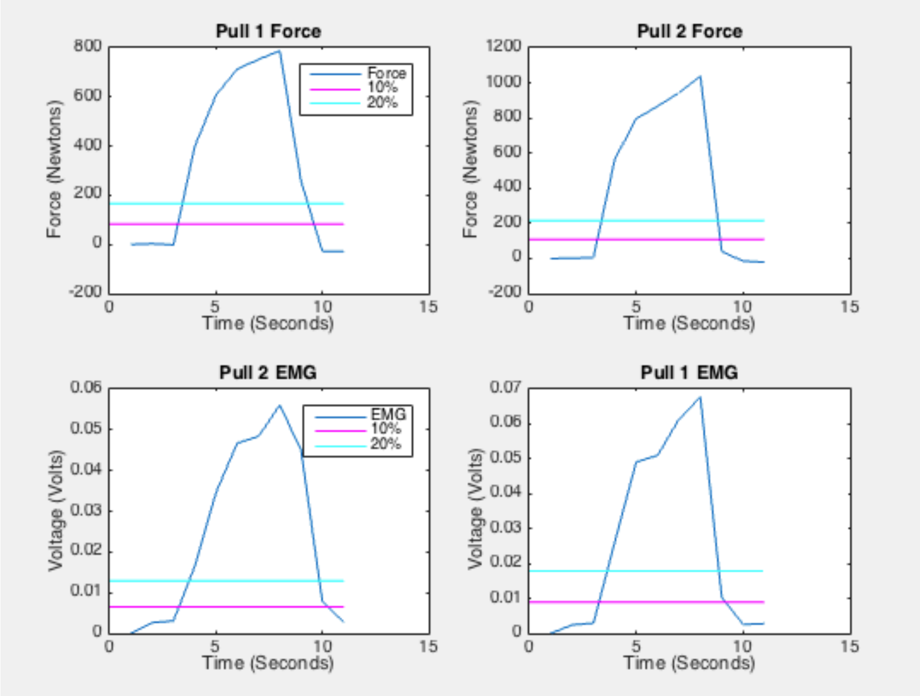

Figure 3.6: Outcome graph for maximum Force (top row) and EMG (bottom row) measurements during isometric testing. Force readings were later converted to Newtons (1v = 200 N).

3.4.3 Stress Relaxation Test

Several measures were obtained from the stress-relaxation data including: 1) instantaneous passive resistance, 2) relaxation of instantaneous passive resistance over the 4-minute period of fixed flexed posture during stress-relaxation tests and 3) the amount of energy dissipated during the test. Instantaneous passive resistance was calculated as the maximum value of the recorded force in the in-line load cell as the subject's legs were raised inside the setup. Relaxation of such initial passive resistance was calculated by quantifying two variables 1) the final recorded values by the load cell before returning participant's leg to its original posture and 2) the difference between the maximum recorded force while raising participant's leg and the final recorded force before returning participant's leg to its original posture. The dissipated energy for each stress-relaxation test was calculated by obtaining the area of hysteresis loop formed by the moment vs. angle relationship during the stress-relaxation tests (Figure 3.8).

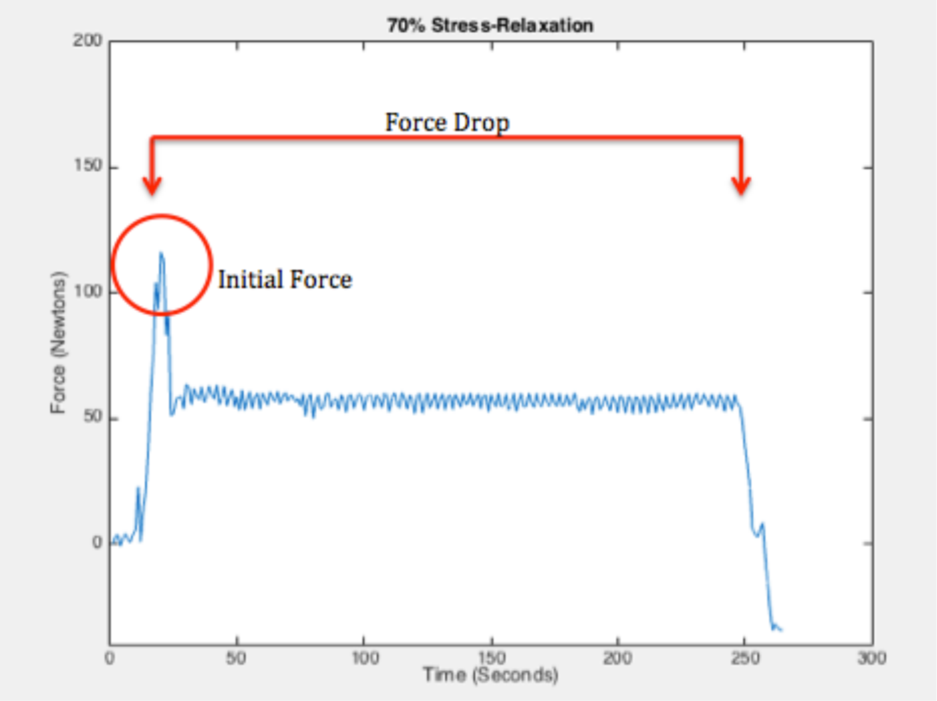

Figure 3.7: Stress relaxation output graph showing the points used for Initial Force calculations and Force Drop calculations.

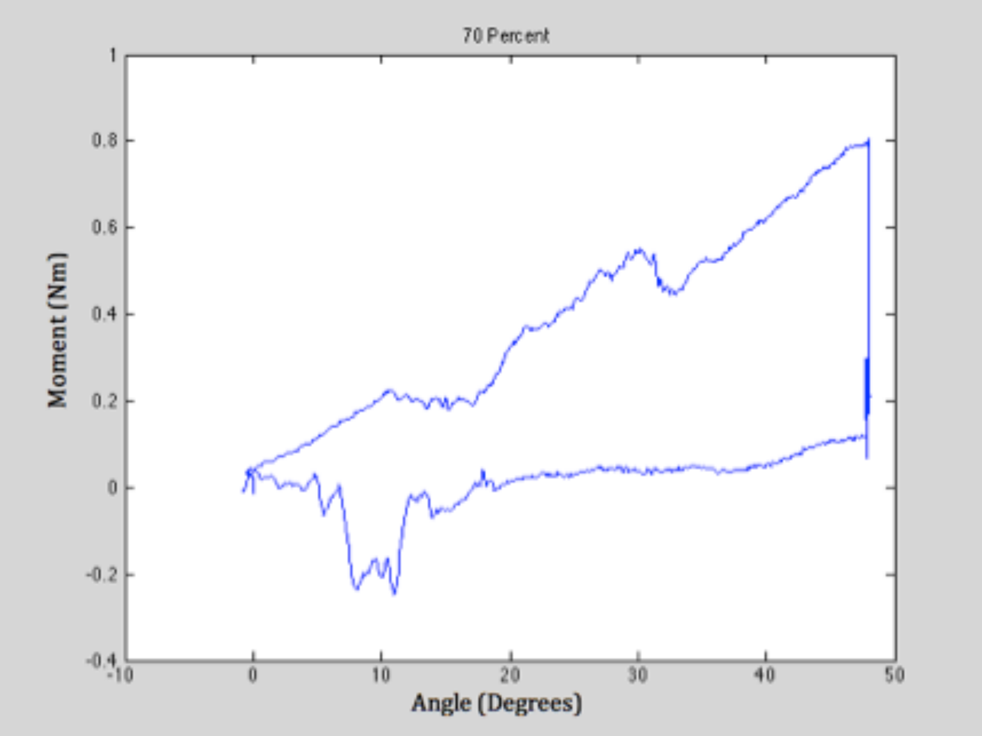

Figure 3.8: Hysteresis Loop

3.5 Statistical Analysis

This study is a 2x2 crossover, repeated measure design. SAS software (Version 9.3, SAS Institute Inc., Cary, NC, USA) was used to evaluate the data. A Mixed Procedure model was used to measure the effects of pre- and post-exposure, with and without body armor. A *p*-value less than 0.05 was used to determine statistical significance.

Chapter 4: Results

This study was a laboratory-based, cross-sectional, one group, two sessions study. Data from fourteen subjects was collected, while only data from twelve was used for calculations. Two male subjects completed session 1 of the study and moved out of the area before session 2 could be completed. No injuries resulted from participation in this study. Below are the results of the experiment data collection (Table 4.1-4.5). Due to the size of the project and availability of time, only the results of the range of motion, isometric trunk testing, and stress relaxation tests are presented below. The data are an average value of the 12 subjects for each test, before and after exposure, during both body armor (BA) and no body armor (NBA) data collection sessions. *P*-values were calculated by comparing the change between pre- and post-exposure on armor days and the change between pre- and post-exposure on no armor days. Additionally, the effect of body armor among the sexes is also reported (Table 4.6 & 4.7). During statistical analysis, the *p*-values were collected and recorded in following tables, with a statistical significance level of 0.05. These *p*-values are a result of comparing the differences pre- and post-exposure on the armor versus no armor days.

4.1 Range of Motion Tests

During each range of motion test, the data from the accelerometers was measured. The accelerometers at the locations of the thorax and pelvis were used and lumbar movement was considered the difference between the thorax and pelvis. Each test was first examined in the plane where the majority of the motion was conducted (i.e. flexion/extension = sagittal plane). The coupled motions in the remaining planes during each test were also of interest; therefore, all three anatomical planes (frontal, sagittal, and transverse) were examined. All range of motion test data is reported using the angle they rotated (degrees).

4.1.1 Flexion/Extension

Sagittal plane motion was the dominating direction, so it was examined first (Table 4.1). On the body armor days, thoracic, pelvic, and lumbar rotation all increased following exposure. On NBA days, thoracic and lumbar rotation increased, while pelvic rotation decreased post-exposure. After statistical analysis, the *p*-value for comparison of pre vs. post changes in thoracic, lumbar, and pelvic rotations between with and without body armor conditions were respectively 0.097, 0.278, and 0.389. These results show no statistically significant differences in pre- vs. post-exposure changes between BA and NBA conditions. Since there was insignificant movement in the other two planes, frontal and transverse, the flexion/extension data was only examined in the sagittal plane.

Table 4.1: Flexion/ Extension test data

	VARIABLE	**ARMOR (BA)**		**NO ARMOR (NBA)**		**P VALUE**
		BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
FLEXION-EXTENSION	Thorax	99 (13)	104 (14)	104 (14)	105 (15)	0.097
	Lumbar	68 (8)	72 (7)	65 (11)	68 (8)	0.278
	Pelvis	32 (12)	33 (13)	39 (15)	37 (13)	0.389

Note: Average rotations of all 12 subjects. Mean (SD) of thorax, lumbar, and pelvic rotations (degrees) in the sagittal plane during flexion/extension test. Lumbar and Pelvic rotations correspond to the time of maximum thorax rotation in the sagittal plane.

4.1.2 Lateral Bending

During this test, the subject bent to both their left and right sides, allowing maximum values to be determined on both sides for all positions, in all planes (Table 4.2). In the lateral bending tests, the majority of the motion was in the frontal plane, making it the first plane we examined during this data analysis. On the armor day, most measurements in the frontal plane increased after the walking exposure. However, on the NBA day, most measurements decreased after the walking exposure. Despite these changes, there were no significant differences between changes found during with and without body armor days. Looking at the simultaneous movement in the transverse plane during lateral bending tests, we found that there was no pattern of the outcome measurements after exposure on either day; thus, no statistically significant differences were found. Additionally, after examining the coupling in the sagittal plane during lateral bending, we found that on both BA and NBA days, coupled motions in the sagittal plane decreased following exposure. However, there were no statistically significant differences in pre- vs. post-exposure changes between days with and without body armor.

Table 4.2: Lateral bending test data

Motion	Plane	VARIABLE	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
			BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
Lateral bending to left	Frontal	T	33 (5)	34 (6)	37 (9)	35 (8)	0.343
		L	28 (5)	28 (6)	30 (7)	29 (7)	0.550
		P	5 (2)	6 (4)	7 (5)	6 (4)	0.623
	Transverse	T	-2 (7)	2 (9)	2 (6)	0 (6)	0.261
		L	2 (5)	8 (10)	4 (5)	5 (6)	0.385
		P	-4 (7)	-6 (4)	-3 (6)	-5 (6)	0.999
	Sagittal	T	8 (7)	5 (8)	10 (9)	3 (7)	0.316
		L	7 (6)	5 (7)	8 (7)	4 (5)	0.769
		P	1 (2)	1 (4)	2 (4)	-1 (3)	0.099
Lateral bending to right	Frontal	T	33 (5)	35 (6)	38 (8)	36 (6)	0.236
		L	28 (6)	30 (6)	30 (7)	30 (6)	0.495
		P	4 (2)	5 (3)	7 (4)	6 (4)	0.373
	Transverse	T	4 (5)	-1 (10)	3 (4)	3 (4)	0.272
		L	-3 (4)	-7 (8)	-2 (5)	-5 (5)	0.715
		P	7 (3)	6 (4)	6 (4)	8 (4)	0.058
	Sagittal	T	10 (9)	9 (4)	14 (12)	8 (8)	0.469
		L	9 (9)	8 (4)	13 (10)	9 (7)	0.578
		P	1 (2)	1 (2)	1 (3)	0 (2)	0.420

Notes: Average rotation of all 12 subjects. Displays the mean (SD) of thorax (T), lumbar (L) and pelvic (P) rotations (degrees) in the frontal, transverse, and sagittal planes during the lateral bending tests. Rotations are reported for bending to each side and were obtained at the time of maximum thorax rotation in the frontal plane for each side.

4.1.3 Axial Twisting

Similar to the lateral bending tests, during this test the subject rotated to both their left and right sides, allowing maximum values to be determined on both sides for all positions, in all planes (Table 4.3). During axial twisting tests, the commanding motion was in the transverse plane, making it the first plane we examined during this test's data analysis. On the BA day, all of the measurements, with the exception of the lumbar measurement on the left side, decreased after exposure. On the contrary, all of the measurements increased following exposure on the NBA days. However, difference in pre- vs. post-exposure changes of our primary kinematics measures during axial twist test also were not significantly different between with and without body armor days. When examining the coupling motion in the frontal plane during axial twisting, there was no trend found in the data following exposure on either day, again, exhibiting no subsequent statistically significant findings. Similarly, when looking at sagittal plane motion, no trends in the data were exhibited on either the armor or no armor day, again, showing no statistically significant findings.

Table 4.3: Axial Twisting test data

Motion	Plane	VARIABLE	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
			BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
Axial twist to left	**Frontal**	T	-3 (6)	-3 (8)	-6 (8)	-5 (8)	0.909
		L	-14 (11)	-14 (11)	-18 (13)	-17 (12)	0.339
		P	11 (7)	11 (8)	12 (6)	12 (8)	0.114
	Transverse	T	59 (16)	57 (17)	61 (16)	62 (20)	0.745
		L	20 (5)	21 (5)	20 (4)	21 (5)	0.696
		P	40 (15)	36 (18)	40 (15)	41 (17)	0.456
	Sagittal	T	1 (7)	2 (7)	3 (8)	2 (8)	0.172
		L	0 (6)	1 (7)	2 (10)	1 (11)	0.473
		P	0 (6)	1 (3)	1 (5)	1 (4)	0.745
Axial twist to right	**Frontal**	T	2 (6)	6 (6)	5 (7)	6 (9)	0.845
		L	13 (10)	17 (9)	18 (12)	15 (14)	0.507
		P	-10 (7)	-11 (7)	-12 (7)	-10 (7)	0.111
	Transverse	T	57 (17)	55 (16)	59 (18)	62 (18)	0.537
		L	21 (7)	20 (6)	20 (6)	21 (6)	0.795
		P	36 (15)	35 (14)	39 (17)	41 (17)	0.543
	Sagittal	T	2 (6)	2 (8)	4 (8)	4 (6)	0.932
		L	2 (8)	2 (7)	4 (7)	5 (9)	0.372
		P	0 (6)	0 (5)	0 (4)	-2 (6)	0.177

Notes: Average rotation of all 12 subjects. Displays the mean (SD) of thorax (T), lumbar (L) and pelvic (P) rotations (degrees) in the frontal, transverse, and sagittal planes during the axial twisting tests. Rotations are reported for twisting to each side and were obtained at the time of maximum thorax rotation in the transverse plane for each side.

4.2 Isometric Trunk Testing

Data from two maximum voluntary exertions (MVEs) was collected using the in-line load cell. As seen below (Table 4.4), we were able to determine the maximum force value from the load cell during each MVE. The two data collections were averaged for the maximum force readings for each subject. This data was then averaged over all 12 subjects and reported in the table below.

Table 4.4: MVE Force (Newtons)

Variable	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
	BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
Force (N)	618 (250)	622 (256)	644 (172)	650 (178)	0.985

Notes: Average of all 12 subjects. Mean (SD) maximum-recorded forces during the isometric trunk testing.

4.2.1 Maximum Force

It can be seen that there are slight increases in the measurements after subjects undergo the walking exposure. On the armor day, the average measurement increase is 3 N. On the NBA day, the average increase is 6 N. When comparing these differences, we found a very high *p*-value of 0.985, showing no statistical significance when looking at the effects of the body armor on exposure induced changes in the MVE force readings.

4.3 Stress Relaxation

Three different factors were examined: the initial force, the drop in force over the four-minute span, and the area of the hysteresis loop (Table 4.5).

Table 4.5: Stress Relaxation test data

Variable	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
	BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
Initial Force	113 (423)	103 (30)	122 (69)	96 (29)	0.401
Force Drop	33 (28)	26 (17)	45 (54)	20 (15)	0.169
Hysteresis Loop Area	6105 (2461)	5697 (2716)	5459 (3108)	6514 (2656)	0.229

Notes: Average of all 12 subjects. Mean (SD) maximum recording of initial force (N), force drop (N) and the hysteresis loop area during the stress relaxation testing.

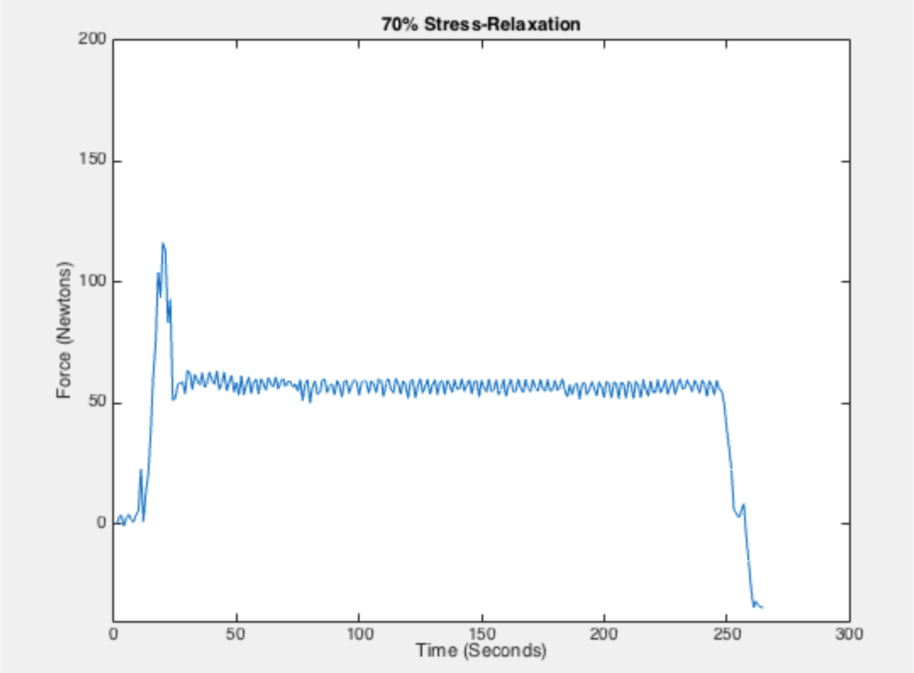

Figure 4.1: Stress relaxation output

4.3.1 Initial Force

The instantaneous passive resistance (referred to as initial force) was considered the maximum value of the recorded force in the in-line load cell as the subject's legs were raised (Fig 4.1). Although participant were exposed to slightly larger rotation after exposure (due to increase in the sagittal plane range of motion, see Table 4.1), the average initial force value for the 12 subjects decreased after walking exposure on both BA and NBA collection days, 10 N and 26 N, respectively (Table 4.5). These pre- vs. post-exposure changes did not show any statistically significance differences between with and without body armor days, with a *p*-value of 0.401, demonstrating little exposure induced effect of the body armor on initial force readings.

4.3.2 Force Drop

The force drop is considered the relaxation of the initial passive resistance over the 4-minute period of fixed flexed posture. This drop in force was calculated by the determining the difference between the initial force value and the last recorded value before the experimenter lowered the subject's legs (Fig. 4.1). The average force drop for the 12 subjects decreased after walking exposure on both the BA and NBA collections days, 7 N and 25 N, respectively (Table 4.5). These pre- vs. post-exposure changes did not show any statistically significance differences between collection days, with a *p*-value of 0.169, demonstrating little exposure induced effect of the body armor on force drop readings.

4.3.3 Hysteresis Loop Area

The last portion of the stress relaxation tests that was examined was the area of the hysteresis loop (Fig 4.2). During the collection days where the subject wore body armor, on average, there was less energy loss after exposure than before. However, on the days they did not wear body armor, there was a greater energy loss during the stress relaxation test post-exposure compared pre-exposure (Table. 4.5). Again, these pre- vs. post-exposure changes demonstrated a non-significant difference between days with and without body armor, with a *p*-value of 0.229.

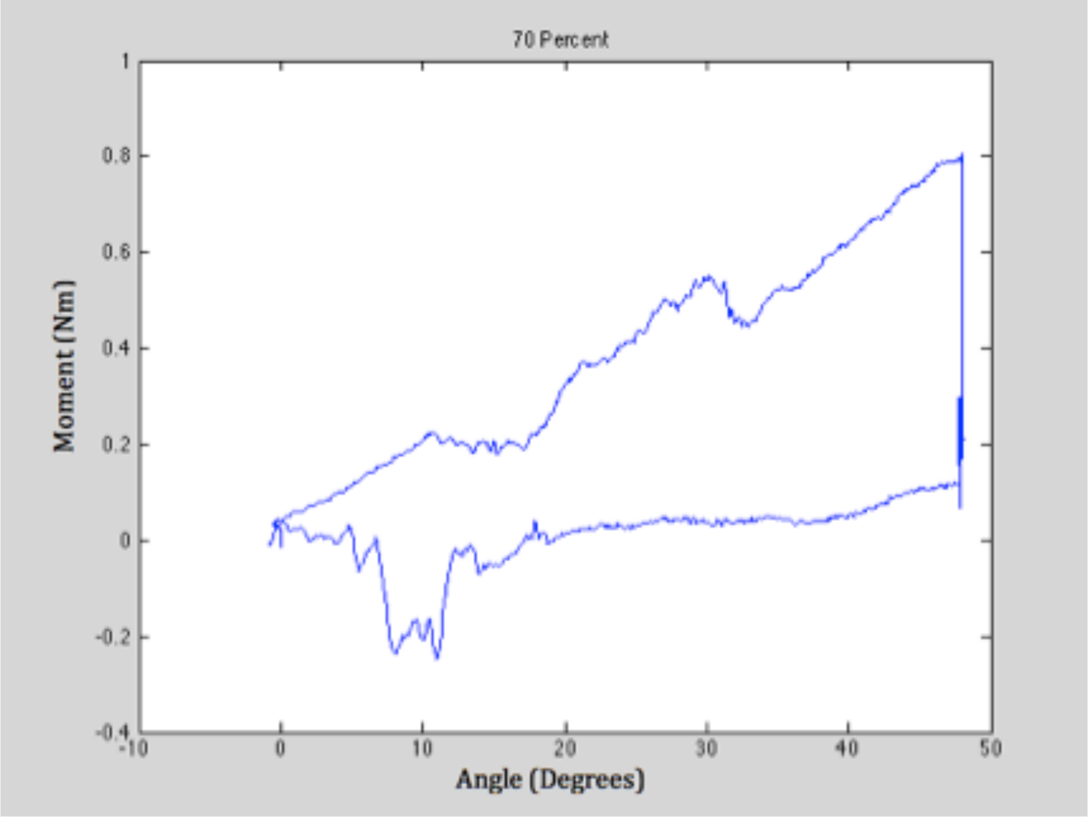

Figure 4.2: Hysteresis Loop

4.4 Gender Differences

Although all subjects were physically fit, there was variation between the sexes. Due to this fact, we further examined the differences among males and females separately to see if there were significant changes in either group as a result of the body armor. All statistics from the overall group analysis were completed again separately among the male group as well as the female group. Through our statistical analysis, the majority of pre- vs. post-exposure changes in outcome measures showed no significant differences between exposure with body armor versus exposure without body armor. Sample results for measures from stress-relaxation tests are given below (Table 4.6). Among the male participants, there was no visible trend among the measurements before and after exposure on either the armor or no armor day. The *p*-values show there were no statistically significant findings on the effects of body armor among the male participants. When examining the female participants, we did see a decrease in almost all tests post-exposure, with the exception of the hysteresis loop area on the no armor day. However, all *p*-values demonstrated a lack of statistical significance when examining the effects of the body armor among the female group.

Table 4.6: Male and Female stress relaxation and isometric trunk testing data

	Variable	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
		BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
MALE	Initial Force	132 (45)	118 (29)	137 (51)	108 (23)	0.575
	Force Drop	34 (24)	31 (18)	36 (32)	21 (14)	0.360
	MVE (Force)	711 (322)	728 (326)	746 (156)	760 (149)	0.951
	Hysteresis Loop Area	6161 (1358)	5993 (3137)	6840 (3393)	8061 (2351)	0.197
FEMALE	Initial Force	94 (34)	88 (25)	106 (85)	85 (30)	0.587
	Force Drop	31 (34)	21 (17)	55 (72)	18 (16)	0.288
	MVE (Force)	527 (118)	517 (104)	542 (124)	541 (136)	0.596
	Hysteresis Loop Area	5032 (2756)	4451 (1667)	3168 (1863)	3882 (1686)	0.870

In spite of this fact, there were a few variables that displayed statistically significant differences between the armor and no armor days. These measures are listed in the table below (Table 4.7).

Table 4.7: Significant changes among male and female groups

	Motion	Plane	Variable	ARMOR (BA)		NO ARMOR (NBA)		P VALUE
				BEFORE EXP	AFTER EXP	BEFORE EXP	AFTER EXP	
Female	Flexion/ Extension	Sagittal	T	105 (13)	112 (13)	111 (12)	113 (13)	0.018
	Axial twist to left	Frontal	P	9 (9)	9 (10)	10 (5)	11 (10)	0.004
Male	Axial twist to right	Frontal	L	16 (9)	18 (7)	-19 (50)	-22 (50)	0.025

Notes: The mean (SD) of the three statistically significant values found during analysis among the male and female groups. Measures are averages of all subjects in each group (males: n=6, females: n=6)

For the female group (n=6), there were two variables that pre- vs. post-exposure changes in them proved to be significantly different between the BA and NBA days. The exposure-induced change in maximum thorax rotation during flexion/extension was approximately 5 degrees larger (*p*=0.0018) during body armor exposure sessions as compared to no armor sessions. Additionally, the changes in maximum pelvic rotation in the frontal plane during axial twisting to the left side was approximately 1 degree smaller (*p*=0.004) during body armor sessions as compared to no armor exposure sessions. We also found a significant difference in pre- and post-exposure changes between armor and no armor days while examining the male group (n=6). The exposure-induced change in maximum lumbar rotation in the frontal plane during axial twisting to the right side was approximately 1 degree smaller (*p*=0.025) during body armor walking exposure sessions as compared to no armor sessions.

Chapter 5: Discussion

Body armor is a large component of the warfighter's load carriage system. The negative consequences induced by body armor can result in great physical, mental, and economic burdens. BA has been a proven cause of many musculoskeletal disorders, the most common being low back pain [6]. In order to control the adverse effects from the weight of the body armor, it first requires an understanding of the underlying mechanisms that link carrying body armor with and increased risk of back injuries. The tests conducted in this study are a part of larger study aimed at understanding the effects of military body armor on the mechanical aspects of the warfighter's musculoskeletal system. The objective of this study was to determine and quantify the body armor-induced changes in trunk mechanical and neuromuscular behavior following 45 minute of walking. In general, walking with body armor was not found to cause more changes in aspects of trunk mechanics studied here as compared to walking without body armor.

5.1 Range of Motion Tests

Range of motion measured in our study primarily emphasized the restricting role of passive tissues. In a fully flexed posture, upper body weight is supported mainly by a passively generated extension moment from spinal ligaments, intervertebral discs, and the passive components of the extensor muscle-tendon unit [27]. When the trunk is flexed and maintained, the passive tissues deform at a slow rate (creep deformation of the spinal tissues) [28]. This provides more laxity in the passive tissue and reduces resistance to a forward flexion moment [28]. It has been found that a greater demand on weakened muscles can facilitate muscle fatigue generation and/or failure in the muscles' ability to maintain lumbar stability [28]. For that reason, we expected to see exposure-induced changes in the range of motion of participants. In spite of our hypotheses, we did not see any significant difference pre- vs. post-exposure between the armor and no armor exposure days. These results do not support the findings of a previous study by Sparto et al 1997.

Their study focused on the effects of fatigue on kinematic and kinetic measures of performance of the trunk [29]. They induced fatigue using a repetitive lifting test in the sagittal plane with a submaximal load at a maximal lifting rate [29]. Results demonstrated that fatigue was associated with decreased knee and hip motion, increased lumbar flexion, and decreased postural stability [29]. The discrepancies in results could be due to the way fatigue was induced in each study.

5.2 Isometric Trunk Testing

The trunk is one of the most commonly affected parts of the body among soldiers. The heavy loads they carry are large risk factors for back injuries due to excess stress on the back muscles, ligaments, and spine [5]. These heavy loads are also a main contributor in muscle fatigue among soldiers [11]. As a result of changes in the active neuromuscular behavior of the trunk due to fatigue, we expected to see exposure-induced changes within our isometric trunk tests that demonstrated impaired performance among participants; however, no significant findings were observed. Our results differ from what was found in a previous study on the effects of load carriage and fatigue by Qu et al 2011 [30]. Using twelve young male participants, the effects of fatigue were considered after running exercises were completed, both with and without carrying loads [30]. They found that fatigue (similar to our exposure period) resulted in larger knee, hip, and trunk range of motion [30]. It is believed that these larger ranges of motion may result in higher muscular tensions, and therefore, a higher risk of injury, muscle strain, and joint problems [30]. One reason for the discrepancies between our results could be due to the sample of participants used. They used a single-sex sample of participants, whereas we used a mixed group of males and females, giving us a wider range of participants. Variation between the two sets of results could also be due to the different ways of inducing fatigue. Qu and Yeo had participants run at a speed of 8 mph (3.58 meters per second) for 10 minutes, three times, while our participants walked at a speed of 1.65 meters per second for 45 minutes.

We are unaware of other studies that have specifically reported on the changes in trunk MVE in response to body armor to compare our finding. However, a study conducted by Blacker, Fallowfield, and Bilzon demonstrated that walking with a backpack load carriage (versus without) showed significant decreases in maximum voluntary isometric exertions of the muscles around the knee [31]. One potential reason as to why we did not observe any significant changes in trunk MVE as compared to the observed changes in knee MVE by Blacker et al could be that the walking protocol is more demanding on the knee as compared to the trunk. Additional discrepancies include longer walking duration (120 minutes) and heavier loads (25 kg) used in the Blacker et al study. The latter two reasons may, however, not be as significant because, using a similar exposure to our study, significant changes in knee MVE have been reported in recent studies [32].

5.3 Stress Relaxation

When we conducted the stress-relaxation tests, we were trying to characterize the passive viscoelastic response of the trunk tissues. We focused on three different factors: instantaneous passive resistance, relaxation of passive resistance over the 4-minutes period (force drop), and the energy dissipated during the test to characterize the changes in passive viscoelastic response of trunk tissues. The added weight of the body armor was expected to cause more creep deformation in the spinal column when completing the walking protocol with body armor as compared with no body armor. Such body armor-induced changes in viscoelastic spine properties were expected to be captured by our measures of passive viscoelastic response of trunk tissues. We expected to see an exposure-induced decrease in the initial passive resistance, a decrease in the force drop, and an increase in the energy dissipated during the test; however, all differences were insignificant between the armor and no armor days. Results from a previous study by Toosizadeh et al using multiple stress relaxation tests exhibited an increase in initial moment and moment drop as the flexion angle increased [33]. While their study did not involve any forms of exposure, we can compare our results to the trends found in their study as flexion angle increased. On average, flexion angle increased post-exposure with and without body armor, 4.67 deg. and 1.92 deg., respectively. Our results demonstrated a small decrease in initial force and force drop post-exposure as flexion angle increased. However, these discrepancies could in part be due to magnitude of differences in the flexion angle between tests and testing time. The changes in our flexion angles differed by a few degrees whereas the previous study tested a range of flexion angles between 30-100% of the participant's maximum flexion angle. Additionally, our tests lasted for a four-minute duration while their tests lasted 16 minutes. As mentioned previously, discrepancies could also be in part due to our study having other contributing factors (i.e., exposure) between testing. Our results more closely resembles those suggestions from previous studies, both *in vitro* and *in vivo*, that repeated stretching of muscle-tendon units (via exposure) significantly reduce peak passive tension [34].

On the other hand, the hysteresis results coincide with those of Toosizadeh et al. In their study, it was found that the viscoelastic state, as measured by the ratio of hysteresis and energy input (RE), was not affected by changes in flexion angle [33]. An almost constant value of RE (0.42) was found at different lumbar flexion angles, suggesting an identical viscoelastic state for the whole trunk over a wide range of angles [33]. This information contradicts our earlier assumptions, yet our results support these previous findings.

5.4 Gender Differences

The few significant results found in our study all came from the smaller, sex-differentiated statistical analyses. While all subjects were considered physically fit, some discrepancies could be found between the size of the male and the female subjects. These large differences, in conjunction with the small sample size, could skew the results; therefore, smaller, sex-differentiated groups were examined to determine if there were any significant results among the sexes. We saw significant differences before and after exposure in both the male and female groups during Axial Twisting tests. The pelvic rotation in the frontal plane among female participants was significantly smaller after exposure with the body armor. The lumbar rotation in the frontal plane among the male participants was also significantly smaller following body armor exposure. This suggests a less coupled motion in the frontal and transverse plane after exposure with the body armor.

There was also a significant difference found in the female group when examining the maximum flexion angle before and after exposure during the Flexion/Extension test. A larger change in the flexion angle was seen in the sagittal plane after exposure with body armor as compared to exposure without body armor. We expected to see these results and results similar to these within the whole group as well. As demonstrated by Sparto et al, it is believed that larger flexion due to reduced passive resistance may suggest a reduced state of spinal stability and therefore, a higher risk of LBP [28, 29]. Our flexion/extension results are also consistent with several previous studies that have suggested that there is a higher prevalent of back pain among women than men [35, 36]. Unlike the larger group analysis of range of motion post-exposure, our results here complement those found by Shin et al and Sparto et al. Similar to our hypothesis, they believed that larger ranges of motion might result in a decline of postural stability and force generation that may indicate an increased risk of injury [28, 29]. While we did see statistically significant changes due to the body armor, these may not be clinically relevant results.

5.5 Limitations

There are several limitations in our study that should be kept in mind when interpreting our findings. First, this study utilized only a small sample size of participants (n=12). Second, one size of body armor was used (size small) for all participants, which was for consistency reasons but also due to our lack of access to multiple body armor sizes. Third, our study was conducted in a temperature and climate-controlled environment, thus removing many factors that greatly affect soldiers in real world military operations (i.e. temperature, weather, terrain, etc.). Finally, we used a short duration of exposure compared to real life situations utilizing body armor.

In conclusion, it is well known that military load carriage, including body armor, can negatively affect performance and lead to musculoskeletal disorders; however, no significant differences between exposure with body armor compared to exposure without body armor were found in our study. The large numbers of soldiers who experience MSDs as a result of their body armor not only negatively affect force generation and force sustainment, but create a substantial economic burden via medical evacuation, treatment, disability payments, and training of replacement personnel [10] [6]. Quantitative data on how body armor affects trunk neuromuscular and mechanical behavior can provide insight into necessary changes to body armor for warfighters. These data could potentially be used for assessing and attempting to minimize risk of MSDs with military body armor without compromising performance and safety of the soldiers.

Chapter 6: Future Work

6.1 Future Work

Quantifying the effects that military-issued body armor has on the trunk's mechanical and neuromuscular behavior expands the platform for research in this area of study. It allows for the identification of the underlying factors that can lead to low back pain and other injuries that result in impaired performance by soldiers. This study helps sheds light on the possibility of many similar subsequent studies.

Any future work in this subject needs to address the limitations that may have affected our results. First, a larger sample population should be used to obtain a more accurate understanding of the effects body armor has on soldiers. While 12 participants is a sufficient number for a study, small differences between participants can highly affect outcomes with a small sample population. Second, obtaining multiple sizes of body armor should be a consideration for future work. In reality, all warfighters receive different BA sizes that are proportional to their stature, with the weight of the BA increasing proportionally to the size. Using the same size BA for all participants might have decreased the actual effects of the body armor induced changes among the larger participants in our study. Third, it would be suggested to use an environment with a more realistic climate. Using a climate-controlled environment removed many factors that greatly contribute to body armor effects in real world military operations (i.e. temperature, weather, terrain, etc.). Fourth, a longer and more realistic exposure period should be used. A minimum of a 24-hour washout period between sessions was provided to each participant in this study. However, warfighters rarely remove body armor in real life situations and depending on mission durations, BA can be worn between 48 and 72 hours [37]. Completing testing on site on military bases could help ensure a realistic testing environment as well as an accurate exposure period if participants are testing after their typical daily activities.

Future studies in this area of research could also focus on trunk mechanical and neuromuscular changes due to the entire load carriage of the solider. While there have been numerous studies on military load carriage effects on the body, we are unaware of one that specifically targets the effects on the trunk muscles similar to our study. Future studies could focus more on the effects of body armor on abdominal muscles. It has been proposed that the abdominal muscles play an important role in the stabilization of the spine by co-contraction [38]. These abdominal muscles may be able to provide segmental control of the spine, and therefore increase stability and reduce the likelihood of LBP [38]. In addition to procedural changes, future studies could also examine ways to reduce the negative effects of body armor on the trunk. These could include lighter weight armor, different weight distribution on the body, or even changes in exposure conditions. This data can then potentially be applied to other affected portions of the body.

Appendix A: Institutional Review Board Forms

A.1 Study Advertisement Flyer

UNIVERSITY OF KENTUCKY RESEARCH

Volunteers Needed for a Research Study About Military Load Carriage

Researchers at the University of Kentucky are conducting a research study to investigate how the trunk muscles adapt when additional weight is placed on the back and extremities.

You may qualify for this study if you:

- are a male or female between the ages of 18 to 35;
- are very fit;
- have military experience (preferred).

The primary investigator of this study is Rebecca Tromp, B.S., a Master's student in Biomedical Engineering at the University of Kentucky.

For further information, contact

Rebecca Tromp, B.S. at

rebecca.tromp@uky.edu

UK
UNIVERSITY OF
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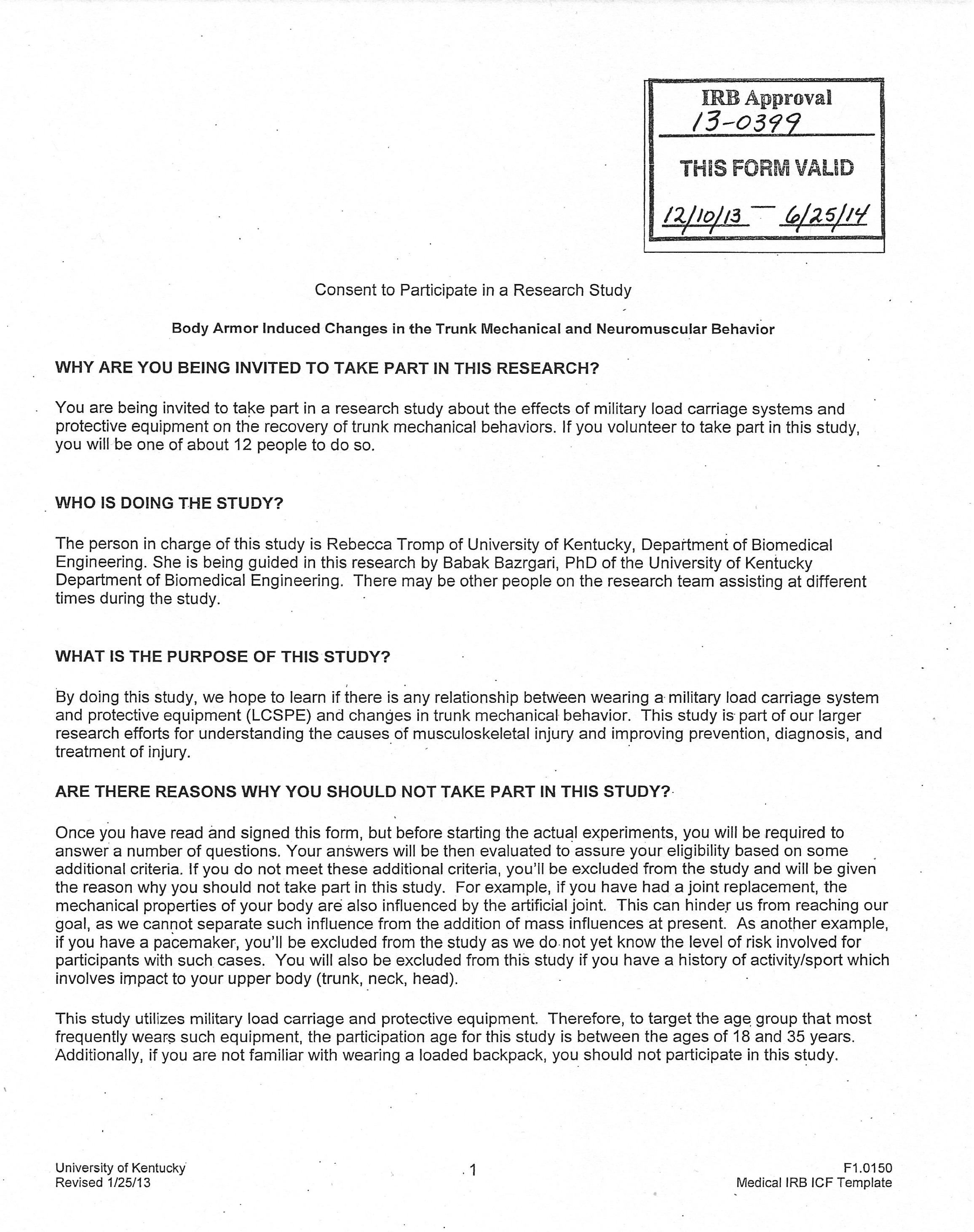
A.2 Consent Form



IRB Approval
13-0399
THIS FORM VALID
12/10/13 – 6/25/14

Consent to Participate in a Research Study

Body Armor Induced Changes in the Trunk Mechanical and Neuromuscular Behavior

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study about the effects of military load carriage systems and protective equipment on the recovery of trunk mechanical behaviors. If you volunteer to take part in this study, you will be one of about 12 people to do so.

WHO IS DOING THE STUDY?

The person in charge of this study is Rebecca Tromp of University of Kentucky, Department of Biomedical Engineering. She is being guided in this research by Babak Bazrgari, PhD of the University of Kentucky Department of Biomedical Engineering. There may be other people on the research team assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

By doing this study, we hope to learn if there is any relationship between wearing a military load carriage system and protective equipment (LCSPE) and changes in trunk mechanical behavior. This study is part of our larger research efforts for understanding the causes of musculoskeletal injury and improving prevention, diagnosis, and treatment of injury.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

Once you have read and signed this form, but before starting the actual experiments, you will be required to answer a number of questions. Your answers will be then evaluated to assure your eligibility based on some additional criteria. If you do not meet these additional criteria, you'll be excluded from the study and will be given the reason why you should not take part in this study. For example, if you have had a joint replacement, the mechanical properties of your body are also influenced by the artificial joint. This can hinder us from reaching our goal, as we cannot separate such influence from the addition of mass influences at present. As another example, if you have a pacemaker, you'll be excluded from the study as we do not yet know the level of risk involved for participants with such cases. You will also be excluded from this study if you have a history of activity/sport which involves impact to your upper body (trunk, neck, head).

This study utilizes military load carriage and protective equipment. Therefore, to target the age group that most frequently wears such equipment, the participation age for this study is between the ages of 18 and 35 years. Additionally, if you are not familiar with wearing a loaded backpack, you should not participate in this study.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research procedures will be conducted at the University of Kentucky, Center for Biomedical Engineering, Biodynamics and Human Musculoskeletal Biomechanics Laboratories. Both laboratories are located in the same building. You will need to come to Biodynamics and Human Musculoskeletal Biomechanics Laboratories in Wenner-Green Research Laboratory at 600 Rose Street 40536-0070 two (2) times during the study. Each of those visits will take about 4 hours. The total amount of time you will be asked to volunteer for this study is 8-9 hours over the next 7 days.

WHAT WILL YOU BE ASKED TO DO?

We will first apply EMG electrodes to your trunk, four on the back muscles and four on the abdominal muscles. Five motion sensors will also be attached, one on the ankle, thigh, pelvis, sternum, and on the head to help record your motion. We will then begin by testing your flexion-relaxation by asking you to move your trunk forward and backward at predetermined speeds. After some preliminary warm up stretches, we will ask you pull as hard as you can against resistance. We will ask you to stay relaxed while we raise your legs and measure your body resistance against such movement. We will also apply quick but small pushes or pulls to your trunk to record reflexes.

We will then ask you to walk on a treadmill for 45 minutes, either with or without the military protective equipment, depending on the testing day. The military protective equipment will be provided for you to wear during one of the testing days. This equipment consists of a military issued vest (~15-23 lbs depending on the size of the vest), upper arm (~3 lbs/each arm) and thigh (~4 lbs/each leg) weights to simulate extremity body armor. After this, we will ask you to repeat the trunk testing done prior to the treadmill exposure.

1st visit (Athletic Clothing)	Informed Consent	Warm Up	Trunk Testing	Treadmill Walk	Repeat Trunk Testing
2nd visit (Military Equipment)	Warm Up	Trunk Testing	Apply Armor	Treadmill Walk	Repeat Trunk Testing

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life. The risks of the study are minor. However, they include a potential for skin irritation due to the adhesives used in the tape and electrode markers. You may also feel some temporary muscle soreness such as might occur after exercising. Subjects participating in physical conditioning may experience muscle soreness and/or musculoskeletal injury associated with inherent risks of cardiovascular, strength training, and therapeutic exercise. To minimize these risks, you will be asked to warm-up before the tasks and tell us if you are aware of any history of skin-reaction to tape, history of musculoskeletal injury, or cardiovascular limitations. During prolonged testing, you may feel dizzy or light-headed, and there is a small risk you could faint. To minimize these risks, you will be asked several times if you are experiencing such symptoms; if so, you will be asked to walk around or sit down

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as appropriate. In addition, hunger may exacerbate such risks, so you will be asked to not come to experimental sessions hungry, and small snacks will be made available should you become hungry. As with any type of physical activity, the risk of a cardiac event has the possibility of occurring. In the unlikely event of a cardiac problem, there is an AED in the laboratory.

There is always a chance that any medical treatment can harm you, and the investigational treatment in this study is no different. In addition to the risks listed above, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

There is no guarantee that you will get any benefit from taking part in this study. Your willingness to take part, however, may, in the future, help better out understanding of the mechanics of the spine and musculoskeletal injury mechanisms of the lower back. We hope to make this research experience interesting and enjoyable for you where you may learn experimental procedures in biomechanical sciences.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to be in the study, there are no other choices except not to take part in the study.

WHAT WILL IT COST YOU TO PARTICIPATE?

We will do our best to minimize any cost to you. Potential costs may include traveling and parking cost. Center for Biomedical Engineering has a designated parking spot for its visitors which can be reserved for study participants during their visit.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

We will make every effort to keep confidential all research records that identify you to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. You will be assigned an identification number to protect your confidentiality. Hard copies of data will be stored in a locked filing cabinet in the laboratory and only authorized personnel will have access to the lab and the key to the cabinet. Electronic data will be stored on a password-protected computer. Collected data will be aggregated and presented without identifying information for individual subjects.

You should know, however, that there are some circumstances in which we may have to show your information to other people. Officials from the University of Kentucky may look at or copy pertinent portions of records that may identify you.

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CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.The individuals conducting the study may need to withdraw you from the study. This may occur if you are not able to follow the directions they give you, if they find that your being in the study is more risk than benefit to you.

If for any reason, you want to withdraw from the study or if we need to withdraw you from the study, any data collected up to that point will not be used and will be deleted from the computers and shredded appropriately.

ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study. It is important to let the investigator/your doctor know if you are in another research study. You should also discuss with the investigator before you agree to participate in another research study while you are enrolled in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you believe you are hurt or if you get sick because of something that is due to the study, you should call Rebecca Tromp at (616-366-1907) immediately.

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

The medical costs related to your care and treatment because of research related harm will be your responsibility. You do not give up your legal rights by signing this form.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will receive $50 for taking part in this study. If you only complete the first testing session but fail to complete the second session within the 7-day time frame they will be paid $10 for your participation in the first part of the study

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Rebecca Tromp at 616-366-1907. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

IRB

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

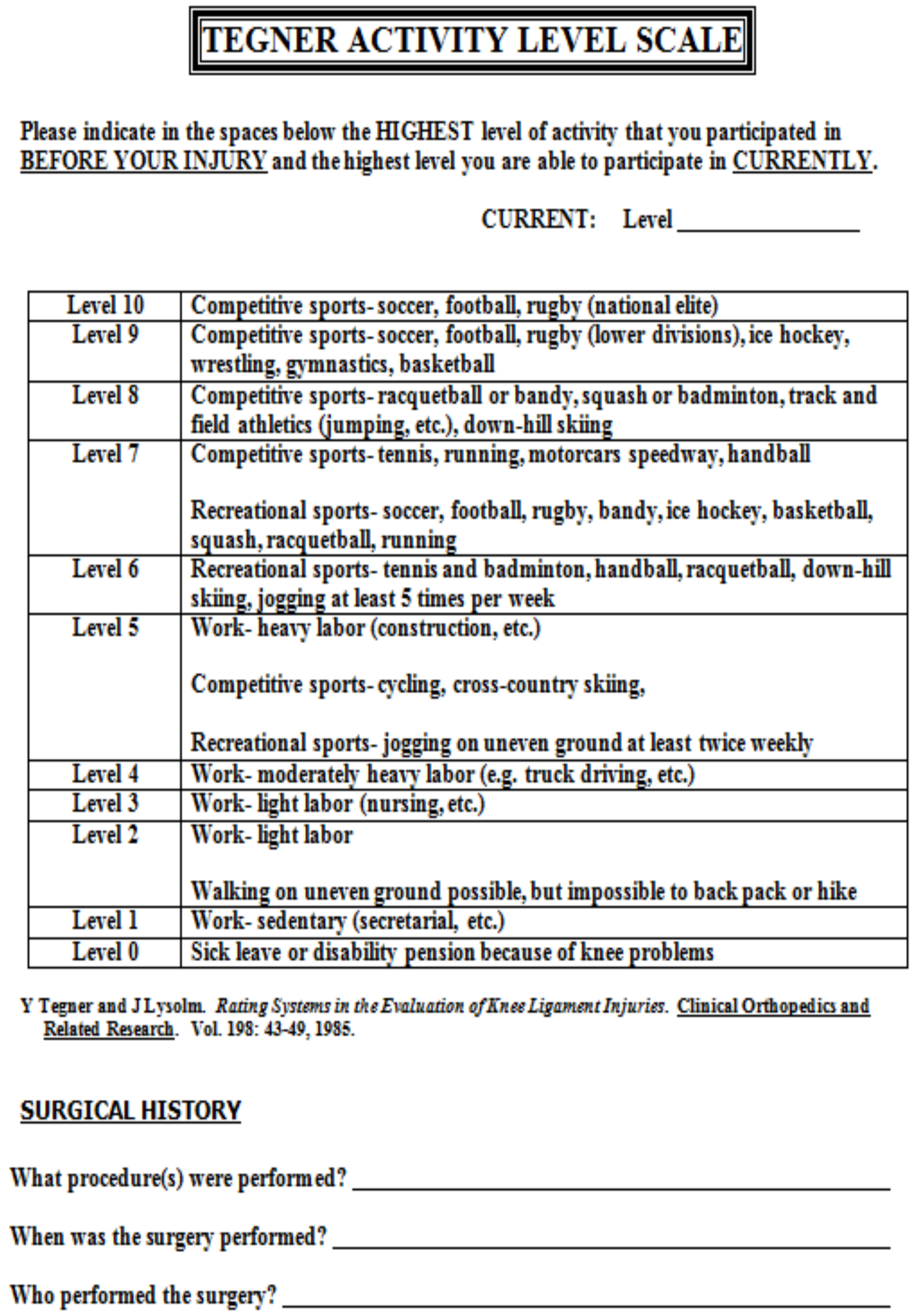
Signature of person agreeing to take part in the study — Date

Printed name of person agreeing to take part in the study

Name of [authorized] person obtaining informed consent — Date

Signature of Investigator

A.3 Tegner Form



TEGNER ACTIVITY LEVEL SCALE

Please indicate in the spaces below the HIGHEST level of activity that you participated in BEFORE YOUR INJURY and the highest level you are able to participate in CURRENTLY.

CURRENT: Level ______________

Level 10	Competitive sports- soccer, football, rugby (national elite)
Level 9	Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball
Level 8	Competitive sports- racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing
Level 7	Competitive sports- tennis, running, motorcars speedway, handball Recreational sports- soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week
Level 5	Work- heavy labor (construction, etc.) Competitive sports- cycling, cross-country skiing, Recreational sports- jogging on uneven ground at least twice weekly
Level 4	Work- moderately heavy labor (e.g. truck driving, etc.)
Level 3	Work- light labor (nursing, etc.)
Level 2	Work- light labor Walking on uneven ground possible, but impossible to back pack or hike
Level 1	Work- sedentary (secretarial, etc.)
Level 0	Sick leave or disability pension because of knee problems

Y Tegner and J Lysolm. *Rating Systems in the Evaluation of Knee Ligament Injuries*. Clinical Orthopedics and Related Research. Vol. 198: 43-49, 1985.

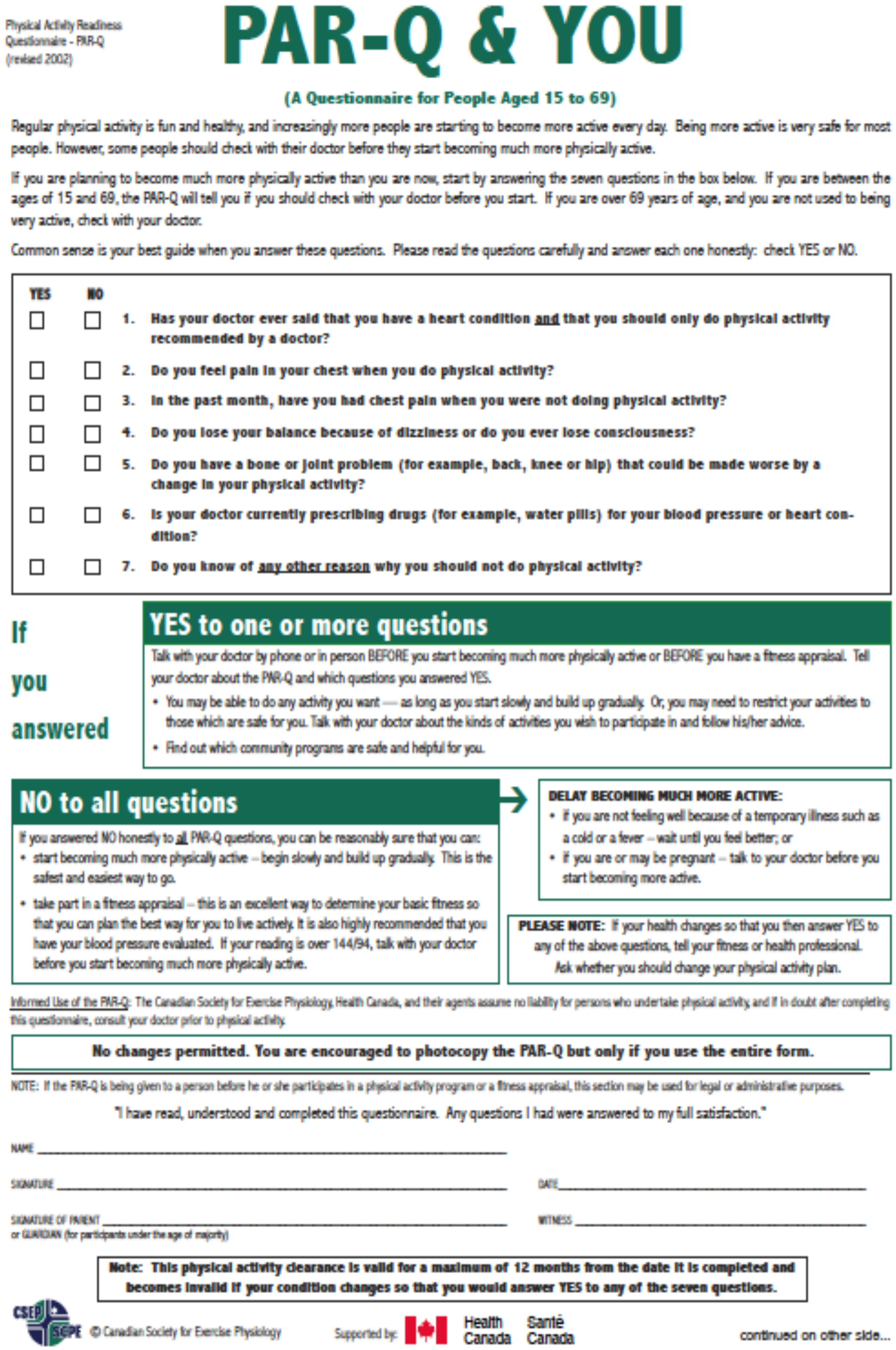
SURGICAL HISTORY

What procedure(s) were performed? ______________________________

When was the surgery performed? ______________________________

Who performed the surgery? ______________________________

A.4 PAR-Q & You Form



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	**NO**	
☐	☐	**1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____________________________

SIGNATURE OF PARENT ________________________________ WITNESS ____________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP SCPE © Canadian Society for Exercise Physiology

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Appendix B: Device Photos

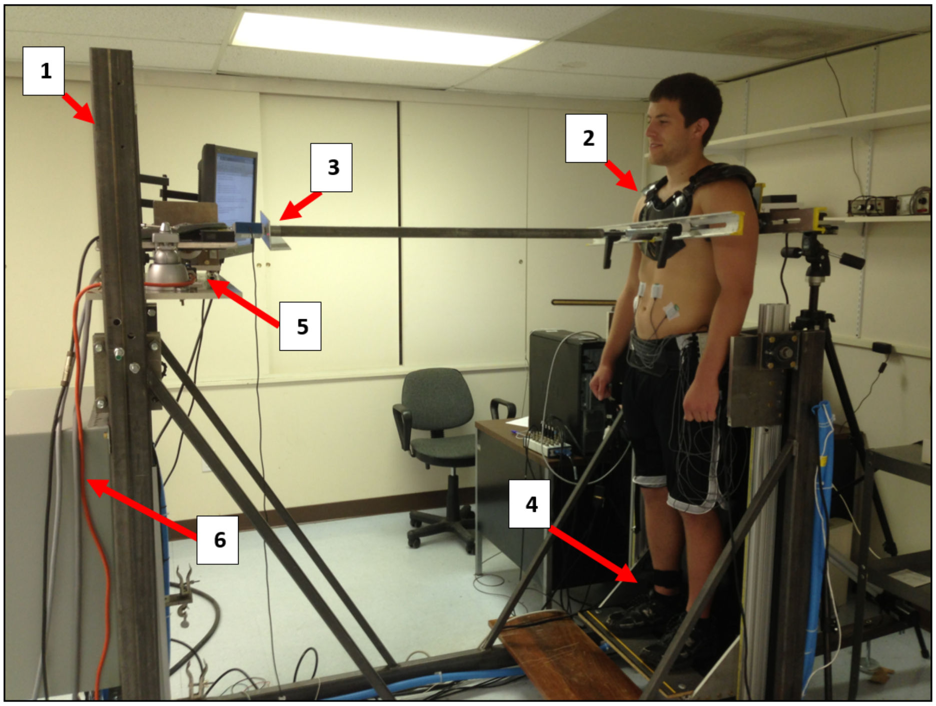

Figure B.1: Perturbation Device. 1) frame, 2) harness, 3) connecting elements, 4) leg platform, 5) motor platform, and 6) electrical components

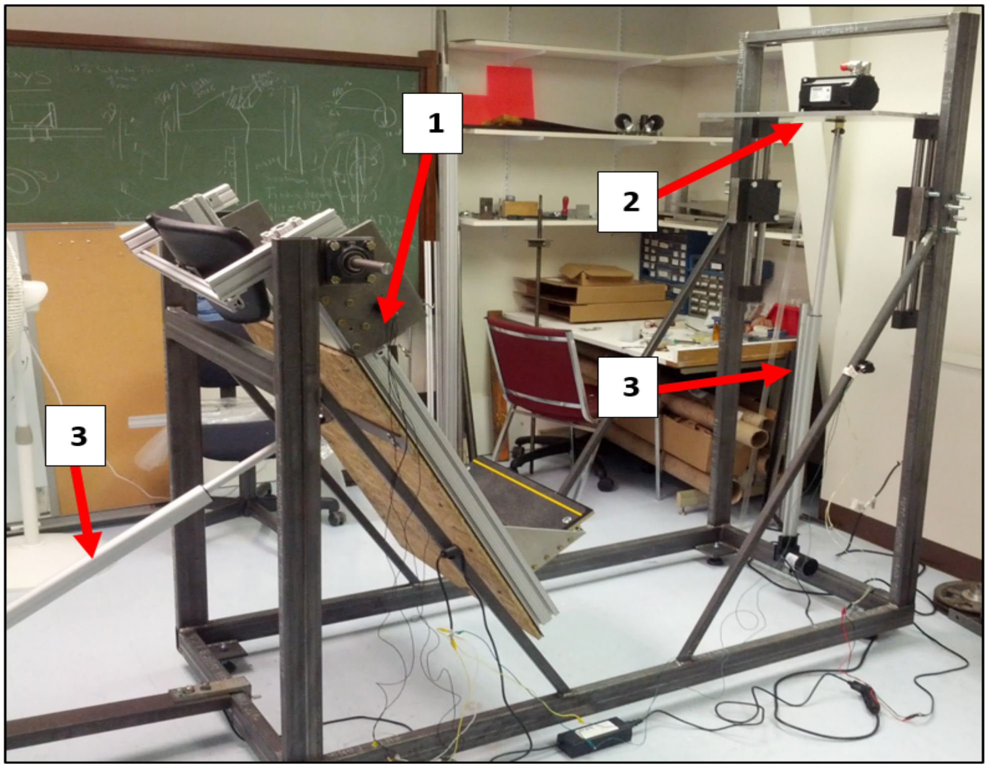

Figure B.2: Alternative view of perturbation device. 1) leg platform, 2) motor platform, and 3) two linear electrical actuators

Figure B.3: Leg Platform. Foot platform can be adjusted to the height of the participant

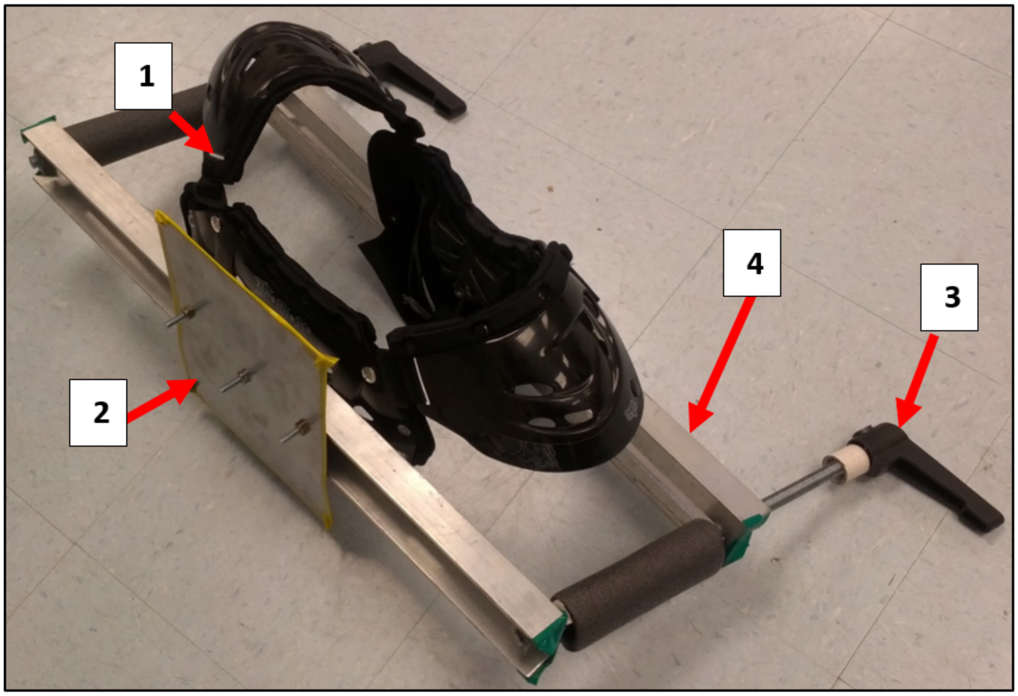

Figure B.4: Harness. 1) Roost deflector, 2) plate for laser sensor, 3) adjustable handles, and 4) rigid U-bars

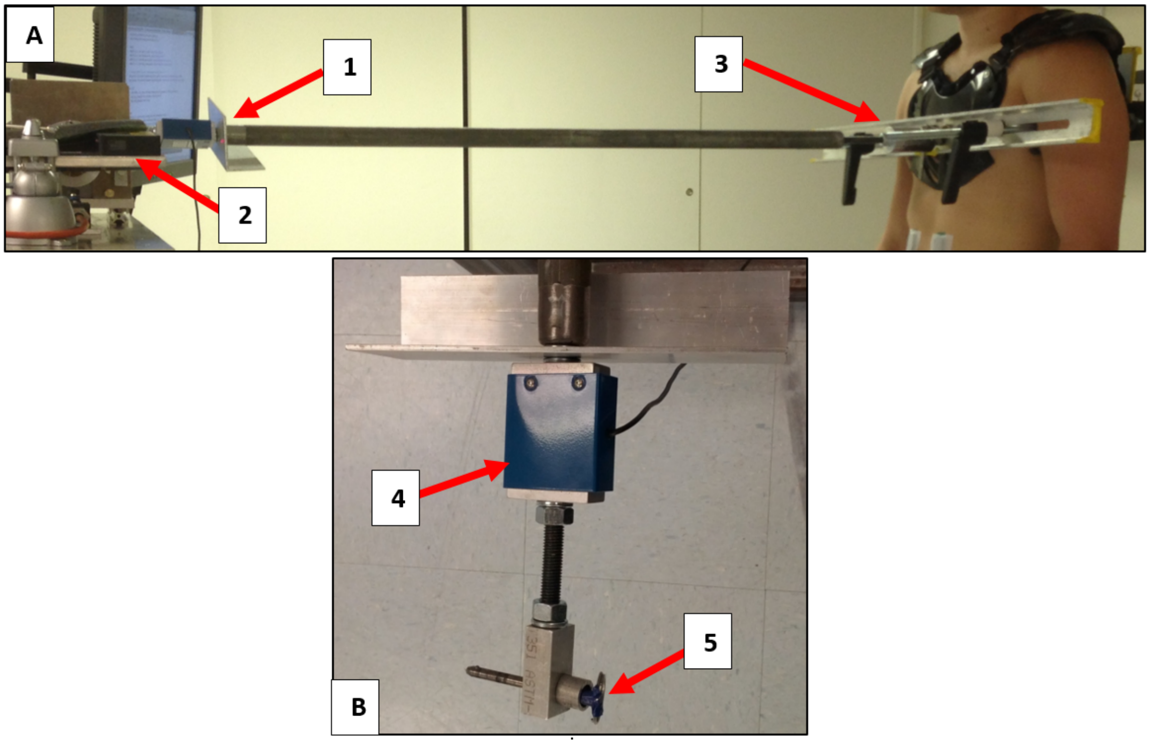

Figure B.5: Connecting Rod Assembly. 1) L-bracket for laser sensor, 2) laser sensor, 3) quick-release system that connects harness to connecting rod, 4) load cell, and 5) quick-release pin to connect to motor

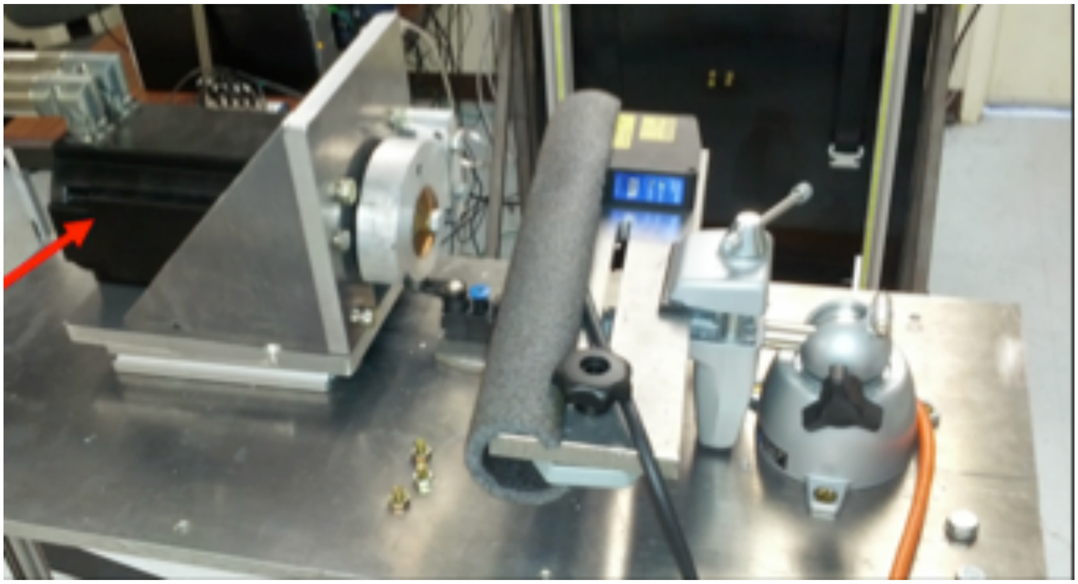

Figure B.6: Motor assembly system

Appendix C: List of Abbreviations

MSD:	Musculoskeletal Disorder
LCSPE:	Load Carriage System & Protective Equipment
BA:	Body Armor
NBA:	No Body Armor
LBP:	Low Back Pain
HMBL:	Human Musculoskeletal Biomechanics Laboratory
EMG:	Electromyography System
ITAR:	International Traffic in Arms Regulations
MVE:	Maximum Voluntary Exertions

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