ABSTRACT

WIDMAYER, REBECCA LYNN. Emergency Medicine Patient Lift Training Simulation in Virtual Reality. (Under the direction of Dr. Karen Chen).

Musculoskeletal disorders are the largest category of workplace injuries in today's workforce. Patient handling is a common cause for workplace musculoskeletal disorders among healthcare workers worldwide. Patient handling varies by clinical setting, and most research has focused on nursing and hospital setting applications. Little research has been done to investigate risks associated with patient handling tasks in emergency settings. Almost 10% of the emergency medicine technician (EMT) workforce is out of work from injury at any given time, and more than half of all EMT back injuries are caused by lifting. There are currently limited resources available to support EMTs in developing targeted training and education. Virtual reality (VR) is a valuable training platform for contexts where performance is important, but difficult to rehearse in a safe environment, and VR has also been shown useful for a variety of training applications involving physically demanding activities, e.g. emergency medicine. Virtual exertions may provide the appropriate intersection of safe, effective environments incorporating physical training. In order to accomplish this, electromyography (EMG) was used. The most common method of normalizing EMG uses a maximum voluntary isometric contraction (MVC), but no definite method has consistently been confirmed as best practice across all tasks. The main goal of this study was to integrate and investigate muscle activity in a virtual environment.

The pilot study aimed to identify the sixteen (or fewer) muscles that contributed to the patient lift task the most using means comparisons of nEMG values across thirty-eight muscles from varying body regions. Fifteen participants were randomly assigned to three muscle groups; shoulder, lower back, and extremities. Participants were asked to complete a three-part lift simulating a typical EMT patient transport, and the muscle activity was tracked using EMG

sensors on muscles in the assigned muscle group. For the virtual exertions study, Muscle activity was tracked and relayed to the computer that rendered visuals of the virtual environment. For this study, nine participants were first asked to complete the same three-part physical lift from the pilot study in order to calibrate the virtual exertions thresholds for three different weights; 100, 150, and 200 pounds. Participants then completed virtual lifts within the cave automated virtual environment. Each lift was the same three-part lift taught and executed during the physical lift portion of the experiment. Participants were instructed to exert their muscles in a way similar to the physical lifts and use the controller move a virtual patient.

The vastus lateralis, upper trapezius, thoracic erector spinae, lumbar erector spinae, extensor carpi radialis, and biceps brachium muscle groups were found to have the highest nEMG values, and were therefore incorporated into the virtual scene. Several MVC trials were conducted to determine the best practice for collected maximum values. For this study, isolated isometric MVC trials yielded the highest, and therefore best, values to be used for normalization. A virtual environment was created where a subject could use muscle exertion to lift three different virtual patients in a manner similar to a typical EMT patient transfer. Muscle activity, perceived workload, effort, and discomfort, and workload were all assessed based on the virtual task being performed. No muscle activity nor perception were significantly affected by either the appearance of the virtual patient nor the muscle threshold required to achieve the lifting task. Participants reported a much higher value for mental demand, effort, frustration, and total workload for the virtual task than for the physical task. Due to the complexity of the task and the specific muscles associated with the relevant lifts, the study shows that virtual exertions may not be the most suitable interface for EMT patient transport training.

Emergency Medicine Patient Lift Training Simulation in Virtual Reality

by
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DEDICATION

For my parents, Kathy and Doug Ellis, who taught me to pursue any path I desired, no matter the difficulty or prejudice, and continue to give me the tools and courage to succeed;

For my siblings, Kristine, Kevin, Matthew, and David, who provide comfort, joy, support, and kindness through each journey I take, regardless of distance;

For my teammates, who helped me to enjoy life, friendship, and achievement outside of school, especially when I thought I had to persist alone;

And for Sam, my husband, very best friend, most loyal supporter, resilient motivator, and the love of my life. I would not be where or who I am today without you.

BIOGRAPHY

Rebecca Widmayer obtained a Bachelor's Degree from the University of Delaware in Chemical and Biomolecular Engineering in 2014. During the following years, she was employed in various healthcare settings. She came to North Carolina State University in 2018 in hopes of pursuing an M.S., focusing on human factors and ergonomics in healthcare.

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1. INTRODUCTION

1.1 Work Musculoskeletal Disorders

1.1.1 Background

Musculoskeletal disorders (MSDs) are injuries and disorders that affect human motion through muscles, bones, nerves, tendons, ligaments, joints, cartilages, and/or spinal discs. In today's workforce, MSDs are the largest category of workplace injuries and are responsible for almost 30% of all worker's compensation costs. In the United States, companies spend over $50 billion on direct costs of MSDs (Centers for Disease Control and Prevention, 2011; Liberty Mutual Insurance, 2017) with indirect costs up to five times as large. A critical review conducted by the National Institute of Occupational Safety and Health (NIOSH) in 1997 showed evidence of a causal relationship between physical exertion at work and MSDs (Bernard et al., 1997). Another review was conducted by de Costa and Vieira in 2009 to evaluate suggested risk factors for work-related musculoskeletal disorders (WMSDs). Several factors were found to be commonly associated with WMSDs; including repetitive motion, awkward and/or sustained postures, and heavy lifting (da Costa and Vieira, 2009). While every type of WMSD has different risk factors, da Costa and Vieira found that lifting was a risk factor for neck, low back, hip, and knee WMSD. Lifting is also a common factor in work-related shoulder pain (Beach, Senthilselvan, and Cherry, 2012).

1.1.2 Lifting

Lifting occurs in many occupational settings, and NIOSH has given special attention to the lifting demands on workers for many years now. In 1981, NIOSH developed its first equation to evaluate lifting demands in the sagittal plane (NIOSH, 1981). This equation was improved and revised in 1991 to apply to a larger range of lifting tasks (NIOSH, 1993). While

the 1981 equation could only be applied to sagittal lifting tasks, the 1991 equation provides methods for evaluating asymmetrical lifts, objects with nonideal hand-container couplings, and a larger range of work durations and lifting frequencies (NIOSH, 1993). With these additions, the revised NIOSH lifting equation now provides guidelines for a more diverse range of lifting tasks. However, as addressed in NIOSH's Applications Manual for the Revised NIOSH Lifting Equation (Waters, 1994), this equation is still not applicable for tasks as variable as patient transfer tasks. As Waters, a contributor of the revised NIOSH lifting equation, addresses in another article (2007), the equation should not be used for patient lifts because the equation does not include factors that account for unpredictable conditions. Patients can be unpredictable in behavior, are sometimes heavier than they appear, and can move and create variable loads for the lifter. Therefore, the NIOSH lifting equation cannot be used in patient transfer tasks unless the patient can follow directions, their weight can be estimated, the lifting is smooth and slow, and the geometry of the lift is not subject to change (Waters, 2007). Unfortunately, this does not apply to many necessary patient handling tasks.

1.1.3 Patient Handling

Patient handling, such as lifting and transfer tasks, is a common cause for WMSD among healthcare workers worldwide. Several previous studies showed that patient handling accounted for 33-72% of musculoskeletal disorder injuries and 53% of compensation costs among patient care staff in a hospital setting (Pompeii, 2009; Kim, 2012; Lipscomb, 2012). In addition to worker safety concerns, there are also significant clinical implications for improper or awkward patient handling; including negative effects on patient safety, comfort, and quality of care (Wicker, 2000). For these reasons, there has been a lot of research and policy focus in the healthcare industry on improving methods for patient handling.

In 1946, a textbook titled Body Mechanics in Nursing Arts was published, including biomechanical illustrations of nurses repositioning patients (Fash, 1946). From there, the idea of "lifting properly" and using body mechanics for patient handling persisted and progressed, eventually leading to projects and curriculums promoting body mechanics training programs for nursing schools (Winters, 1950). The hypothesis behind body mechanics training was that nurses could use skill rather than strength to prevent musculoskeletal injuries (Gill, 1958). The body mechanics lessons of Winters and Fash were absent of scientific foundation and evidence. (Nelson, 2003). Unfortunately, as was the case in many worker safety cultures until recently, this model blamed injuries on the worker rather than the system.

Luckily, it soon became widely recognized that the hazards of patient handling could not be alleviated by training alone (Dehlin, Berg, Anderson, & Grimby, 1981; Nelson et al., 2003; Snook, Campanelli, and Hart, 1978; Wood, 1986). Research focus switched from analyzing the worker to conducting task analyses and biomechanical evaluations of patient handling activities (Nelson, 2003). Research studies are now focused on delivering evidence-based recommendations and practices to reduce WMSD in care providers; including patient ergonomic assessment protocols, patient handling equipment and devices, and patient lift teams. (Nelson and Baptiste, 2004). Garg (1999) showed a 62% decrease in injuries from resident transfers, 64-86% fewer lost and restricted workdays for nurses, and an 84% decrease in workers' compensation costs after implementing patient handling programs in seven nursing homes and one hospital. NIOSH conducted a similar study implementing a safe resident handling and moment program, and injuries were reduced by 61% (Collins et al., 2004).

In a multi-faceted program implemented across 23 high-risk long-term care units in seven facilities, 96% of nurses ranked lifting equipment as the most important program element

(Nelson et al., 2006). A collective assessment of the biomechanical laboratory studies showed that mechanical lifting equipment could significantly reduce the biomechanical stress that lead to musculoskeletal injuries when compared to manual methods (Garg et al., 1992; Marras et al., 1999; Zhuang et al., 1999). However, surveys suggest that only 15% of nurses use lifting equipment when transporting patients (Evanoff et al., 2003). In addition, recent NIOSH data suggests that lift equipment was not used for 82% of patient handling injuries (Gomaa et al., 2015). Many factors have been noted for why nursing staff use or do not use patient lift equipment; such as availability of equipment, availability of staff to assist, staff preference, patient ability to assist with lift, equipment proximity, patient mobility, and patient impairments (Kucera et al., 2019). Therefore, though patient lift equipment is a promising resource to reduce WMSD in nursing, there is still much to be done to enhance effectiveness of ergonomic intervention efforts to prevent work-related patient-handling injuries (Kucera et al., 2019).

Patient handling varies by clinical setting, and so far, most research has been focused on nursing and hospital setting applications. Some research has studied the risk of transferring patients on and off stretchers and beds in acute care (Owen, Keene, and Olson, 2000) and in the operating room (Garb and Dockery, 1995; Owen, 2000; Wicker 2000), but little research has been done to investigate risks associated with patient handling tasks in emergency settings. (Nelson and Baptiste, 2006). And while there is promise for implementing patient lift equipment and ergonomic programs in nursing fields, these may not be reasonable or attainable in emergency medicine transport in the near future.

1.1.4 Emergency Medicine

After nurses, emergency medical technicians (EMTs) incur the highest musculoskeletal injury burden (10.3/100 FTEs) from patient handling activities (Pompeii, 2009). Almost 10% of

the EMT workforce is out of work from injury at any given time (Stunek, Ferketich, and Crawford, 2007), and more than half of all EMT back injuries are caused by lifting (Hogya and Ellis, 1990). During a typical 12-hour shift, an EMT may perform more than 50 lifts, and in almost every call, EMTs are required to lift loads in excess of the NIOSH maximum weight for a lift under ideal conditions (Coffey et al., 2016). Recently, obesity and a lack of physical fitness among both the general population and within EMT agencies have contributed to increases in injuries and chronic WMSDs. According to the National Association of Emergency Medical Technicians (NAEMT, 2012):

- EMS practitioners are seven times more likely than the average worker to miss work as a result of injury
- Half of all EMS workers suffer back pain annually
- One out of four EMS practitioners will suffer a career-ending injury within the first four years of service
- Back injury is the most frequently cited reason for leaving EMS

These issues are well documented, but little has been done to improve conditions in emergency medicine. The American Council on Exercise (ACE) did an evaluation of EMTs and recommended physical-fitness assessments and exercise guidelines for EMS practitioners that will ultimately help reduce the number and severity of musculoskeletal injuries on the job. However, there are currently limited resources available to support EMTs in developing targeted training and education to support existing and new candidates in optimizing their physical readiness (ACE, 2012).

Similar to the patient lift devices being introduced in nursing settings, some prehospital urgent care companies have purchased mechanized stretchers and loading systems in order to

reduce the prevalence of WMSDs (Armstrong et al., 2017). Very few studies have been conducted to determine the effectiveness of these devices, but preliminary results are promising. Armstrong et al. (2017) found that powered stretcher and load systems reduced stretcher related MSDs by 78%. More evidence is needed to support these devices, and many companies are reluctant to purchase such high-cost machines. Due to the slow uptake of patient lift equipment and the changing patient population, patient transfers will continue to be regular, demanding tasks that put EMTs at risk for WMSDs for years to come. For this reason, *it is necessary to develop alternative training methods to facilitate education surrounding physical health and movement for EMTs.*

1.2 Virtual Reality Training

Creating an appropriate learning environment for EMTs in critical to providing adequate training for on-the job-tasks. Virtual reality (VR) is a well-established and valuable training platform for contexts where performance is important, but difficult to rehearse in a safe environment, .e.g., military, police, and firefighting (NRC, 1994; Series, 1997; Reheingold, 1991; Peruch et al., 2000). Immersive VR has also been shown useful for a variety of training applications involving physically demanding activities, e.g. emergency medicine (Andreatta et al., 2010), manufacturing processes (Mujber, Szecsi, and Hashmi, 2004), physical rehabilitation (Henderson, Korner-Bitensky, and Levin, 2007), and mining (van Wyk and de Villiers, 2009). Therefore, using VR in EMT training should provide a useful platform for learning physically demanding tasks in a safe environment.

1.3 Virtual Exertions

Providing an adequate environment for training is necessary, but providing feedback on physical tasks would be even more beneficial due to the nature of EMT patient lifts and the

history of WMSDs caused by them. Virtual exertions may provide the appropriate intersection of safe, effective environment training while incorporating physical training. Virtual exertions is a method utilizing biofeedback from electromyography (EMG) and movement for interacting with virtual objects in VR. More specifically, virtual exertions incorporate EMG signal outputs as inputs into the code determining whether a virtual object can move. If the participant is exerting the appropriate amount, the signal output will be read by the program as an input and allow the virtual objects to move within the virtual environment. Using this method, muscle contractions help the user to work with virtual objects in VR, evoking the sense of exerting force on physical objects (Chen et al., 2015). *By using virtual exertions, EMT training may be able to incorporate physical and situational training together in a safe and active environment.*

1.4 Studying Muscle Activity using Electromyography

In order to utilize and understand muscle activity during EMT patient handling tasks during training, electromyography (EMG) was used. EMG has been around since the 1600s (Carm and Kasman, 2011), and is used to measure action potentials of motor units in muscles (Basmajian, 1967). EMG applications have continued to develop from isometric applications, to using time-frequency techniques to assess muscle function in dynamic conditions (Bonato et al., 1996), and then to real-world and real-time applications (Bonata et al., 2002). EMG is commonly used to study muscle activity during lifting tasks (Andersson, Ortengren, and Herberts, 1977; Ekholm, Arborelius, and Nemeth, 1982; Yates and Karwowski, 1992; Granata and Marras, 1995) and has also been used specifically to study patient handling tasks (Marras et al., 1999). Most lifting studies focus on trunk muscle EMG Andersson, Ortengren, and Herberts, 1977; Ekholm, Arborelius, and Nemeth, 1982; Yates and Karwowski, 1992; Granata and Marras, 1995, Marras et al., 1999). Others have focused on hip extensor muscles (Vakos et al.,

1994), shoulder (Yates and Karwowski, 1992), lower extremities (Buhr, Chaffin, and Martin et al., 1999), and upper extremities (Lee et al., 2015). However, less interest has been shown in understanding muscle activity throughout the entire body during lifting tasks; specifically, *which muscles are most extensively used to capacity during lifting.*

In order to compare EMG signals across muscles and subjects, EMG must be normalized (De Luca, 1997). Normalization is performed by dividing the EMG signals during a task by a reference EMG value. The most common method of normalizing EMG uses a maximum voluntary isometric contraction (MVC) as the reference EMG value (Halaki and Ginn, 2012). Many other methods have been investigated, such as the torque-velocity test (Rouffet and Hautier, 2008), isokinetic maximum voluntary contraction (Burden and Bartlett, 1999), submaximal exertions (Marras and Davis, 2001), power output, and task specific methods (Albertus-Kajee et al., 2010). Some of these methods produced reproducible and repeatable results, but each were specific to the task investigated and have not been extended to other muscles or tasks. The reliability and repeatability of normalization methods is still being examined and improved, but *no definite method has consistently been confirmed as best practice across all tasks.*

1.5 Motivation

With the prevalence of WMSDs, especially in the EMT occupation and related to patient handling tasks, it is important to develop more appropriate training platforms to prepare the workforce for physically demanding tasks. The ultimate objective was to investigate the effectiveness of virtual exertions in emergency medicine lifting tasks with regards to muscle exertions and mental demand.

The first research question was which muscles are primarily used during paramedic lifting tasks. The present research has focused on specific muscle groups, but this study aimed to look at all muscle groups and narrow down the muscles that are used at the highest capacity to perform the relevant patient handling tasks.

The second research question was what MVC method was most appropriate for the investigated muscles. With various normalization methods shown to be effective in the literature, utilizing multiple methods may allow for more accurate MVC values to normalize the EMG data. The pilot study was designed to investigate these first two research questions.

Using the results of the pilot study, the virtual exertions study was designed to continue to investigate the second research question as well as the following questions. The third research question was whether full body EMG and a complex patient handling task could be incorporated into VR using a virtual exertions method. The only other virtual exertions study performed (Chen et al., 2015) focused on a simple bicep curl while using EMG on only a few arm muscles. This study attempted to expand the scope of virtual exertions to include more muscles and a more complex task.

The fourth research question was whether a participants' perceived workload or muscle activity would differ between physical patient lifting tasks and virtual patient lifting tasks. Evaluating perceived workload will indicate the appropriateness and difficulty of the virtual task compared to the equivalent physical task.

The fifth research question was whether the participants' perceived effort, perceived discomfort, or muscle activity varied based on the appearance of the patient or the weight threshold they needed to reach. This information will indicate any variability that occurs based on either the virtual image factors or physical response factors.

1.6 Hypotheses

Based on the existing literature, the below null hypotheses (H) were formulated. For the chosen patient handling tasks, it is expected that the muscles with the highest normalized values will be from muscle groups from all three investigated regions of the body (H1). Regarding the best MVC method for normalizing EMG values during EMT lifts, the muscle activity values are not expected differ between MVC methods (H2). Using similar technology to the previous virtual exertions study, it is expected that full body EMG and a complex patient handling task utilizing virtual exertions can be incorporated into VR (H3).

In terms of physical and virtual tasks, it is hypothesized that there will be no difference between physical and virtual tasks in perceived workload (H4) nor muscle activity (H5) required to complete the tasks. For the virtual tasks, it is expected that perceived effort (H6, H7), perceived discomfort (H8, H9), and muscle activity (H 10, H11) will not differ based on the virtual patient appearance nor the required weight threshold.

2. METHODOLOGY

2.1 Pilot Study

The main goal of this study was to integrate and investigate muscle activity in a virtual environment. The electromyography technology available for muscle activity acquisition only had sixteen sensors, but thirty-eight muscles were identified from the literature as relevant muscles to lifting tasks. Therefore, it was necessary to reduce the number of muscles being analyzed and integrated into the virtual exertions study from thirty-eight to sixteen or less. The pilot study aimed to identify the sixteen (or fewer) muscles that contributed to the patient lift task the most.

2.1.1 Technology

This experiment took place in the North Carolina State University Ergonomics Lab. Muscle activity was tracked using Trigno EMG wireless sensors (see Figure 1). These sensors are used to measure and wirelessly transmit surface EMG signals to the Delsys EMGworks software (Delsys Incorporated, Natick, MA). This software includes a Real-Time Acquisition module and a Data Analysis module.

Figure 1 Trigno EMG wireless sensors
((Delsys Incorporated, Natick, MA)

In addition to the EMG technology, a dynamometer (Biodex System 4 MVP^{TM}, Biodex Medical Systems, Shirley, NY) was used for creating isometric muscle contraction while measuring maximum voluntary contraction (discussed in Section 2.1.7.3). The Biodex

dynamometer allows the researcher to isolate specific muscle exertion directions using anatomy-specific attachments (see Figure 2).

Figure 2 Biodex dynamometer set up for left knee flexion/extension (Biodex System 4 MVP^{TM}, Biodex Medical Systems, Shirley, NY)

2.1.2 Participants

Fifteen participants ages 18-35 (M = 22.7, SD = 4.9) were recruited for the study, including 8 females and 7 males. Five participants each were placed into three muscle groups; shoulder, lower back, and extremities. In general, the samples represented a younger and active population, as all participants were recruited online or by flyers posted on North Carolina State University campus, predominantly consisting of undergraduate students. All participants had no physical disabilities, no musculoskeletal injuries in the past 3 months, and indicated they were willing to lift/move heavy objects at the time of experiment participation. Each participant was compensated at a rate of $10.00 per hour. The experiment lasted approximately 2 hours for each participant.

2.1.3 Task Description

Participants were asked to complete a three-part, two-person lift with the researcher. This lift simulated a typical three-part EMT lift performed during patient transport, as used by

Makhoul et al. (2017). These lifts are often identified as the most demanding lifts by paramedics (Coffey et al., 2016). The three parts are explained in further detail in Section 2.1.7.4. The three-part lift was completed in order three times, with a one-minute rest in between each full lift sequence.

2.1.4 Independent variables

The control variables for this experiment were the muscles that were being measured and the MVC methods being used. The list and locations of all thirty-eight muscles are shown in Table 1 and Figure 3 below, broken up by muscle groups. Five participants were randomly assigned to each muscle group.

Table 1 Muscles assigned to each muscle group

Shoulder Muscle Group	Lower Back Muscle Group	Extremities Muscle Group
1. Right anterior deltoid (RAD) 2. Left anterior deltoid (LAD) 3. Right middle deltoid (RMD) 4. Left middle deltoid (LMD) 5. Right posterior deltoid (RPD) 6. Left posterior deltoid (LPD) 7. Right upper trapezius (RUT) 8. Left upper trapezius (LUT) 9. Right middle trapezius (RMT) 10. Left middle trapezius (LMT) 11. Right lower trapezius (RLT) 12. Left lower trapezius (LLT)	13. Right rectus abdominus (RRA) 14. Left rectus abdominus (LRA) 15. Right external oblique (REO) 16. Left external oblique (LEO) 17. Right internal oblique (RIO) 18. Left internal oblique (LIO) 19. Right latissimus dorsi (RLD) 20. Left latissimus dorsi (LLD) 21. Right thoracic erector spinae (RTES) 22. Left thoracic erector spinae (LTES) 23. Right lumbar erector spinae (RLES) 24. Left lumbar erector spinae (LLES)	25. Right extensor carpi radialis (REC) 26. Left extensor carpi radialis (LEC) 27. Right flexor carpi radialis (RFC) 28. Left flexor carpi radialis (LFC) 29. Right triceps (RTRI) 30. Left triceps (LTRI) 31. Right biceps brachium (RBI) 32. Left biceps brachium (LBI) 33. Right hamstring (RHAM) 34. Left hamstring (LHAM) 35. Right vastus lateralis (RVL) 36. Left vastus lateralis (LVL) 37. Right biceps femoris (RBI) 38. Left biceps femoris (LBI)

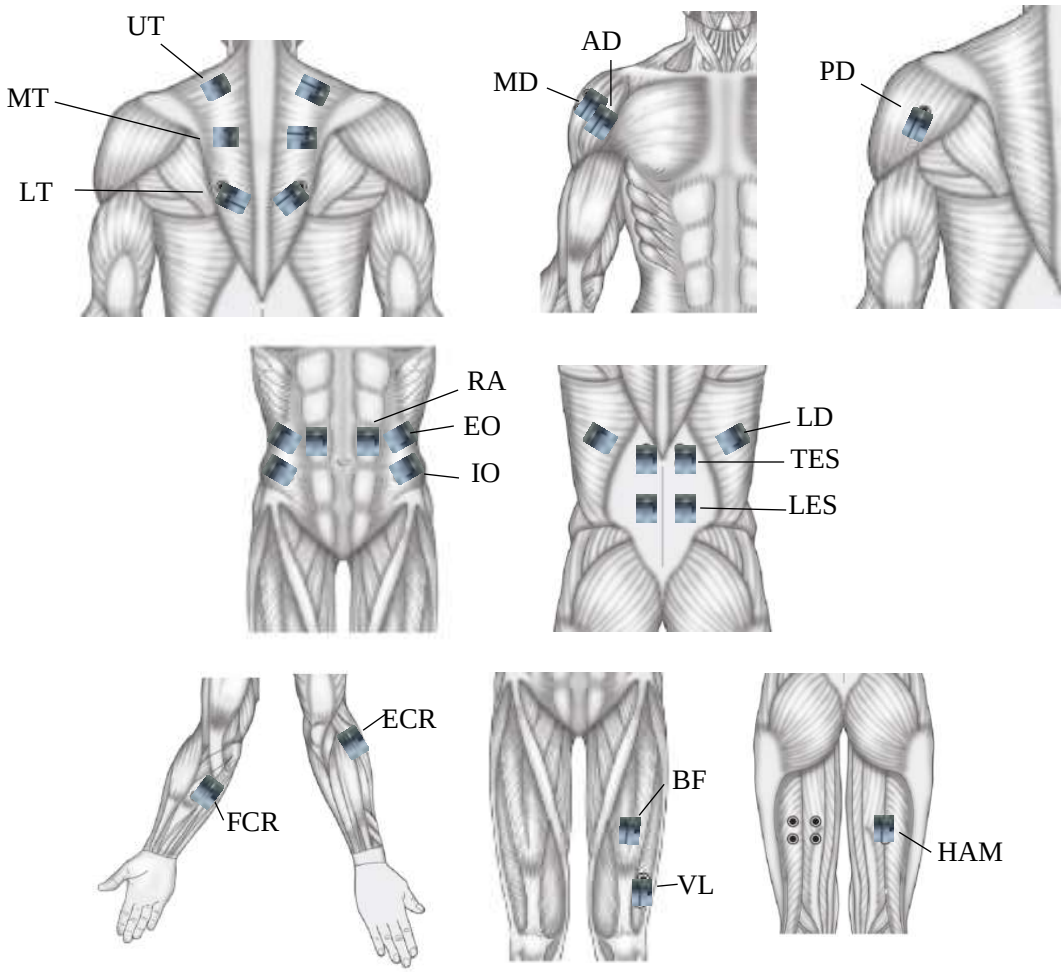

Figure 3 EMG sensor locations

2.1.5 Dependent variables

The relevant response variables were the muscle exertions, the muscle chosen for inclusion in the VR setting, and best MVC method. The raw EMG data was rectified and filtered using a fourth-order Butterworth filter with a 10 Hz low pass and 350 Hz high pass filter. These data were divided by each MVC measured (filtered in the same way), resulting in normalized EMG. MVC methods were deemed best if they yielded the highest muscle activity signal.

2.1.6 Experimental Design

This study utilizes an independent measures, between subjects design with three groups; shoulder muscles, lower back muscles, and extremity muscles. Subjects were randomly assigned

to each of the three groups, with five subjects for each group. Due to the low number of available EMG sensors (16) and the number of muscles to be assessed (38), it was necessary to form three separate groups, each with less than 16 muscles to be assessed, in order to reduce the amount of time in the lab for each participant.

2.1.7 Procedures

Participant eligibility was assessed via an online survey platform (Qualtrics Survey Software, Qualtrics, Provo, Utah). After completing the survey, eligible participants scheduled a time for complete the experiment with the experimenter. Upon arrival at the Ergonomics Lab, the experimenter provided a participant with a brief introduction to the study.

2.1.7.1 Questionnaire

At the beginning of the experiment, the participants were presented with an informed consent form (see Appendix A: Pilot Study Informed Consent Form). If they agreed to participate, they were asked to complete a brief demographic questionnaire (see Appendix B: Demographic Questionnaire). Information collected using the demographic questionnaire included self-reported information about age, gender, overall health status, and upper-limb health.

2.1.7.2 EMG Prep

We were interested in studying muscle groups located in the low back, the shoulder region, the upper extremities, and the lower extremities. There were three major regions, and each muscle region had 6 or 7 bilateral muscle pairs. See Table 1 for a list of the muscles studied in each muscle region. The participants were randomly assigned to a muscle region. Once the consent and questionnaires forms were completed, the experimenter placed the EMG sensors (12-14 per participant) on the muscles in the assigned group. EMG sensors are electrodes placed

on the surface of the skin, and medical or athletic tape can be used to secure the electrodes in place if necessary. See Appendix C: Electrode Placements for electrode placement of each of the thirty-eight selected muscles.

2.1.7.3 MVC

The MVC is the greatest (maximum) tension that a muscle can generate or support, discussed in detail in Section 1.4. It is found by applying an opposing force to the participant's muscle that requires the participant to exert maximum effort in that muscle for a short period of time. The Biodex System 4 MVPTM was used in static positions to create isometric muscle contractions in appropriate directions for each muscle Figure 4.

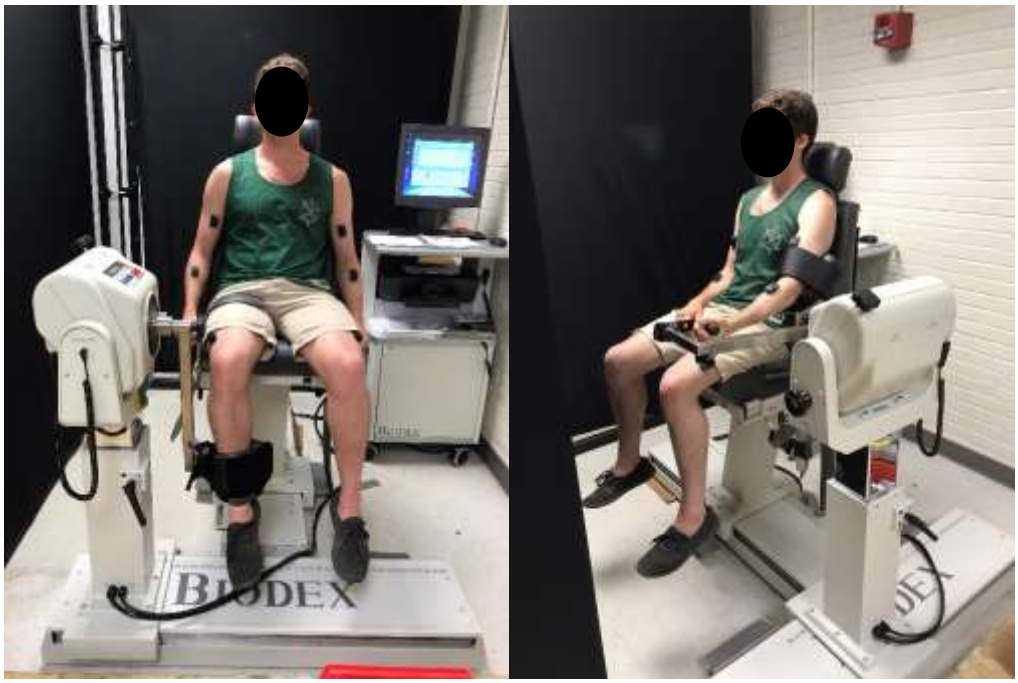

Figure 4 Biodex setup for right leg flexion/extension (left) and left wrist flexion (right)

See Appendix D: Maximum Voluntary Contraction Methods for Biodex setup for each muscle. For each shoulder muscle, abduction, adduction, flexion, extension, internal rotation, and external rotation MVC trials were performed. These were completed in order to evaluate the effectiveness of different MVC methods, as previously conducted by Gatti et al. (2007). For this

study, the MVC was performed for three seconds, three times per muscle, with a one minute rest between each MVC. Participants were given the option to warm up by stretching their legs and arms (as if warming up before exercising) if desired.

2.1.7.4 Lift

After MVC trials were completed for each muscle, the experimenter demonstrated the appropriate lifting methods for the patient transport lifts to be performed, as suggested by the EMS1 Network (Milus, 2007). Proper lifting techniques include:

1. Position yourself as close as possible to the object you are intending to lift.
2. Feet placed apart to provide a stable base.
3. Feet as close to the body board as possible.
4. Tighten abdominal muscles and keep your back flat for the entirety of the lift.
5. Lift with your legs. Place body weight on heels and balls of your feet. Push up by tightening your hips, hamstrings, and gluts as you rise.

The participant then attempted the lifts while receiving feedback from the experimenter. The participant was reminded that he/she should immediately notify the experimenter and stop performing the lift if he/she feels any discomfort at any time of the study. In each trial, the participant lifted a weighted backboard (to simulate a stretcher with a patient) in three motions similar to the patient lift shown in Section 2.1.3. The task was to transport the weighted backboard from the ground laterally onto a “stretcher”, then lift the weighted backboard to standing height, then lift onto a higher surface similar to an ambulance loading height. These motions are shown below in Figure 5.

Figure 5 Patient transport task. Action 1: Top Left → Top Right/Middle Left → Middle Left → Middle Right → Bottom Left. Action 2: Bottom Left → Middle Right. Action 3: Middle Right → Bottom Right

The total weight being lifted was be about 150 pounds, a typical patient weight. After the participant completed the practice trials, the patient transport task was performed by the participant three times, with one minute breaks in between each trial.

2.1.7.5 Post-Lift Survey

After the three trials, the participant was directed to have a seat and complete the discomfort survey (Appendix E: Body Discomfort Survey). After the survey was complete, the EMG sensors were removed and the study was completed. The entire length of the study took around 2 hours per participant.

2.1.8 Statistical Data Analyses

After data collection, 15 participants' data were available for analysis. Abnormal data resulting from sensor deviation/movement were removed prior to data analysis. Sensors that had moved or fallen off the participant during the experiment were noted and removed prior to data analysis. Any nEMG values resulting in a value higher that 300 was also removed, as these data were likely the result of an insufficient MVC trial for that participant or sensor movement. A student's t-test was performed to determine if there was a significant difference among the average normalized EMG (nEMG) value for each muscle. Then Tukey's post hoc test was conducted to identify differences among the levels. A significance level of $p \leq 0.05$ was used to identify statistical significance of any effect. The main goal of this data analysis was to determine between five and seven bilateral muscle pairs to include in the virtual exertions study.

A secondary goal of this study was to determine best practices for various MVC methods used to normalize the EMG data. In this pilot study, the MVC trial that generated the highest normalized EMG value was recorded for each shoulder muscle. The counts for how many times each method produced the highest nEMG value were added and compared using a Pearson Chi-Square test to test for independence between MVC methods and muscle pairs. A significance level of $p \leq 0.05$ was used to identify statistical significance of any effect.

2.2 Virtual Exertions Study

With the primarily used muscle pairs identified in the pilot study, the main goal to integrate muscle activity into a virtual environment could progress. Integrating multiple technologies in order to create a training environment for paramedics required the coordination of multiple computer systems and networks.

2.2.1 Technology

2.2.1.1 Equipment and Software

This experiment also took place in the North Carolina State University Ergonomics Lab. The Biodex dynamometer (System 4 MVP^{TM}, Biodex Medical Systems, Shirley, NY) was again used for creating isometric muscle contraction while measuring maximum voluntary contraction. Muscle activity was again tracked using Trigno EMG wireless sensors and Delsys EMGworks software. Muscle activity was relayed from Trigno Control Utility to the computer that rendered visuals of the virtual environment. Using Trigno Control Utility was necessary in order to create a connection between the EMG sensors and the Unity code used to control the virtual environment without using EMGworks software. Unity, a cross-platform game engine, was used for developing the virtual environment task (Unity Technologies, San Francisco, CA). The virtual scenarios were displayed in a 10 ft x 12 ft x 9 ft four-faced (C4) rear-projection cave automated virtual environment (CAVE) that consisted of one floor and three walls (see Figure 7).

2.2.1.2 Virtual Exertions

The virtual exertions muscle activity control algorithm was written in C# and programmed in Microsoft Visual Studio (Microsoft, Redmond, WA). First, the program was used to collect calibration data for each of the three actions within the patient lift for the three

designated patient weights by clicking the appropriate action button (shown in Figure 6 below) for the current weight to start and stop data collection for each motion.

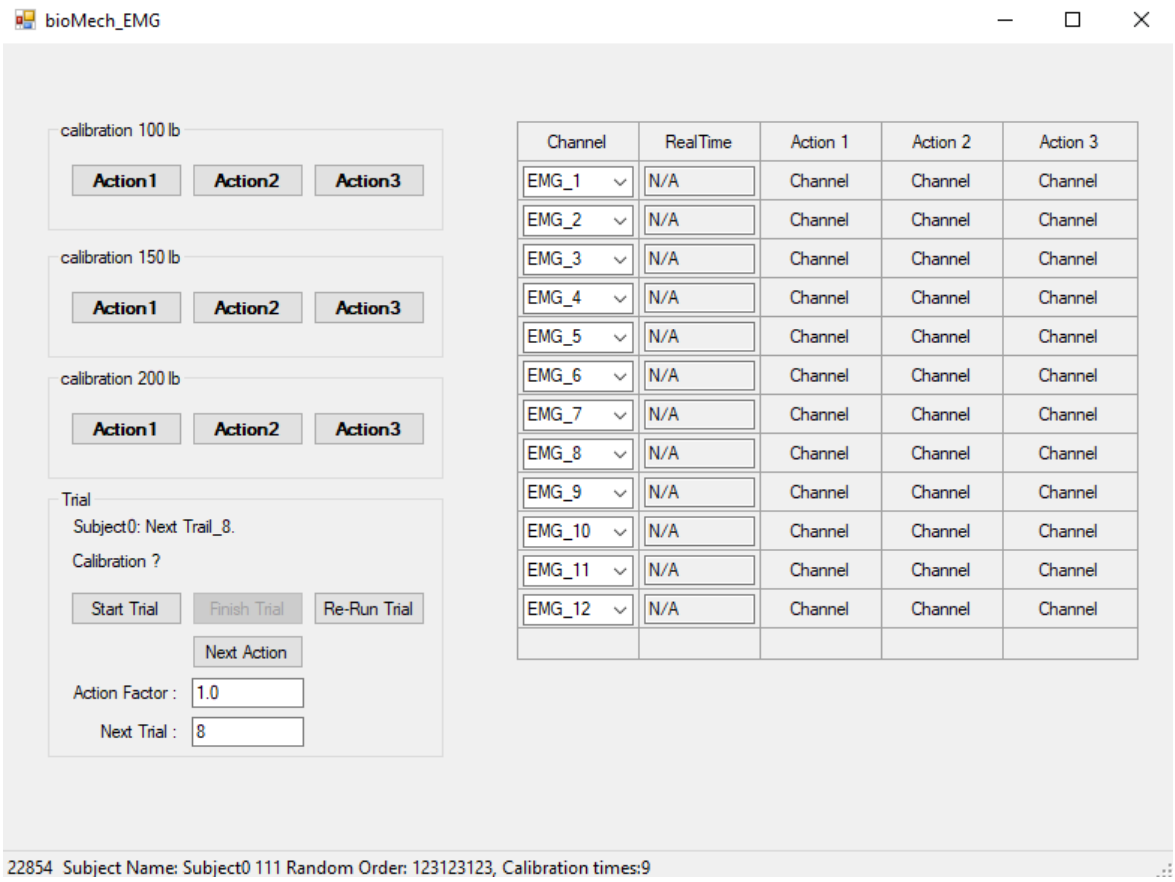

Figure 6 EMG calibration and virtual exertion interface

During data collection a moving root mean square (RMS) of real-time EMG with a window of 850 samples was calculated, and then the integrated RMS was sent to the VR workstations at 60 Hz. This integrated RMS was compared against the user-specific linear regression of each muscle RMS that was collected during calibration, which was the threshold value for moving the virtual object. The output from virtual exertions for each muscle was binary; 1 if the integrated RMS value was greater than or equal to the calibration RMS value, and 0 if the value was less than the calibration value. These twelve binary outputs (one for each muscle) were read by the Unity program active within the CAVE. If the string of binary numbers were all 1's, indicating that each muscle had reached the calibration threshold, then the Unity code would allow the

objects within the CAVE to be moved by the participant. The virtual exertions program also contained an action factor input. The action factor for the threshold could be changed if the thresholds were not being met. For example, if the action factor was changed to 0.5, the participant's EMG signal output would only need to be 50% of the calibration threshold in order for the virtual objects to be movable. This would allow the participants to be able to move the virtual objects even if they could not reach the full calibration values.

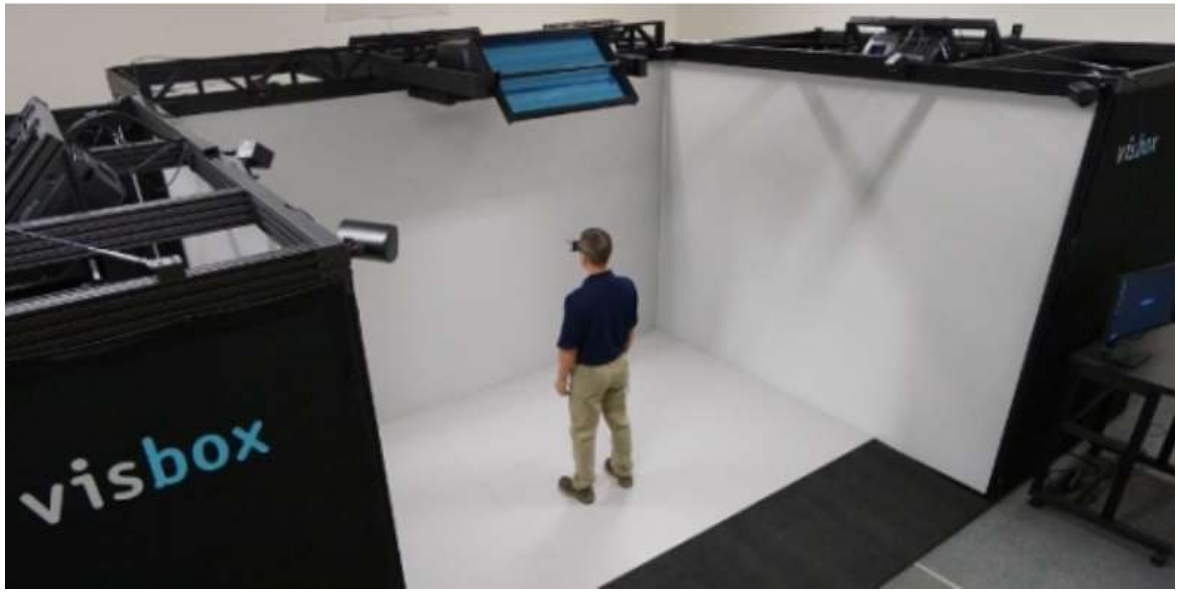

Figure 7 VisCube C4 (Vixbox, Inc., St. Joseph, IL)

One 3-D projector (VisCube C4™, Vixbox, Inc., St. Joseph, IL) with maximum brightness of 4,500 lumens per projector, with a total of 1,920 × 1,200 pixels each, projected images on each surface of the CAVE. Stereo glasses (Active Stereo, Vixbox, Inc., St. Joseph, IL) were worn to view images in stereoscopy (see Figure 8). Position data were acquired using a wireless ultrasound tracking system (TRACKPACK 4, A.R.T. Advanced Realtime Tracking, Weilheim i.OB, Germany), which included four position tracking cameras (TRACKPACK/E, A.R.T. Advanced Realtime Tracking, Weilheim i.OB, Germany) allow full 6-degrees-of-freedom position tracking. Position trackers were mounted on the top rim of the shutter glasses to create

images from the user's viewpoint (see Figure 8), and another tracker was attached to a wand controller (Figure 9) held in the dominant hand of the user to track the hand location. Motion of the hand was tracked and recorded, and the trackers were sampled at 120 Hz.

Figure 8 Stereo glasses with attached position trackers (Vixbox, Inc., St. Joseph, IL)

Figure 9 Wand controller (Vixbox, Inc., St. Joseph, IL)

2.2.2 Participants

Nine participants ages 18-32 (M = 23.4 , SD = 4.0) were recruited for the study, including 3 females and 4 males. In general, the samples represented a younger and active population, as all participants were recruited online or by flyers posted on North Carolina State University campus, predominantly consisting of undergraduate students. All participants had no

physical disabilities, no musculoskeletal injuries in the past 3 months, no history of epileptic seizure or blackout, no tendency for motion sickness, no sensitivity to flashing lights, no history of Lasik or similar eye surgery, and indicated they were willing to lift/move heavy objects at the time of experiment participation. Each participant was compensated at a rate of $10.00 per hour. The experiment lasted approximately 2-3 hours for each participant.

2.2.3 Task Description

Participants were first asked to complete the same three-part physical lift from the pilot study (explained in Section 2.1.7.4) with the researcher. These lifts served as calibration trials for the muscle activity thresholds used in the virtual exertions code. The three-part lift was completed in order (Action 1 first, then Action 2, then Action 3) three times for three different weights; 100 pounds (roughly the average weight of a 13-year-old), 150 pounds (roughly the average weight for a woman), and 200 pounds (roughly the average weight for a man). A one-minute rest was provided in between each full lift sequence per weight, with three minute rest periods between each weight.

Participants then completed virtual lifts within the CAVE. Each lift was the same three-part lift taught and executed during the physical lift portion of the experiment. Participants were instructed to exert their muscles in a way similar to the physical lifts and use the controller move the virtual patient. Through a virtual exertions program, the EMG signal output from each muscle was compared to the EMG signal output from the corresponding calibration trial. If the output was equal to or higher than the calibration output for each muscle, the object within the CAVE became movable. The action factor for the threshold could be changed if the thresholds were not being met. For example, if the action factor was changed to 0.5, the participant's EMG signal output would only need to be 50% of the calibration threshold in order for the virtual

objects to be movable. The action factor was roughly reduced by 0.1 for every failed attempt at the virtual lift. There were three different virtual patients; a child, a woman, and a man. These patients were designed to correspond to the calibration physical lift weights. The participant performed the lift on each patient three times, for a total of nine lifts. All lifts were completed within one experimental session.

2.2.4 Independent variables

The control variable for the physical lift was the weight of the backboard and the MVC method used. The control variables for the virtual lifts were the virtual patient displayed and the exertion threshold to be met. Each combination of virtual patient (child, woman, or man) and exertion threshold (100, 150, or 200 pounds) were completed once by each participant for a total of nine lifts.

2.2.5 Dependent variables

The response variables for both the physical and virtual lifts were the muscle exertion nEMG values (calculated using the same methods from Section 2.1.5), discomfort survey responses, and NASA-TLX survey (Hart, 1988) responses. The virtual lifts also had perceived exertion responses.

2.2.6 Experimental Design

A matched pairs design was used to compare MVC methods between isolated MVC methods and a full body simulated isometric lift method. Matched pairs design was also used to compare NASA TLX, rated work, and rated energy after the physical and virtual trials.

This virtual lift utilized a 9 x 9 Latin Square design balanced for first-order residual effects due to fatigue across trials (Williams, 1949). The nine conditions (rows) to be balanced across nine participants (columns) also had two distinguishing factors; weight threshold and

virtual patient image displayed. The weight threshold had three levels; 100, 150 and 200 pounds. The virtual patient image also had three levels; child, woman, and man. Each combination of the three levels of each of these factors was given a random number to be used in the Latin Square design (see Table 2).

Table 2 Randomization of combinations of virtual patient image and weight threshold for experiment trials

	100	**150**	**200**
Child	6	8	4
Woman	7	1	3
Man	2	5	9

The order and subjects were randomized and applied to the 9 x 9 Latin Square, according to Williams' (1949) experimental design. The resulting order of trials (reorganized) is shown below in Table 3).

Table 3 Order of virtual lift trials based on Latin Square design

S1	S2	S3	S4	S5	S6	S7	S8	S9
7	6	4	2	9	5	8	1	3
8	7	5	3	1	6	9	2	4
9	8	6	4	2	7	1	3	5
1	9	7	5	3	8	2	4	6
2	1	8	6	4	9	3	5	7
3	2	9	7	5	1	4	6	8
4	3	1	8	6	2	5	7	9
5	4	2	9	7	3	6	8	1
6	5	3	1	8	4	7	9	2

Legend	100 lb	150 lb	200 lb
Child			
Woman			
Man			

2.2.7 Procedures

Upon arrival at the Ergonomics Lab, the experiment provided a participant with a brief introduction to the study.

2.2.7.1 Questionnaire

At the beginning of the experiment, the participants were presented with an informed consent form (see Appendix F: Virtual Exertions Study Informed Consent Form). If they agreed to participate, they were asked to complete a brief demographic questionnaire (see Appendix B: Demographic Questionnaire). Information collected using the demographic questionnaire included self-reported information about age, gender, overall health status, and upper-limb health.

2.2.7.2 EMG Prep

From the pilot study, twelve muscles were identified to be evaluated for this experiment (see Table 4).

Table 4 Selected muscles from pilot study for use in virtual exertions study

Muscle	Original Muscle Group from Pilot Study
1. Right upper trapezius 2. Left upper trapezius	Shoulder
3. Right thoracic erector spinae 4. Left thoracic erector spinae 5. Right lumbar erector spinae 6. Left lumbar erector spinae	Lower Back
7. Right extensor carpi radialis 8. Left extensor carpi radialis 9. Right biceps brachium 10. Left biceps brachium 11. Right biceps femoris 12. Left biceps femoris	Extremities

Once the consent and questionnaires forms were completed, the experimenter placed the EMG sensors (12 per participant) on the predetermined muscles. EMG sensors are electrodes placed on the surface of the skin, and medical or athletic tape can be used to secure the electrodes in place if necessary. The electrodes for the chosen muscles were placed in identical locations to the pilot study locations (see Appendix C: Electrode Placements).

2.2.7.3 MVC

The MVC collection was done using the same protocol from the pilot study with two exceptions. First, the MVC for the upper trapezius muscles was changed to be a resisted shrug or elevation (Mathiassen, Winkel, and Hagg, 1995). In addition, a full body MVC trial was introduced. This MVC method used a counteractive lift device (Figure 10) to simulate an isometric lift identical to the patient lift performed in the experiment. This method was chosen based on a similar method useds for dynamic, task-specific EMG normalization by Albertus-Kajee (2010) and Rouffet and Hautier (2008).

Figure 10 Participant using counteractive lift MVC device

Each MVC was performed for three seconds, three times per muscle, with a one minute rest between each MVC. Participants were given the option to warm up by stretching their legs and arms (as if warming up before exercising) if desired.

2.2.7.4 Physical Lift

After MVC trials were completed for each muscle, the experimenter demonstrated the appropriate lifting methods for the patient transport lifts to be performed as suggested by the EMS1 Network (Milus, 2007). Proper lifting techniques include:

1. Position yourself as close as possible to the object you are intending to lift.
2. Feet placed apart to provide a stable base.
3. Feet as close to the body board as possible.
4. Tighten abdominal muscles and keep your back flat for the entirety of the lift.
5. Lift with your legs. Place body weight on heels and balls of your feet. Push up by tightening your hips, hamstrings, and gluts as you rise.

The participant then attempted the lifts while receiving feedback from the experimenter. The participant was reminded that he/she should immediately notify the experimenter and stop performing the lift if he/she feels any discomfort at any time of the study. In each trial, the participant lifted a weighted backboard (to simulate a stretcher with a patient) in three motions similar to the patient lift shown in Section 2.1.3. The task was to transport the weighted backboard from the ground laterally onto a "stretcher" (Action 1), lift the weighted backboard to standing height (Action 2), and then lift onto a higher surface similar to an ambulance loading height (Action 3). These motions are shown in Section 2.1.7.4 in Figure 5. For this experiment, three total weights, 100, 150, and 200 pounds, were used to reflect different patient weights. After the participant completed the practice trials, the patient transport task was performed by the participant three times per weight, with one minute breaks in between each trial per weight, and three minute rest periods between each weight. While these physical lifts were being performed, the EMG calibrations were being collected by a research assistant. These calibrations collected the root mean square of the signal outputs for all twelve muscles for each of the three actions involved in the lift. The interface is shown below in **Error! Reference source not found.**.

2.2.7.5 Post-Physical Lift Surveys

After the nine lifts, the participant was directed to have a seat and complete the discomfort survey (Appendix E: Body Discomfort Survey). The participant was then directed to complete the NASA-TLX survey (Figure 11, Appendix G: NASA TLX Survey and Analysis Worksheets) on the lab computer. The survey interface is shown below (Figure 11). After the surveys were completed, the participant was introduced to the CAVE.

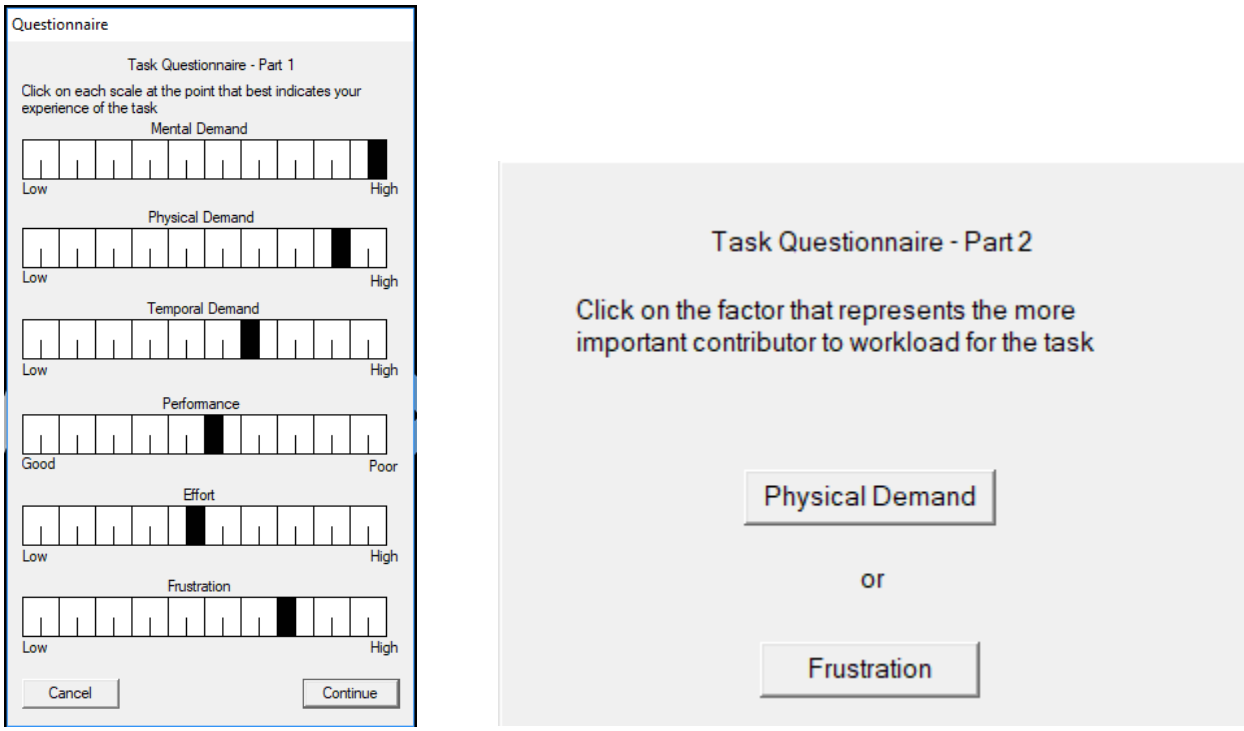

Figure 11 NASA TLX survey user interface

2.2.7.6 Virtual Environment

The participant was first introduced to the CAVE structure, which is a 10ft×12ft×9ft space with large screens that serve as the projection surface of 3D images. Participants wore 3D glasses in order to see the 3D images (Figure 8). The virtual scene, shown below (Figure 12), illustrated a cityscape with a patient on a backboard in the road next to an ambulance. This scene

was meant to depict a typical scenario where an EMT may be required to perform a patient transport task.

Figure 12 Virtual scene for virtual lifts

The participant was instructed on how to use the wand controller (shown in Figure 9), which can be used to move the backboard with the patient, as well as the stretcher. The participant was then given a chance to practice using the controller and become comfortable within the CAVE. Once the participant confirmed they were ready to begin virtual lifts, the virtual exertions code was made active and the scene was reset.

2.2.7.7 Virtual Lift

The participant was instructed to position his/herself in front of the backboard, and attempt to perform the patient lift the same way they did for the physical lifts (see Figure 13). The virtual lift also included three actions; transporting the patient on the backboard laterally onto a stretcher (Action 1), lifting the stretcher to standing height (Action 2), then lifting the stretcher higher to ambulance loading height (Action 3).

Figure 13 Participant performing virtual lift in CAVE

With the virtual exertions code active, the virtual patient would not move unless the participant's muscles were activated to the appropriate threshold. The experimenter was able to adjust the thresholds if the participant was having trouble reaching the appropriate muscle exertion, using the Action Factor. The experimenter also gave the participant verbal feedback on which muscles were not reaching the thresholds, and therefore preventing the virtual patient from moving. The thresholds corresponded to the analogous actions from the physical lift calibrations and was changed based on which action was being completed in the virtual environment.

The participant completed the three-part lift sequence a total of nine times. Each patient, the child, woman, or man (shown below in Figure 14), was shown three times. Each threshold calibration, 100, 150, or 200 pounds, was used three times. The combination of patients and thresholds is described further in Section 2.2.6. After each trial, the participant was asked to rate their level of effort and their level of discomfort from 1 to 10. After answering both questions,

the scene was reset to the next randomly assigned combination of patient and threshold. The participants were unaware of what weight threshold they were required to meet in the trial.

Figure 14 Virtual patient images for child (left), woman (middle), and man (right)

2.2.7.8 Post-Virtual Lift Surveys

After the nine lifts, the participant was directed to have a seat and complete another discomfort survey (Appendix E: Body Discomfort Survey) based on the virtual lifts. The participant also completed another the NASA-TLX survey (Appendix G: NASA TLX Survey and Analysis Worksheets) on the lab computer based on the virtual lifts. After the surveys were completed, the EMG sensors were removed and the study was complete. The entire length of the study took around 2-3 hours per participant.

2.2.8 Statistical Data Analyses

All nine subjects collected were available for data analysis. Due to the experimental design, the calibration trials were not filtered or altered for any outliers that occurred in the physical tasks. Therefore, any outliers would have been included in the Trigno data input into the virtual environment. For this reason, no outliers were removed prior to data analysis. During analysis, there were no concerning values from the nEMG data.

2.2.8.1 MVC Methods and Survey Responses

First, a matched pairs comparison was used to test the differences among the maximum nEMG for each muscle between different MVC methods. A significance level of $p \leq 0.05$ was

used to identify statistical significance of any effect. Next, a matched pair comparison was utilized to compare the NASA TLX survey factor responses (value, weight, and rank respectively) and the body discomfort survey responses (rated work and rated energy) after the physical lifts and the same responses after the virtual lifts. A significance level of $p \leq 0.05$ was used to identify statistical significance of any effect in all matched pair analyses.

2.2.8.2 Virtual Exertions Analyses

As mentioned in Section 2.2.6, a Latin Square design balanced for first-order residual effects due to fatigue across trials was used. This statistical model was used to compare the fixed effects of weight and image as well as a weight and image interaction effect on maximum nEMG per muscle, perceived effort, and perceived discomfort across all subjects within the virtual tasks. The statistical model was

$$y_{ijk} = \mu + \sigma_i + \tau_j + \alpha_k + \epsilon_{ijk}$$

where μ = overall mean, $\sigma = subject\ (i = 1, \ldots, 9)$,, τ = trail effect (j = 1, …, 9), α = treatment effect (k = 1,…,9), and ϵ_{ijk} is the random error. The treatment includes image effect, weight threshold effect, and the image and weight interaction effect.

In order to compare maximum nEMG values between the physical and virtual tasks, a fixed effects model was used. The statistical model was

$$y_{ijk} = \mu + \sigma_i + \tau_j + \alpha_k + \epsilon_{ijk}$$

where $\mu = overall\ mean,\ \sigma = subject\ (i = 1, \ldots, 9),\ \tau = trial\ (j = 1,2),$ $\alpha = weight\ (k = 1,2,3)$, and $\epsilon = random\ error$. For this model, trial is either the physical lift (1) or the virtual lift (2). A matched pair comparison was also used to determine any differences between the physical lifts and the virtual lifts in the order they were completed. Specifically, the

physical lift for each weight was matched with the first, second, and third virtual trial the subject faced with that corresponding weight threshold.

3. RESULTS

3.1 Pilot Study

Table 5 presents the descriptive statistics for each muscle pair (bilateral) measured across all trials for each subject in descending order. Muscle abbreviations are defined in Table 1. The descriptive statistics for each muscle measured across all trials for each subject can be found in Appendix I: Descriptive Statistics for Muscle nEMG.

Table 5 Ordered descriptive statistics for bilateral muscle pairs

Muscle Pair	Mean nEMG	Std Error
VL	116.41	8.24
UT	102.90	7.93
TES	99.18	7.65
LES	94.67	7.79
EC	89.25	10.64
BI	76.80	7.93
MD	70.55	7.53
FC	69.95	8.79
BF	67.10	8.41
LT	65.81	7.53
PD	65.51	7.53
MT	65.34	7.79
LD	64.34	7.79
IO	57.64	8.41
TRI	55.84	7.65
HAM	51.08	7.53
EO	40.98	7.53
AD	37.52	7.53
RA	21.50	7.53

The difference between muscle pairs was found to be highly significant ($F(18.497) = 9.1468$, $p < 0.0001$). Table 6 shows the results and differences when comparing means using the post-hoc Tukey-Kramer HSD test. Muscle pairs not connected by the same letter at significantly different ($\alpha = 0.05$). For visual interpretation, a graph of mean nEMG values across muscle pairs is presented in Figure 15.

Table 6 Connecting letters report for all pairs using Tukey-Kramer HSD test

Muscle Pair								Mean nEMG
VL	A							116.41
UT	A	B						102.90
TES	A	B						99.18
LES	A	B	C					94.66
EC	A	B	C	D				89.25
BI	A	B	C	D	E			76.80
MD		B	C	D	E	F		70.55
FC		B	C	D	E	F		69.95
BF		B	C	D	E	F		67.10
LT		B	C	D	E	F		65.80
PD		B	C	D	E	F		65.51
MT		B	C	D	E	F		65.34
LD		B	C	D	E	F		64.34
IO			C	D	E	F	G	57.64
TRI				D	E	F	G	55.84
HAM				D	E	F	G	51.08
EO					E	F	G	40.98
AD						F	G	37.52
RA							G	21.50

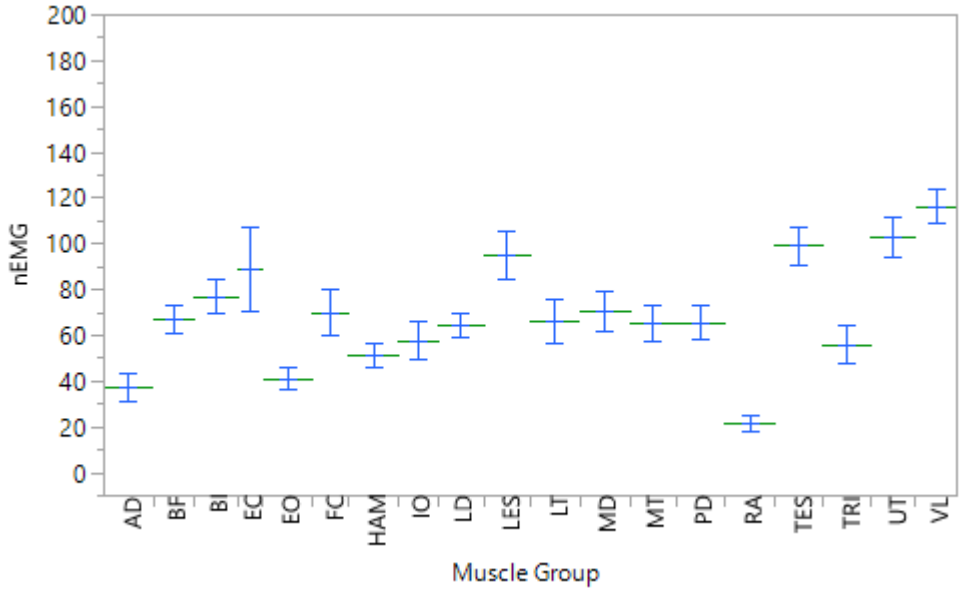

Figure 15 Mean nEMG values with ±1 SE bars per muscle pair

Table 7 shows the how many times each MVC trial (adduction, abduction, flexion, extension, or external rotation) resulted in the highest muscle signal for each bilateral shoulder muscle pair. No internal rotation MVC trials resulted in the highest muscle signal for any of the six muscle pairs.

Table 7 Counts for maximum muscle signal per MVC trial for each shoulder muscle pair

	Adduction	Abduction	Flexion	Extension	External Rotation
AD	2	1	6	0	1
MD	5	3	1	0	1
PD	3	1	2	1	3
UT	1	3	4	0	2
MT	4	0	1	1	4
LT	4	1	2	0	3

Using the Pearson Chi-Square test for analysis, the effect of MVC trial per shoulder muscle pair on maximum muscle exertion ($\chi^2 = 22.814$, $p = 0.2980$) was not found to be significant. This was specifically testing for independence between the MVC method used and each muscle pair.

3.2 Virtual Exertions Study

3.2.1 MVC Methods

The mean difference between isolated MVC methods and the full body simulated isometric lift method was not found to be significant ($p = 0.25$),. Table 8 shows how many times out of the nine participants that each muscle had a higher task MVC value than isolated MVC value. In total, the task MVC value was higher 31% of the time.

Table 8 Count of number of task specific MVC trials with greater values than matched isolated MVC trial

Muscle	Count of Task MVC Trial > Isolated MVC Trial
RTES	3
LTES	1
RLES	2
LLES	3
RUT	3
LUT	3
RBI	1
LBI	2
RECR	4
LECR	5
RVL	4
LVL	3
Total Task MVC > Isolated MVC	34
Total MVC Trials	108
% Task MVC > Isolated MVC	0.31

3.2.2. Survey Responses

Figure 16 and Figure 17 show the descriptive statistics for the matched pair comparison between the NASA TLX survey factor responses (value, weight, and rank respectively) after the physical lifts and the same responses after the virtual lifts. Significant mean differences ($p < 0.05$) are highlighted with an asterisks.

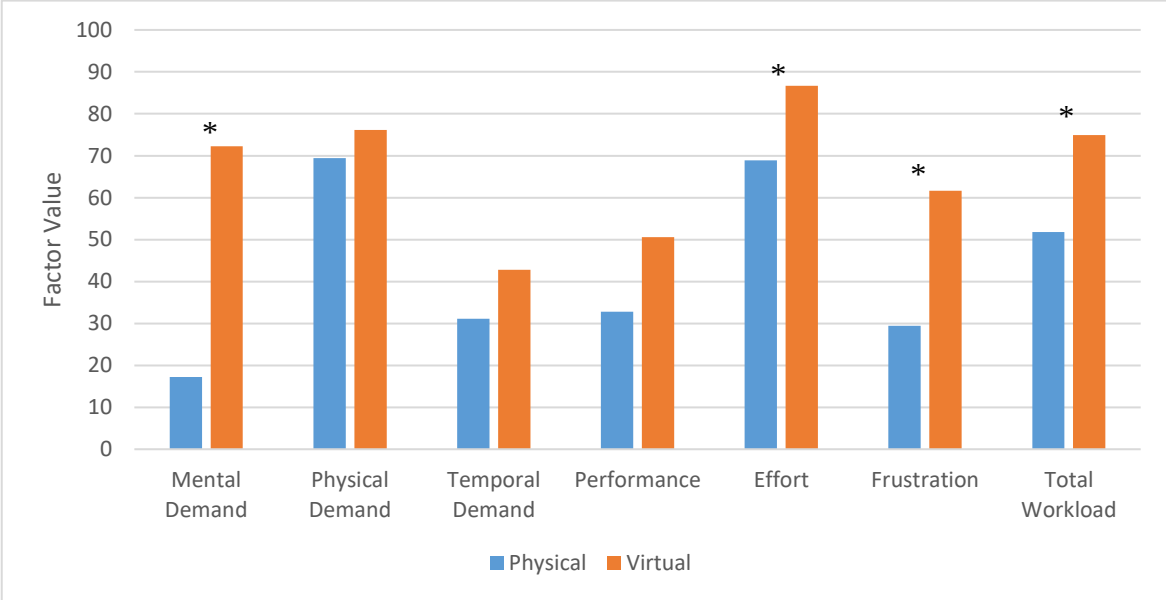

Figure 16 Descriptive statistics for matched pair comparison between the value of each factor after the physical and virtual lifts. * signifies statistical significance ($p < 0.05$)

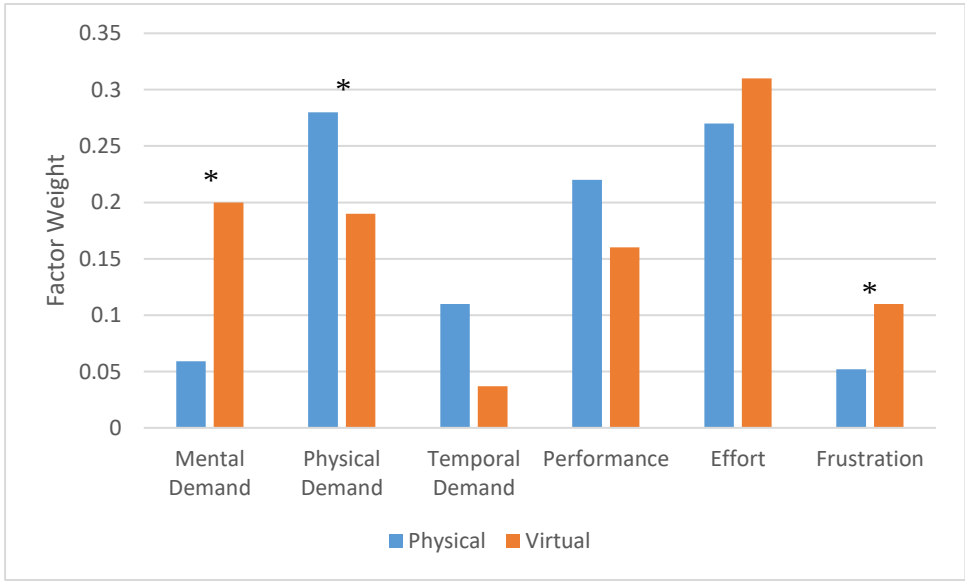

Figure 17 Descriptive statistics for matched pair comparison between the weight of each factor after the physical and virtual lifts. * signifies statistical significance ($p < 0.05$)

Table 9 shows the average factor rankings for physical and virtual lifts across all subjects.

Table 9 NASA TLX factor ranks for physical and virtual lifts

	Physical Lifts	*Virtual Lifts*
1	Physical Demand	Effort
2	Effort	Mental Demand
3	Performance	Physical Demand
4	Temporal Demand	Performance
5	Mental Demand	Frustration
6	Frustration	Temporal Demand

The rankings are ordered from most contributing to workload (1, highest weight) to least contributing (6, lowest weight). The red arrows show changes in rank (weight) that were statistically significant ($p < 0.05$). See Appendix H: NASA TLX Results for values, mean differences, and significance values for all factors.

For the matched pair comparison between the body discomfort survey factor responses after the physical lifts and the same responses after the virtual lifts, the energy left after the lift was found to be significantly lower after the virtual lift ($p = 0.0302$), while the difficulty of work was not found to be significantly different ($p = 0.93$).

The Latin Square Design tested the effect of subject, trial, image, weight, and image-weight interaction on output values. For the output values of perceived effort and perceived discomfort, none of these fixed effects had a significant effect on the output except the subject effect at a 0.05 significance level. The p-values for each effect and output are shown below in Table 10. Significant mean differences ($p < 0.05$) are highlighted in green.

Table 10 Significance values for fixed effects in statistical model for perceived exertion and discomfort

Effect	Perceived Exertion p-value	Perceived Discomfort p-value
Subject	0.0314	<0.0001
Trial	0.8714	0.5591
Image	0.0684	0.4658
Weight	0.7236	0.2428
Image - Weight	0.5681	0.8323

3.2.3. Maximum nEMG

None of the fixed effects in the Latin Square design had a significant effect on maximum nEMG for any muscle except the right extensor carpi radialis (RECR) at a 0.05 significance level. For the RECR, weight ($p = 0.0125$), image-weight interaction ($p = 0.0499$) and trial ($p = 0.0193$) all had a significant effect on the nEMG value. See Appendix J: Descriptive Statistics for Latin Square Design for significance values for all subjects.

A fixed effect model was also used to compare maximum nEMG values between the physical and virtual tasks. Table 11 shows the significance values for each effect on the output for each muscle. Significant mean differences ($p < 0.05$) are highlighted in green.

Table 11 Significance values for subject, trial, and weight fixed effects on maximum nEMG values per muscle

	RTES	LTES	RLES	LLES	RUT	LUT	RBI	LBI	RECR	LECR	RVL	LVL
Subject	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0001	<.0001
Trial	0.0004	<.0001	0.0008	0.2828	<.0001	0.0093	<.0001	0.6115	<.0001	0.0021	<.0001	0.3966
Weight	0.7041	0.3111	0.9966	0.3492	0.152	0.3474	0.0138	0.2732	0.0314	0.9374	0.6144	0.564

The matched pair differences between the calibration nEMG values and virtual trial nEMG values by weight can be found in Appendix L: Mean Differences of Maximum nEMG Values in Physical vs. Virtual Lifts.

4. DISCUSSION

There is an urgent need to reduce injury risk in the EMT workforce. Developing a more appropriate training platform may better prepare current and future EMTs for the physically demanding tasks necessary for the job. This study investigated the possibility of implementing virtual exertions in a virtual reality environment to create a better training environment for EMTs. This was completed by first assessing the muscular implications of relevant EMT patient lifting tasks, then incorporating the muscles with the highest values during that task into the proposed virtual environment.

Returning to the hypotheses of the study, the patient handling tasks were expected to use muscles from each of the three investigated regions of the body (H1). The pilot study identified 38 muscles in various regions of the body that have been previously studied during lifting tasks. After evaluating the results, this study supported H1, as the muscles with highest nEMG values were from each of the three designated muscle groups; shoulder, lower back, and extremities. The upper trapezius had a high value because shrugging is necessary in the patient lift, as was elbow flexion (performed by the biceps) and strong grip (extensor carpi radialis). The erector spinae muscle, the muscles in the back, also had high nEMG values which was expected since back muscles are commonly known to be exerted during most lifting tasks. Lastly, the vastus lateralis had a high value as a quadricep muscle used in knee extension while incorporating the leg to lift heavy loads. This indicates that while concentrated studies focusing on specific muscle groups can be appropriate when studying those specific muscles, the whole body needs to be considering when muscles for whole body specific tasks are being utilized. The existing literature currently focuses on specific muscle groups, in particular lower back and shoulder musculoskeletal disorders. These findings suggest that incorporating muscles from a variety of

muscle groups could allow researchers to understand more fully the musculoskeletal implications of potentially dangerous occupational tasks.

In order to investigate the best MVC method for normalizing EMG data from EMT lifts, the muscle activity values between the various shoulder movements were compared during the pilot study. These movements included six different motions; flexion, extension, abduction, adduction, internal rotation, and external rotation. The MVC EMG values between the different shoulder motions did not differ significantly, as expected (H2). During the virtual exertions study, a full-body task related MVC method was completed and compared to isolated, isometric MVC values. Once again, the MVC values between the two methods did not differ significantly. This contradicts a similar study done using the torque-velocity test and PPO method for cycling (Rouffet and Hautier, 2008; Albertus-Kajee, 2010), which showed that a task specific MVC task had a higher EMG amplitude than the isometric isolated MVC trials. However, these cycling studies only investigated muscles in one body region. This present study showed that the task MVC was higher for some muscles 31% of the time, suggesting that the task MVC was not universally higher because of the wide scope of muscles being investigated.

The full body EMG and complex EMT patient handling task utilizing virtual exertions was successfully incorporated into a CAVE (H3). Due to the novelty of virtual exertions research, the outcomes could only be compared to the single other study conducted using virtual exertions. The dependent variables were not identical, so direct comparison was not possible. Between the physical and virtual tasks, perceived workload (H4) had several significant differences. Perceived workload values were collected using the NASA TLX survey, which record values for six different factors potentially contributing to the participant's workload. Total workload, mental demand, effort, and frustration values were all significantly higher

following the virtual lifts than those reported following the physical lifts. These findings are concerning for a training task, because it is likely that the task will be much more challenging in a real world setting. However, it is possible that the virtual task was dissimilar enough to cause some frustration and increased necessary effort and mental demand in order to navigate the differences between a physical environment and a novel virtual environment. With more time to familiarize themselves with the CAVE, participants may have become more comfortable within the virtual environment. It is also possible that these factors were higher due to the novelty of virtual exertions. Exerting muscles without physical feedback and gravity or a counterweight may have been what caused the increase in mental demand, frustration, and effort. In particular, muscles that many people do not normally think to consciously flex (i.e. back muscles or shoulder muscles) were difficult for participants to isolate without a counterweight. In addition, the code used to measure the signal output against the calibration values only used one value for each of the three actions involved in the lift. The lifts were very dynamic, and the signals were not consistent throughout the whole motion due to the muscles going through a lot of motion and change in position. If the signals went below the threshold at any point in the task, the virtual patient would freeze in midair and the participant would have to reengage their muscles in order to finish that particular action. This often led to some visible frustration and was an added complexity of the task that could potentially be eliminated by fine tuning the virtual exertions code.

Muscle activity was compared between the physical lifts done for calibration and the virtual lifts completed within the CAVE. There were several significant differences between the muscle activities required to complete the tasks (H5). Specifically, the nEMG maximum values were significantly higher during the physical lifts for 9 of the 12 investigated muscles. When

looking at the nEMG differences between physical and virtual lifts when broken up by weight, there were more significantly different values as the weights were increased. This suggests that participants had trouble reaching muscle signals that were required to lift heavier weights. This is likely due to much of what made the task difficult. Isolating specific muscles without counterweight could be very difficult, especially as the counterweights increased in the physical lift. Participants were always unable to reach the full calibration signal for all twelve muscles in the virtual environment, no matter which threshold the program was referencing.

In order to investigate the effect of patient image and weight threshold, a Latin Square design was used. For the virtual tasks, perceived effort (H6, H7), perceived discomfort (H8, H9), and muscle activity (H10, H11) did not differ (except for RECR) based on the virtual patient appearance nor the required weight threshold. This was unexpected, as it was thought that participants would either recognize the difference in weight threshold or would change their behavior or response based on the patient they saw. If this were the case, there would be significant differences for either the image or weight effect. Neither of these outcomes were true. The RECR muscle activity was higher for the higher weight thresholds. This particular muscle was likely significant because the right hand was the hand the participant held the wand in during the virtual tasks. It is probable that as the participant exerted force to move subjects with heavier weight thresholds that may have taken longer, they began to squeeze the wand tighter. Having a physical object to hold likely affected how that particular muscle behaved different. Other than this muscle, no other muscle had significant differences for any of the fixed effects except between subjects. One explanation is that the participants were so focused on the task at hand and finding success (through the objects moving), that they did not note the appearance of the patient nor the difference in muscle activity they were exerting. Another explanation is that

the trials were truly not different for them because of image nor weight. One participant noted that they felt they were either exerting as much force as possible or not exerting force at all. With the goal of successfully moving the patient, the participants may not have adjusted their muscle exertion based on feedback or appearance, but merely tried their hardest for success each time. This may have been even more relevant due to the fact that no participant reached the calibration threshold for all muscles in any of the virtual lifts.

5. LIMITATIONS

Several limitations to this study must be addressed. The weight of the backboard in the pilot study was only 130 pounds, while the weight of typical transported patient may be much higher. A heavier patient may require a different proportion of muscle exertion for the patient transporter. The pilot study experiment was done under laboratory conditions, not in an actual emergency medicine setting. Various transfer techniques may be required in occupational settings. Electromyography poses many inherent limitations in data collection and analysis. Many nEMG values were above 100%, which should not be possible if the MVC trials truly collect the maximum contraction that each muscle can produce. This suggests that more focused studies could be done to determine best practices for full body normalization for functional tasks that collect a more accurate MVC value or provide a better way to normalize EMG data.

Issues within virtual reality are still being realized as the technology advances. The CAVE allows more movement freedom to the participant, but does not block out all external stimuli. With the overall novelty of virtual exertions, there are still many areas for improvement when implementing this technique. If the subject's muscles fell below the threshold, the virtual patient would stop mid-motion. This is perceptibly not equivalent to a real world setting, and so

may contribute to the subjects' virtual environment experience. In addition, many of the subjects noted that they felt the postures they were assuming in order to reach the exertion thresholds in the virtual settings were unnatural and did not reflect their postures when completing the physical tasks. For example, in Figure 18 you can see the participant squatting and twisting in an unnatural way in order to move the virtual patient. Awkward postures are commonly associated with WMSDs (da Costa and Vieira, 2009), so this is a concern for experimental design.

Figure 18 Participant assumes awkward position in order to meet muscle exertion thresholds

6. CONCLUSIONS

This study created a virtual environment that incorporated muscle exertion feedback in order to train EMTs on patient lifting tasks. Several MVC trials were conducted to determine the best practice for collected maximum values. For this study, isolated isometric MVC trials yielded the highest, and therefore best, values to be used for normalization. The pilot study identified six muscle pairs most used during a typical EMT patient handling task, and these

muscles were incorporated as physical feedback to the virtual environment. A virtual environment was created where a subject could use muscle exertion to lift three different virtual patients in a manner similar to a typical EMT patient transfer. Muscle activity, perceived workload, effort, and discomfort, and workload were all assessed based on the virtual task being performed.

On the basis of the findings of this study, no muscle activity nor perception were significantly affected by either the appearance of the virtual patient nor the muscle threshold required to achieve the lifting task. Participants reported a much higher value for mental demand, effort, frustration, and total workload for the virtual task.

The complexity of this task should not be ignored. This task involved twelve muscles and three different physical actions. Participants often had trouble engaging their muscles without a physical object to counteract their motion. It was difficult for participants to isolate specific muscles that were not meeting the threshold. In addition, many muscle exertions never met the same thresholds in the virtual environment as they did in the physical environment. This was especially true as the weight of the virtual patient increased.

For future virtual exertion studies, it may prove useful to identify muscles that participants are more easily able to manipulate on a scale instead of all or none in terms of muscle force and exertion. It may also be useful to incorporate muscles that should be used, rather than only muscles that are currently being used. For example, if injury could be avoided by activating core muscles, but participants do not currently activate their core muscles, an important lifting muscle would not be integrated into the virtual exertions program using the same methods used in this study. The process by which muscles are selected should be further investigated for each task being studied.

Due to the complexity of the task and the specific muscles associated with the relevant lifts, the study shows that virtual exertions may not be the most suitable interface for EMT patient transport training. Virtual exertions are likely more appropriate in simple tasks using lighter weights. Appropriate tasks may include occupational tasks in assembly fields or lifting tasks for objects with lower weights. Altering the virtual exertions program to be less strict about the number of muscles that need to hit the threshold, choosing muscles that are easier to isolate, and performing less complex and dynamic tasks may all help to improve the experience of the virtual exertions user. Virtual exertions is still a very young technology, and further research is needed to implement and improve virtual environments that will allow virtual exertions to be utilized effectively and appropriately.

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APPENDICES

Appendix A: Pilot Study Informed Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study: Full Board Investigation of Muscle Activity during Patient Transfer Tasks
Principal Investigator: Rebecca Ellis
Faculty Sponsor (if applicable): Dr. Karen Chen

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of the primary muscle groups used and postural changes experienced during patient transfer tasks.

The study uses electromyography (EMG) to measure muscle activity. EMG is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). Motor neurons transmit electrical signals that cause muscles to contract. An EMG system translates these signals into graphs, sounds or numerical values that a specialist interprets.

You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those who participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above or the NC State IRB office as noted below.

What is the purpose of this study?
The purpose of this research study is to determine the primary muscle groups used and postural changes experienced during patient transfer tasks.

Am I eligible to be a participant in this study?
In order to be a participant in this study, you must be between the ages of 18 and 55 and be willing to lift/move heavy objects. You cannot participate in this study if you have a physical disability or have had a musculoskeletal injury in the past three months.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to:

1. Complete a demographic questionnaire requesting information about your age, gender, overall health status, and upper-limb health.
2. Provide body measurements such as weight, arm length, height, etc.
3. Have up to 16 electromyography electrodes (muscle activity sensor) attached to your muscles (attachments can be located anywhere on the arm, upper back, or front torso) at a time. The electrodes will be secured using medical or athletic tape. Your arm might have to be shaved if you have hair where the electrodes need to be placed.
4. Have 18 motion tracking markers placed on bony landmarks on your body (including arm, leg, head, and trunk areas), which will be tracked by motion capture cameras. Markers will be attached using double-sided adhesive tape.
5. Complete a brief training for the experiment task to be completed. The training entails learning the proper patient transfer techniques used in the field by emergency medicine professionals, which is described in Step 7.
6. You will be asked to exert at your maximum level of muscle exertion for a short period of time for various muscle groups; including legs, arms, back, and shoulder in order to determine the maximum

voluntary contraction of these muscles. For example, the experimenter will apply an opposing force to your arm and you will exert force to counter it. This technique is repeated for the various muscle groups. The maximum voluntary contraction is used to normalize the electromyography data and it is a common approach to compare data across different individuals.
7. Perform a physical task procedure; specifically, a patient transfer task. In each trial, you will lower your body and grab the handle of a load that has a comparable size and shape to a person on a backboard on the ground, transfer the load onto a stretcher, and then stand up to load the stretcher onto a higher surface similar to an ambulance loading height. Each trial will take about 30 seconds, with a one-minute break between each of the trials. Each set of three trials will therefore take around 3-5 minutes.
8. An experimenter will also be present for questions. You will be given frequent breaks during task performance. Water will be provided.

Risks and Benefits

This experiment involves bending and lifting exercises. You will be properly trained on exercise technique before you are asked to perform these exercises. There is a chance of temporary muscular fatigue from determining maximum voluntary contraction and from the lifting tasks, which may be similar to those following a workout. However, you will receive a period of rest after each trial to allow your muscles to recuperate. In addition, you will be monitored throughout the experiment. The likelihood of any injury or excess pain from this experiment is slim. If you are experiencing pain, please let an experimenter know and we will stop the experiment. You will be compensated for your time regardless. Electromyography is considered non-invasive, and it poses minimal risk. There may be some discomfort or skin irritation where the electrodes are attached to the skin because of the tape. All sites of attachment will cleaned following the experiment.

There is no direct benefit to you as a result of participation in this experiment. You may gain some insight into how ergonomics research is conducted on biomechanical systems and using electromyography. The results of the study are expected to support the development of knowledge on the primary muscle groups associated with patient transfer tasks in emergency medicine. In addition, design recommendations will be developed in order to incorporate muscle exertions and postural changes into virtual reality training simulations.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. All data are collected using a password-protected desktop computer in a locked laboratory space. No data will be stored on laptops. All our data are de-identified. Upon the completion of data collection, we will be transferring data over to an encrypted server maintained by our department's full-time IT Director, Justin Lancaster. No reference will be made in oral or written reports that could link you to the study. All payment information will be immediately submitted to the accounting staff in the Industrial and Systems Engineering Department for record purposes, and they will be locked in the office of the department accountant.

Compensation
For participating in this study you will receive $10 per hour. If you withdraw from the study prior to its completion, you will be paid at a rate prorated for the amount of time present. For example; if you participate for 1.5 hours, you will receive $15.

Emergency Medical Treatment
If you are hurt or injured during the study session(s), the researcher will contact the University’s emergency medical services at 515-3333 for necessary care. There is no provision for free medical care for you if you are injured as a result of this study.

What if you are a NCSU student?
Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you are a NCSU employee?
Participation in this study is not a requirement of your employment at NCSU, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher, Rebecca Ellis, at rellis6@ncsu.edu or (919) 515-7210.

What if you have questions about your rights as a research participant?
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB Office via email at irb-director@ncsu.edu or via phone at 1.919.515.4514. You can also find out more information about research, why you would or would not want to be in research, questions to ask as a research participant, and more information about your rights by going to this website: http://go.ncsu.edu/research-participant

Consent To Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Participant's signature_____ **Date** _____

Investigator's signature_____**Date**_____

Appendix B: Demographic Questionnaire

General Health Status Questionnaire

1. Subject ID: _____
2. Ethnic background: (circle one)
    a. American Indian or Alaskan Native
    b. Asian
    c. Native Hawaiian or Other Pacific Islander
    d. Black or African American, not of Hispanic origin
    e. Hispanic
    f. White, not of Hispanic origin
    g. Other
3. Gender:
    a. Female
    b. Male
4. Age: _____ years old
5. Height: _____ in/cm
6. Weight: _____ [lb, kg]
7. Dominant hand
    a. Right
    b. Left
8. Have you ever had an injury to your hand, arm, shoulder, neck, back, or leg?
    a. Yes
    b. No

    If yes, please explain_____

    _____

    Is this still a problem now?_____

    _____

9. Have you ever had injuries that would limit your ability to exercise your neck, shoulder, back, arms, or legs?
    a. Yes
    b. No

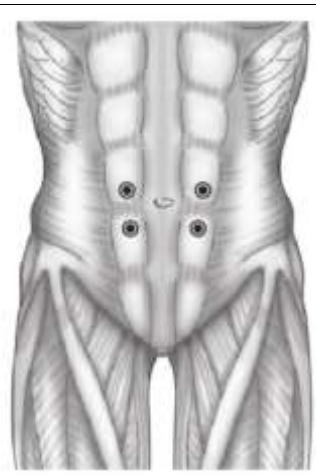
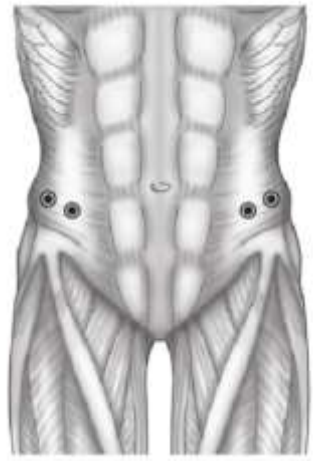
    If yes, please explain_____

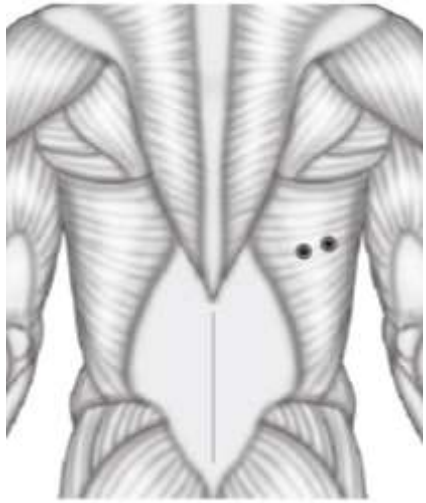
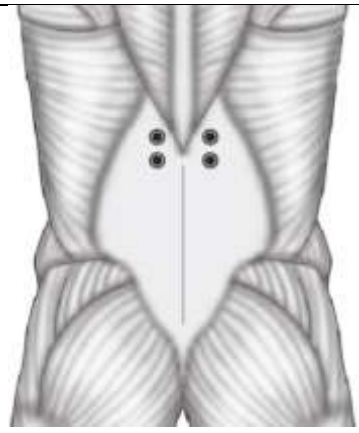
    _____

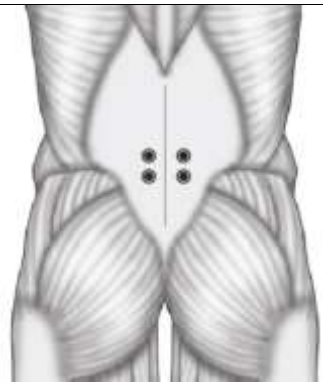
    Is this still a problem now?_____

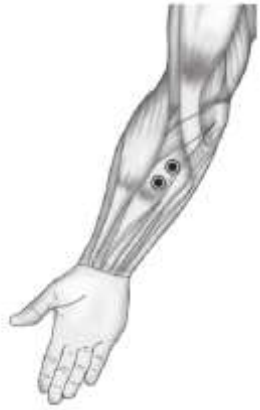
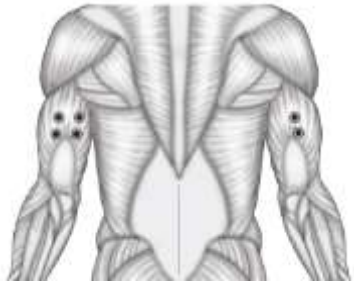
    _____

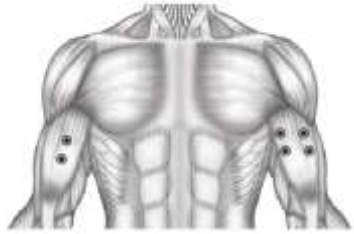
Appendix C: Electrode Placements

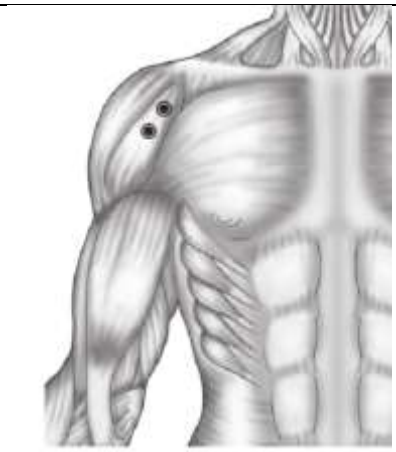
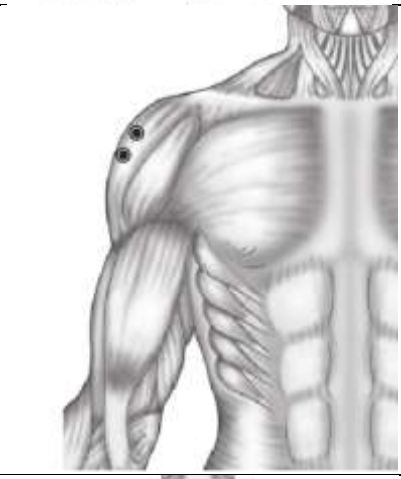
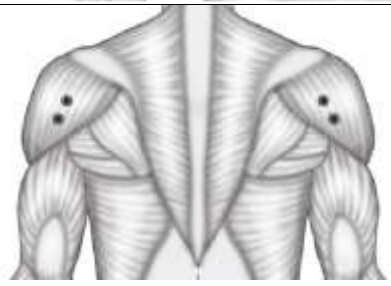
Muscle	# of Electrodes	Muscle Group	Specific Location	Image	Behavioral Test
1. Rectus Abdominus	2	Lower Back	Palpate the abdominal wall in the area close to the umbilicus. Locate the muscle mass. A thick pad of adipose tissue may be a problem. The electrodes are placed 3 cm apart and parallel to the muscle fibers of the rectus so that they are located approximately 2 cm lateral and across from the umbilicus over the muscle belly. (Cram's) 3 cm lateral to umbilicus (Marris)		From the supine posture, have the patient do a curl-up. If standing, have the patient tighten the abdomen (suck it in) or do the pelvic tilt.
2. External Oblique	2	Lower Back	Palpate iliac crest and locate the anterior superior iliac spine. Two active electrodes are placed 2 cm apart, lateral to the rectus abdominis and directly above the ASIS, between the crest and the ribs at a slightly oblique angle so that they run parallel to the muscle fibers. (Cram's)		Rotation of the torso, diagonal sit-up.

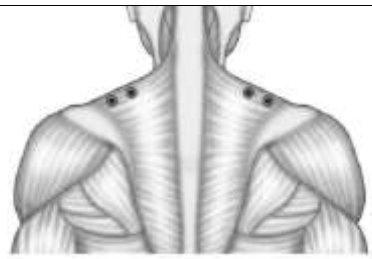
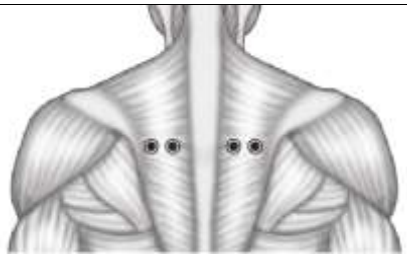
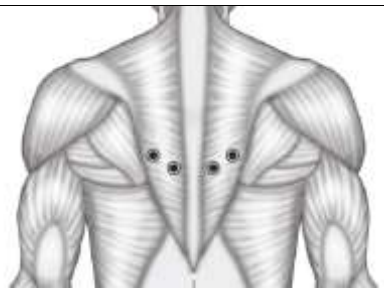
			Approximately 15 cm lateral to the umbilicus (Marris).		
3. Internal Oblique		Lower Back	Approximately midway between the anterior superior iliac spine and symphysis pubis, above the inguinal ligament (Marris)		
4. Latissimus Dorsi	2	Lower Back	Palpate the scapula. Two active electrodes are placed (2 cm apart) approximately 4 cm below the inferior tip of the scapula, half the distance between the spine and lateral edge of the torso. They are oriented in a slightly oblique angle of approximately 25 degrees. (Cram's) Lateral to Tg over the muscle belly (Marris)		Extend, adduct, or medially rotate the arm.
5. Thoracic Erector Spinae	2	Lower Back	To find T-12, have patient forward flex, and palpate where the lowest rib joins the spine. Going laterally from the spine approximately 2 cm, the electrodes are placed 3 cm apart, so that they run parallel to the		Prone extension, return from forward flexion of trunk.

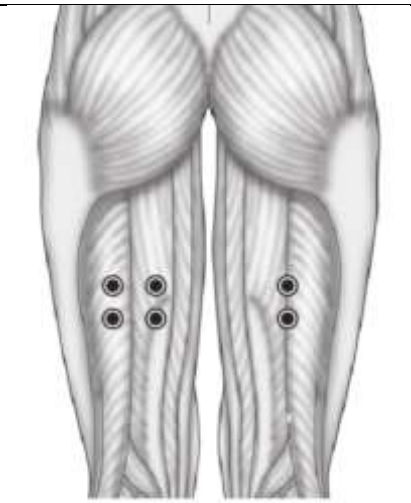
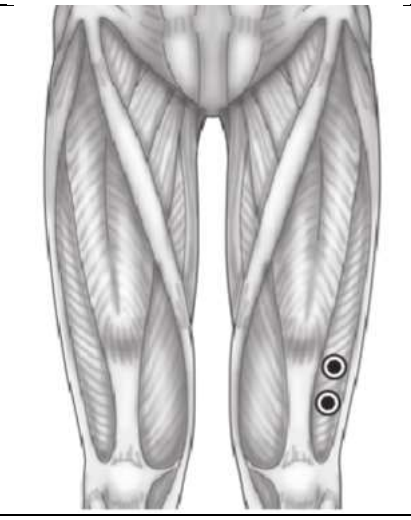
			spine over the fleshy muscle mass. It is best to place these electrodes while the patient is in slight forward flexion. (Cram's) 5 cm lateral to Tg spinous process (Marris)		
6. Lumbar Erector Spinae	2	Lower Back	Palpate the iliac crest. Two active electrodes are placed parallel to the spine, 2 cm apart, approximately 2 cm from the spine over the muscle mass. Electrodes best placed while patient is in a slight forward flexion, hands resting on knees and supporting torso. (Cram's) 3 cm lateral to L3 spinous process (Marris)		Forward flexion and return to midline of the torso
7. Extensor Carpi Radialis	2	Extremities	Ask the patient to flex the wrist and palpate the muscle mass approximately 5 cm distal from the lateral epicondyle of the elbow, on the dorsal side of the arm just lateral to the brachioradialis. Place two active electrodes 2 cm apart over the muscle		Wrist extension and radial deviation

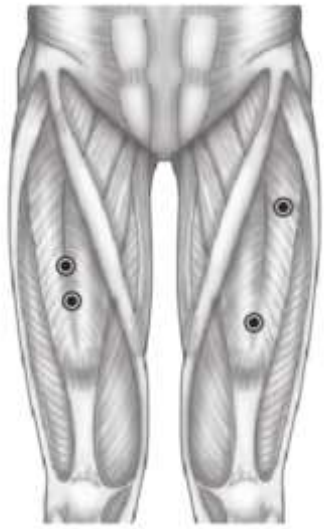
			mass that emerges, with the electrodes running in the direction of the muscle fibers.		
8. Flexor Carpi Radialis	2	Extremities	Support the arm with the fingers while palpating the ventral aspect of the forearm near the elbow on the medial side of the arm. Ask the patient to flex the wrist. Place two active electrodes, 2 cm apart, over that muscle mass so that they run in the direction of the muscle fibers.		Wrist flexion
9. Triceps	2	Extremities	To monitor from the lead head of the triceps, two active electrodes (2 cm apart) are placed parallel to the muscle fibers, 2 cm medial from the midline of the arm, approximately 50% of the distance between the acromion and the olecranon or elbow. Do not place too distally. Palpate and place in the arm position to be studied. To place on lateral aspect of triceps		Extension of the forearm (resistance augments signal)

			muscle, palpate the lateral aspect of the triceps region during an isometric contraction. Two active electrodes (2 cm apart) placed parallel to the muscle fibers, approximately 2 cm lateral from the midline of the arm, approximately 50% of the distance between the acromion and the olecranon or elbow.		
10. Biceps Brachium	2	Extremities	Ask the patient to flex his or her forearm in the supinated position. Palpate the muscle mass in the dorsal aspect of the upper arm that emerges. Place two active electrodes (2 cm apart) parallel to the muscle fibers and in the center of the mass. Placing electrodes more laterally will emphasize detection of should flexion, and placing the electrodes more medially will emphasize detection of adduction and		Flex the forearm. Resisted flexion augments the signal.

			internal rotation.		
11. Anterior deltoid	2	Shoulder	Palpate the clavicle. Two active electrodes, 2 cm apart, are placed on the anterior aspect of the arm, approximately 4 cm below the clavicle so that they run parallel to the muscle fibers.		Forward flexion, abduction, and horizontal adduction of the arm.
12. Middle deltoid	2	Shoulder	Active electrodes are placed on the lateral aspect of the upper arm, 2 cm apart, and approximately 3 cm below the acromion, over the muscle mass so that the electrodes run parallel to the muscle fibers		Abduction of arm
13. Posterior deltoid	2	Shoulder	Palpate the spine of the scapula. Two active electrodes are placed 2 cm apart and approximately 2 cm below the lateral border of the spine of the scapula and angled on an oblique angle toward the arm so that they run parallel to the muscle fibers.		Extension, abduction, and lateral rotation of the arm

14. Upper trapezius	2	Shoulder	Place two electrodes 2 cm apart so that they run parallel to the muscle fibers of the upper trapezius, along the ride of the shoulder, slightly lateral to and one-half the distance between the C7 cervical spine and the acromion. Palpate the muscle mass and place over muscle belly.		Shoulder elevation/shrug, lateral bending of the head
15. Middle trapezius	2	Shoulder	Locate the medial border of the spine of the scapula (root). Place electrodes horizontally 2 cm apart next to the root		Retract scapula and abduct arms through the full range of motion
16. Lower trapezius	2	Shoulder	Palpate the interscapular region. Have the patient retract and depress the scapula and then flex the arm to at least 90 degrees. Palpate the inferior medial border of the scapula for the muscle mass that emerges. Place electrodes on an oblique angle, approximately 5 cm down from the scapular spine. The two active electrodes are		Adduction of arms; retraction of the shoulder back and down at a 45-degree angle.

			placed next to the medial edge of the scapula at a 55-degree oblique angle.		
17. Hamstring	2	Extremities	Two electrodes, 3 to 4 cm apart, may be placed parallel to the muscle in center of the back of the thigh, approximately half the distance from the gluteal fold to the back of the knee		With patient in prone position, ask to flex the knee against resistance. In standing position, have patient flex knee
18. Vastus Lateralis	2	Extremities	Two electrodes, 2 cm apart, placed approximately 3 to 5 cm above patella on an oblique angle lateral to midline		Extend knee while seated or squat while standing

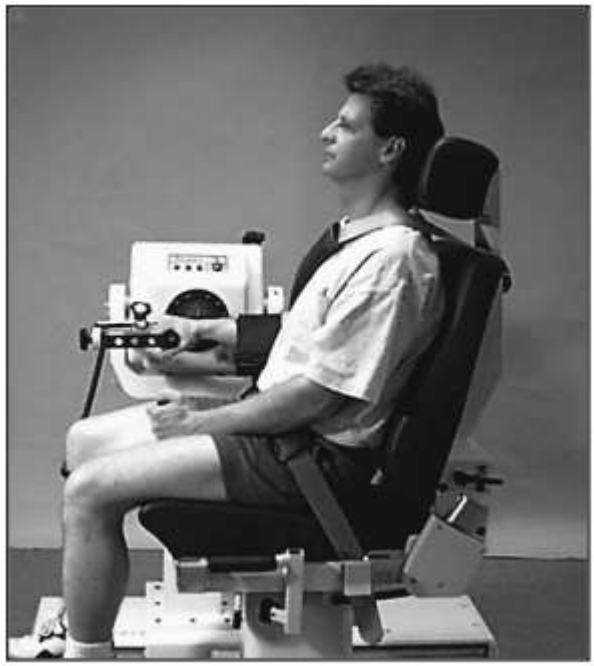
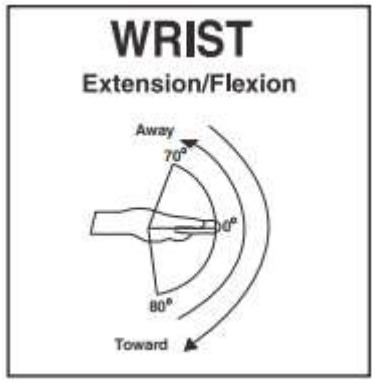
19. Biceps femoris	2	Extremities	Center of anterior surface of the thigh, approximately halfway between the knee and iliac spine. Two electrodes placed 2 cm apart, parallel to muscle fibers OR with a wide spacing (10 to 15 cm apart) to monitor from the quadriceps in general.		While patient is seated, extend knee. While standing, squat slightly.

Appendix D: Maximum Voluntary Contraction Methods

Muscle	MVC Method	
20. Rectus Abdominus	Upper trunk flexion was used to activate the RA. This took the form of an adapted sit up, with knees flexed at 45°. With the feet held in position and resistance placed across the trunk at a line superior to the xiphisternal joint, the participant was asked to forcefully flex the trunk. (Electromyographic response of global abdominal stabilizers in response to stable- and unstable-base isometric exercise. Atkins SJ1, Bentley I, Brooks D, Burrows MP, Hurst HT, Sinclair JK.)	
21. External Oblique	A lying side bend was used to determine upper trunk EO MVC. With the feet secured, participants were asked to bend upward while lying on their side. Resistance was placed at a level superior to the xiphisternal joint. (Electromyographi	

	c response of global abdominal stabilizers in response to stable- and unstable-base isometric exercise. Atkins SJ1, Bentley I, Brooks D, Burrows MP, Hurst HT, Sinclair JK.)	
22. Internal Oblique	To generate a MVC of the IOs, participants were asked to lay supine with their lower limbs secured to a plinth using an adjustable belt. Participants were asked to lift their shoulders similar to when performing a curl sit-up, using as much force as possible against the manual resistance provided by researchers. (Abdominal bracing during lifting alters trunk muscle activity and body kinematics Pieter Coenen PhD Amity Campbell PhD Kevin Kemp-Smith PhD Peter O'Sullivan(Prof) Leon Straker(Prof))	
23. Latissimus Dorsi	Various methods	

24. Thoracic Erector Spinae	An adapted lower trunk extension was performed for ES. Participants lay in the prone position, with feet secured by a second tester. The participant raised shoulders and trunk from the floor, with resistance placed at a level equivalent to the inferior border of the scapula. (Electromyographic response of global abdominal stabilizers in response to stable- and unstable-base isometric exercise. Atkins SJ1, Bentley I, Brooks D, Burrows MP, Hurst HT, Sinclair JK.)	
25. Lumbar Erector Spinae	An adapted lower trunk extension was performed for ES. Participants lay in the prone position, with feet secured by a second tester. The participant raised shoulders and trunk from the floor, with resistance placed at a level equivalent to the inferior border of the scapula. (Electromyographic response of	

	global abdominal stabilizers in response to stable- and unstable-base isometric exercise. Atkins SJ1, Bentley I, Brooks D, Burrows MP, Hurst HT, Sinclair JK.)	
26.		
27. Extensor Carpi Radialis		Wrist Extension/Flexion   • Dynamometer Orientation: 0˚ • Dynamometer Tilt: 0˚ • Seat Orientation: 0˚ • Seatback Tilt: 85˚ • Elbow Flexion: 90˚

		• Axis of Rotation: Axis of rotation for this pattern lies between the proximal row of the carpals, at the capitate bone, and the radius at the radiocarpal joint. • Ready Position: Full Flexion
28. Flexor Carpi Radialis		See "Extensor Carpi Radialis"
29. Triceps	To generate MVC for BB and TB, the shoulder and elbow were maintained at 90°, while manual resistance was applied at the forearm in the direction towards the body (BB MVC) and away from the body (TB MVC). The participant's forearm was in a neutral position. The possible influence of gravity was ruled out by having the upper limb resting on a support. Testing, which activated mostly the muscles of the forearm, was done with a hand dynamometer (JBA Zb. Staniak, Poland) squeezed in the hand. During this test, the arm and the forearm were hanging down.	  • Dynamometer Orientation: 30˚ • Dynamometer Tilt: 0˚ • Positioning Chair Orientation: 0˚ • Seatback Tilt: 85˚ • Axis of Rotation: Passes through the center of the trochlea and the capitulum, bisecting the longitudinal axis of the shaft of the humerus. • Ready Position: Full Flexion
30. Biceps Brachium	See "Triceps"	

31. Anterior deltoid	See “Shoulder EMG”	
32. Middle deltoid	See “Shoulder EMG”	
33. Posterior deltoid	See “Shoulder EMG”	
34. Upper trapezius	See “Shoulder EMG”	
35. Middle trapezius	See “Shoulder EMG”	
36. Lower trapezius	See “Shoulder EMG”	
37. Hamstring	Knee flexion	  • Dynamometer Orientation: 90˚ • Dynamometer Tilt: 0˚ • Seat Orientation: 90˚ • Seatback Tilt: 70 - 85˚ • Axis of Rotation: Axis is through the lateral femoral condyle on a sagittal plane.

		• Ready Position: Full Flexion
38. Vastus Lateralis	Knee extension	See “Hamstring”
39. Biceps femoris	Knee extension	See “Hamstring”

Appendix E: Body Discomfort Survey

Discomfort Survey

Please complete this **Discomfort Survey**. Fill in all of the boxes below. Please respond honestly and thoughtfully. Your responses are anonymous. Thank you.

Participant #: _____

Trial #: _____

Model: _____

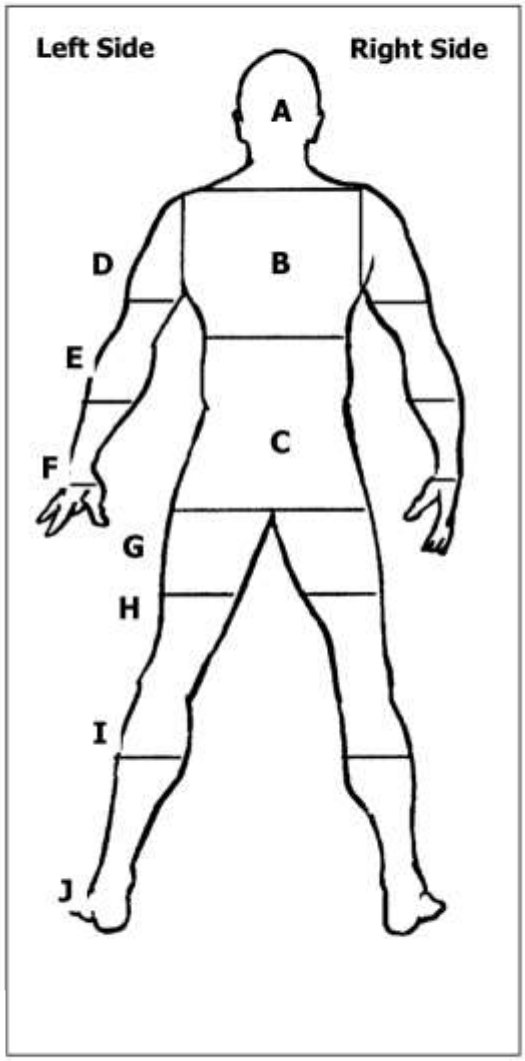
1. Describe symptoms (if any) by writing the letters (**N, T, A, B**) on the body diagram on the area of the body involved. **(SEE KEY BELOW FOR DEFINTIONS)**

N=Numbness T=Tingling A=Aching B=Burning

2. Rate discomfort for each region (A-J) by writing the number (0 to 10) in the box.

0=NONE: No discomfort at all.
5=MODERATE: Moderate discomfort, some difficulty in performing general activities.
10=MAX: Maximum discomfort (unable to function, admitted to the hospital.)

	BODY PART	NONE		MAX
A	Head/Neck/Eyes	0....		... 10
B	Upper/Mid Back	0....		... 10
C	Low Back/Pelvis	0....		... 10
D	Shoulder/Upper Arm	0....		... 10
E	Elbow/Mid Arm	0....		... 10
F	Forearm/Wrist	0....		... 10
G	Hand	0....		... 10
H	Upper Leg/Hip	0....		... 10
I	Mid Leg/Knee	0....		... 10
J	Lower Leg/Foot	0....		... 10



3. Please respond to questions below:

	MIN		MAX
How hard is your work (physical/mental demands?	0....		... 10
How much energy do you have left after work?	0....		... 10

OVER FOR ADDITIONAL COMMENTS

FORM: DC031505 ErgoSystems Consulting Group, Inc. www.ergosystemsconsulting.com

Appendix F: Virtual Exertions Study Informed Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study/Repository: Emergency Medicine Patient Lift Training Simulation in Virtual Reality (eIRB #16665)
Principal Investigator: Rebecca Ellis, rellis6@ncsu.edu, (215) 237-2634
Faculty Point of Contact: Dr. Karen Chen, kbchen2@nscu.edu, (919) 515-6403

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate and to stop participating at any time without penalty. The purpose of this research study is to investigate posture differences and similarities when performing a lifting task related to emergency medicine patient transport in both physical and virtual environments.

The study uses electromyography (EMG) to measure muscle activity. EMG is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). Motor neurons transmit electrical signals that cause muscles to contract. An EMG system translates these signals into graphs, sounds or numerical values that a specialist interprets. The study will also use a CAVE (Cave Automatic Virtual Environment), which is a 10ft×12ft×9ft space with large screens that serve as the projection surface of 3D images. Participants will wear 3D glasses in order to see the 3D images.

You are not guaranteed any personal benefits from being in this study. Research studies also may pose risks to those who participate. You may want to participate in this research because you may gain some insight into how ergonomics research is conducted on biomechanical systems using electromyography, motion tracking, and virtual reality. You may not want to participate in this research because this experiment involves bending and lifting exercises that may cause muscle fatigue as well as virtual environments that may cause motion sickness or nausea.

In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above or the NC State IRB office (contact information is noted below).

What is the purpose of this study?
The purpose of this research study is to investigate postures and muscle activities when performing a lifting task related to emergency medicine patient transport in both physical and virtual environments.

Am I eligible to be a participant in this study?
There will be approximately 15-20 participants in this study.
In order to be a participant in this study you must be between the ages of 18 and 55 and be willing to lift/move heavy objects
You cannot participate in this study if you have a physical disability, have had a musculoskeletal injury in the past three months, have a history of epileptic seizure or blackout, are sensitive to flashing lights, have a tendency for motion sickness when experiencing visual motion conflicts, or have a history of Lasik eye surgery.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to:

1. Complete a demographic questionnaire requesting information about your age, gender, overall health status, and upper-limb health.

2. Allow researcher to collect body measurements such as weight, arm length, height, etc. using self-reporting questionnaires and/or a tape measure.
3. Have up to 16 electromyography electrodes (muscle activity sensor) attached to your muscles (attachments can be located anywhere on the arm, upper back, or front torso). The electrodes will be secured using medical or athletic tape. Your arm might have to be shaved if you have hair where the electrodes need to be placed.
4. Have 18 motion tracking markers placed on bony landmarks on your body (including arm, leg, head, and trunk areas), which will be tracked by motion capture cameras. Markers will be attached using double-sided adhesive tape.
5. Complete a brief training for the experiment task to be completed. The training involves learning the proper patient transfer techniques used in the field by emergency medicine professionals, which is described in Step 7.
6. You will be asked to exert at your maximum level of muscle exertion for a short period of time (around 3 seconds) for various muscle groups; including legs, arms, back, and shoulder in order to determine the maximum voluntary contraction (MVC) of these muscles. The MVC is determined depending on the muscle group. For the lower back muscle group, participants will perform body weight exertions pushing against the experimenter's hands on their shoulders. For the shoulder, lower extremity, and upper extremity muscle groups, the participant will sit in a Biodex chair and push against the appropriate attachment (assembled by the experimenter) in the direction of maximum muscle exertion. The MVC trials will last 3-5 seconds with 3 trials per muscle. Breaks of 1 minute will be provided between each contraction. The maximum voluntary contraction is used to normalize the electromyography data and it is a common approach to compare data across different individuals.
7. Perform a physical task procedure; specifically, a patient transfer task. Each trial will take about 30 seconds, with a one-minute break between each of the trials. Each set of three trials will therefore take around 3-5 minutes.
    a. In the physical lift trial, you will lower your body and grab the handle of a load that has a comparable size and shape to a person on a backboard on the ground, transfer the load onto a stretcher, and then stand up to load the stretcher onto a higher surface similar to an ambulance loading height.
    b. In the virtual lift trial, you will mimic the physical lift task while using muscle exertion typically used for lifting in order to lift a virtual patient in the CAVE.
8. An experimenter will also be present for questions. You will be given frequent breaks during task performance. Water will be provided. No audio or video recording or photos will be taken. The entire study will take place in the Ergonomics Laboratory located in Room 457 of Daniels Hall.

The total amount of time that you will be participating in this study is approximately 2 hours.

Risks and benefits

This experiment involves bending and lifting exercises. You will be properly trained on exercise technique before you are asked to perform these exercises. There is a chance of temporary muscular fatigue from determining maximum voluntary contraction and from the lifting tasks, which may be similar to those following a workout. However, you will receive a period of rest after each trial to allow your muscles to recuperate. In addition, you will be monitored throughout the experiment. The likelihood of any injury or excess pain from this experiment is slim. If you are experiencing pain, please let an experimenter know and we will stop the experiment. You will be compensated for your time regardless. Electromyography is considered non-invasive, and it poses minimal risk.

There may be some discomfort or skin irritation where the electrodes are attached to the skin because of the tape. All sites of attachment will cleaned following the experiment. It is also possible that participants may experience motion sickness symptoms while in the CAVE. This risk will be minimized by excluding participants that are historically prone to motion sickness or nausea. On top of this precaution, participants will be constantly monitored for signs of motion sickness. If signs are seen of motion sickness or the participant reveals any discomfort, he or she will be asked to remove the headset and sit down until the symptoms subside. If the symptoms do not subside, the participant will be able to terminate his or her involvement in the study without penalty. You will be compensated for your time regardless.

There is no direct benefit to you as a result of participation in this experiment. You may gain some insight into how ergonomics research is conducted on biomechanical systems and using electromyography, motion capture, and virtual reality. The results of the study are expected to support the development of knowledge on the primary muscle groups associated with patient transfer tasks in emergency medicine. In addition, design recommendations will be developed in order to incorporate muscle exertions and postural changes into virtual reality training simulations.

Right to withdraw your participation

You can stop participating in this study at any time. In order to stop your participation, please let an experimenter know and we will stop the experiment. If you choose to withdraw your consent and stop participating you can expect to be compensated for your time regardless.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. All data are collected using a password-protected desktop computer in a locked laboratory space. No data will be stored on laptops. Data will be stored securely on an NC State managed computer. All our data are de-identified. Upon the completion of data collection, we will be transferring data over to an encrypted server maintained by our department. Individual data with identifiable details removed may be made available to the public as required by a professional association, journal, or funding agency. All payment information will be immediately submitted to the accounting staff in the Industrial and Systems Engineering Department for record purposes, and they will be locked in the office of the department accountant.

Compensation
For participating in this study you will receive $10 per hour. If you withdraw from the study prior to its completion, you will be paid at a rate prorated for the amount of time present. For example; if you participate for 1.5 hours, you will receive $15.

Emergency medical treatment
If you are hurt or injured during the study session(s), the researcher will contact the University's emergency medical services at 911 for necessary care. There is no provision for compensation or free medical care for you if you are injured as a result of this study.

What if you are an NCSU student?
Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you are an NCSU employee?
Participation in this study is not a requirement of your employment at NCSU, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher Rebecca Ellis, at rellis6@ncsu.edu or (919) 515-7210.

What if you have questions about your rights as a research participant?
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (institutional Review Board) Office via email at irb-director@ncsu.edu or via phone at 1.919.515.8754. You can also find out more information about research, why you would or would not want to be a research participant, questions to ask as a research participant, and more information about your rights by going to this website: http://go.ncsu.edu/research-participant

Consent To Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Participant's printed name _____

Participant's signature _____ **Date** _____

Investigator's signature _____ **Date** _____

Appendix G: NASA TLX Survey and Analysis Worksheets

Subject ID:_____Task ID:

RATING SHEET

MENTAL DEMAND

Low **High**

PHYSICAL DEMAND

Low **High**

TEMPORAL DEMAND

Low **High**

PERFORMANCE

Good **Poor**

EFFORT

Low **High**

FRUSTRATION

Low **High**

Subject ID:_____ **Date:**_____

SOURCES-OF-WORKLOAD TALLY SHEET		
Scale Title	*Tally*	*Weight*
MENTAL DEMAND		
PHYSICAL DEMAND		
TEMPORAL DEMAND		
PERFORMANCE		
EFFORT		
FRUSTRATION		

Total count = _____

(NOTE - The total count is included as a check. If the total count is not equal to 15, then something has been miscounted. Also. no weight can have a value greater than 5.)

Subject ID: — — — — — **Task ID:** _____

WEIGHTED RATING WORKSHEET			
Scale Title	*Weight*	*Raw Rating*	*Adjusted Rating* (Weight X Raw)
MENTAL DEMAND			
PHYSICAL DEMAND			
TEMPORAL DEMAND			
PERFORMANCE			
EFFORT			
FRUSTRATION			

Sum of "Adjusted Rating" Column =____ _

WEIGHTED RATING =
(i.e.. (Sum of Adjusted Ratings)/15)

Appendix H: NASA TLX Results

Table 12 Descriptive statistics for matched pair comparison between the value of each factor after the physical and virtual lifts. Green highlight signifies statistical significance ($p < 0.05$)

	Physical	Virtual	Mean Difference	p-value
Mental Demand	17.22	72.22	55	0.0001
Physical Demand	69.44	76.11	6.67	0.13
Temporal Demand	31.11	42.78	11.67	0.12
Performance	32.78	50.56	17.78	0.19
Effort	68.89	86.67	17.78	0.025
Frustration	29.44	61.67	32.22	0.0009
Total Workload	51.78	74.89	23.11	0.0018

Table 13 Descriptive statistics for matched pair comparison between the weight of each factor after the physical and virtual lifts. Green signifies statistical significance ($p < 0.05$)

	Physical	Virtual	Mean Difference	p-value
Mental Demand	0.059	0.2	0.14	0.0024
Physical Demand	0.28	0.19	0.096	0.0117
Temporal Demand	0.11	0.037	0.074	0.051
Performance	0.22	0.16	0.067	0.081
Effort	0.27	0.31	0.037	0.27
Frustration	0.052	0.11	0.059	0.0353

Appendix I: Descriptive Statistics for Muscle nEMG

Table 14 Descriptive statistics for mean nEMG per muscle

Muscle	Mean nEMG	Std Error
LAD	46.562	10.413
LBF	61.365	11.642
LBI	77.434	11.185
LEC	91.261	12.753
LEO	41.017	10.413
LFC	74.227	11.185
LHAM	45.367	10.413
LIO	79.890	12.753
LLD	77.323	10.413
LLES	106.855	10.778
LLT	92.148	10.413
LMD	56.425	10.413
LMT	60.868	11.185
LPD	68.035	10.413
LRA	22.215	10.413
LTES	112.350	10.778
LTRI	51.586	10.778
LUT	124.362	11.642
LVL	108.990	11.642
RAD	28.486	10.413
RBF	72.832	11.642
RBI	76.213	10.778
REC	85.223	18.036
REO	40.934	10.413
RFC	63.761	13.443
RHAM	56.798	10.413
RIO	41.751	10.778
RLD	49.357	11.185
RLES	82.475	10.778
RLT	39.461	10.413
RMD	84.665	10.413
RMT	69.207	10.413
RPD	62.993	10.413
RRA	20.791	10.413
RTES	86.889	10.413
RTRI	59.814	10.413
RUT	85.731	10.413
RVL	123.261	11.185

Appendix J: Descriptive Statistics for Latin Square Design

Table 15 Descriptive statistics for each maximum nEMG output per muscle and perception results in Latin Square Design

	Image	Weight	Image x Weight	Subject	Trial
RTES	.0518	.5065	.1801	<0.0001	.6703
LTES	.8590	.7386	.1517	<0.0001	.3444
RLES	.8445	.6527	.0480	<0.0001	.3218
LLES	.9307	.1764	.5606	<0.0001	.4056
RUT	.9652	.2596	.8188	<0.0001	.3500
LUT	.4551	.6923	.8537	<0.0001	.4147
RBI	.5994	.2979	.7805	<0.0001	.4313
LBI	.6546	.5965	.4652	<0.0001	.0591
RECR	.8362	.0125	.0499	<0.0001	.0193
LECR	.3504	.8816	.9076	<0.0001	.2634
RVL	.0978	.5636	.5847	0.0038	.6672
LVL	.7773	.8096	.1853	<0.0001	.4106
Perceived Effort	.0684	.7236	.5681	.0314	.8714
Perceived Discomfort	.4658	.2428	.8323	<0.0001	.5591

Appendix K: Average Significance Values for Each Muscle

Table 16 Significance values for the effect of image and weight on the maximum nEMG reached per muscle across all subjects

	IMAGE P-VALUE	WEIGHT P-VALUE
RTES	.2966	.9321
LTES	.9348	.8022
RLES	.9997	.9992
LLES	.8142	.9791
RUT	.9734	.9640
LUT	.8988	.8724
RBI	.9358	.7468
LBI	.8433	.8279
RECR	.9210	.2657
LECR	.6193	.9755
RVL	.1770	.6229
LVL	.9369	.9515

Appendix L: Mean Differences of Maximum nEMG Values in Physical vs. Virtual Lifts

Table 17 Significance values for the matched pair comparison between maximum nEMG values per muscle across all subjects in physical (Cal) vs virtual lifts for 100 lb

100 lb	V1 vs Cal p-value	V2 vs Cal p-value	V3 vs Cal p-value	VA vs Cal p-value
RTES	0.9738	0.2237	0.2400	0.4869
LTES	0.3642	0.9991	0.5422	0.6518
RLES	0.3558	0.3559	0.3558	0.3558
LLES	0.2054	0.4328	0.7099	0.7453
RUT	0.2281	0.1213	0.0734	0.1298
LUT	0.6086	0.7496	0.8702	0.7047
RBI	0.0538	0.0509	0.0222	0.0371 (Cal > VA)
LBI	0.8768	0.4862	0.2546	0.3064
RECR	0.0003	0.0031	0.0031	0.0013 (Cal > VA)
LECR	0.2463	0.0089 (Cal > V2)	0.6342	0.7272
RVL	0.5103	0.4154	0.5839	0.4892
LVL	0.3868	0.4352	0.4617	0.4134

Table 18 Significance values for the matched pair comparison between maximum nEMG values per muscle across all subjects in physical (Cal) vs virtual lifts for 150 lb

150 lb	V1 vs Cal p-value	V2 vs Cal p-value	V3 vs Cal p-value	VA vs Cal p-value
RTES	0.3252	0.2717	0.2345	0.2760
LTES	0.5615	0.4253	0.5921	0.5116
RLES	0.3560	0.3559	0.3559	0.3560
LLES	0.1320	0.2742	0.6540	0.2943
RUT	0.7606	0.5524	0.0962	0.4380
LUT	0.2885	0.2520	0.0390 (Cal > V3)	0.1458
RBI	0.0063 (Cal > V1)	0.0290 (Cal > V2)	0.0138 (Cal > V3)	0.0116 (Cal > VA)
LBI	0.6051	0.4395	0.3993	0.5323
RECR	0.0009 (Cal > V1)	0.0095 (Cal > V2)	0.0055 (Cal > V3)	0.0032 (Cal > VA)
LECR	0.0438 (Cal > V1)	0.0303 (Cal > V2)	0.8193	0.1706
RVL	0.2560	0.1965	0.1774	0.2049
LVL	0.5184	0.4352	0.4910	0.4703

Table 19 Significance values for the matched pair comparison between maximum nEMG values per muscle across all subjects in physical (Cal) vs virtual lifts for 200 lb

200 lb	V1 vs Cal p-value	V2 vs Cal p-value	V3 vs Cal p-value	VA vs Cal p-value
RTES	0.3284	0.3363	0.3099	0.3204
LTES	0.1525	0.3486	0.1584	0.1812

RLES	0.3559	0.3559	0.3560	0.3559
LLES	0.0998	0.3164	0.1213	0.1574
RUT	0.0356 (Cal > V1)	0.0096 (Cal > V2)	0.0151 (Cal > V3)	0.0162 (Cal > VA)
LUT	0.1566	0.0757	0.0825	0.0932
RBI	0.0122 (Cal > V1)	0.0028 (Cal > V2)	0.0086 (Cal > V3)	0.0066 (Cal > VA)
LBI	0.3045	0.7259	0.5654	0.8697
RECR	0.0035 (Cal > V1)	0.0298 (Cal > V2)	0.0707	0.0221 (Cal > VA)
LECR	0.0139 (Cal > V1)	0.0083 (Cal > V2)	0.6334	0.0428 (Cal > VA)
RVL	0.6765	0.0083 (Cal > V2)	0.0228 (Cal > V3)	0.1273
LVL	0.6143	0.1278	0.8808	0.7651

Muscle	V1 vs Cal Mean Difference nEMG	V2 vs Cal Mean Difference nEMG	V3 vs Cal Mean Difference nEMG	VA vs Cal Mean Difference nEMG
RTES	-0.1591	-0.2257	-0.222	-0.2023
LTES	-0.1284	-0.0729	-0.105	-0.1021
RLES	577.6	583.8	624.5	595.3
LLES	-0.3021	-0.2082	-0.1119	-0.2074
RUT	-0.3325	-0.3524	-0.4141	-0.3663
LUT	-0.3319	-0.3928	-0.4721	-0.3989
RBI	-0.5854	-0.5525	-0.5906	-0.5762
LBI	-0.2786	0.3207	1.134	0.3921
RECR	-1.387	-1.193	-1.149	-1.243
LECR	-0.553	-0.575	-0.033	-0.387
RVL	-0.3801	-0.6084	-0.6489	-0.5458
LVL	2.057	0.5658	0.9567	1.193