

UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY



En Route Care in Confined Spaces: Medic Posture Assessment

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14. ABSTRACT The confined space of common medical evacuation (MEDEVAC) configurations requires strenuous positions and painful postures of Critical Care Flight Paramedics (CCFPs) during patient loading and unloading during en route care. The goal of this study was to identify areas for design improvements or loading techniques to limit awkward or painful postures experienced by the CCFP that may lead to injury or musculoskeletal disorders (MSD). A total of 17 human subjects participated in the study. The subjects were healthy members of the U.S. Army, Reserve, and/or National Guard. Subjects were dressed in full gear and marked to track body movement. Markers were placed on the head, torso, left arm, and left leg. Before motion trials began, a static trial captured the subject's standing posture. Ten motion trials were conducted. Six trials were recorded loading and unloading manikins onto the Basic Medical Interior (BMI) and four trials were recorded using the Interim MEDEVAC Mission Support System (IMMSS). Motion data was captured and analyzed to calculate the kinematics of the subject's major body segments. The simulated medic's posture was investigated to identify potentially dangerous postures that are known to lead to injury or MSD. Force estimates were calculated on the data to estimate the force at the L5/S1 vertebral disk.						
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A position evaluation was be conducted to allow the subjects to state which factors caused the most difficult postures and document their experience. From the position evaluation all the subjects mentioned at least one posture and one area of the body negatively affected. The estimated compressive force calculations were all over the recommend safe lifting limit.

Summary

The confined space of common medical evacuation (MEDEVAC) platforms requires strenuous positions and painful postures of Critical Care Flight Paramedics (CCFPs) during patient loading and unloading. The goal of this study was to characterize the postures used to load and unload patients and compare them to known acceptable limits for preventing musculoskeletal disorders (MSD). These findings will contribute to the development of future MEDEVAC platforms and prevent injuries to the CCFPs during patient loading and unloading procedures.

This is a characterization study investigating medic postures during patient loading and unloading procedures on a simulated U.S. Army HH-60 or UH-60 MEDEVAC helicopter interior. Quantitative data were obtained through recording body movement and posture using motion capture technology and by calculating the kinematics of the subjects' major body segments. Qualitative data were derived from a verbal questionnaire about each litter position where the subjects could discuss any actions or postures they felt were uncomfortable or painful.

A total of 17 human subjects participated in the study. The subjects were healthy members of the U.S. Army, Reserves, and/or National Guard. Subjects performed patient loading and unloading procedures on a simulated MEDEVAC platform while motion data was collected through an optical motion capture system. Subjects were dressed in full gear and had attached marker plates to track body movement. Singular markers were placed on the head, torso, pelvis, left arm, and left leg. Before motion trials began, a static trial captured the subject's standing posture. The static trial was used to define the digital body model and label different body segments on the motion capture software. Four litter bearers then lifted and assisted the subjects with loading and unloading a simulated patient onto the MEDEVAC platform. Ten motion trials were conducted. Six trials were recorded loading and unloading manikins onto the Basic Medical Interior (BMI) and four trials were recorded using the Interim MEDEVAC Mission Support System (IMMSS). Motion data were captured and analyzed to calculate the kinematics of the subject's major body segments. The simulated medic's posture was investigated to identify potentially dangerous postures that are known to lead to injury or MSD. A verbal questionnaire on the litter positions was used to allow the subjects to state which factors caused the most difficult postures and document their experience.

All subjects mentioned at least one adverse posture and one area of the body negatively affected. The compressive force was estimated for the vertebral disk between the fifth lumbar and first sacrum vertebrae (L5/S1) for two scenarios, the subject lifting half the manikin weight and the subject lifting one quarter of the manikin weight. The calculated values were over the safe lifting limit of 770 pounds (lb) for all the subjects for every trial. If it was assumed the subject only took one quarter of the weight, there was an average reduction of 40% of force, compared to lifting half the weight.

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Introduction

Medical evacuation (MEDEVAC) platforms and enroute care operations are continuously evaluated to optimize patient care and provider capabilities. Enroute care providers on MEDEVAC aircraft perform their duties in confined spaces in combination with high forces, awkward postures, continuous or prolonged gripping, and repetitive motions that often results in serious, life-long musculoskeletal disorders (MSD). MSD is defined as a condition or disorder that involves the muscles, nerves, tendons, ligaments, joints, cartilage, or spinal discs (Torma-Krajewski et al., 2009a). MSD develops gradually and increases in frequency when a person handling materials manually engages in repetitive lifting or performs tasks improperly. Specifically, patient loading and unloading presents enroute care providers with the challenge of lifting heavy loads while restrained to awkward and potentially painful postures. It has been shown that posture plays a role in medical provider injuries (Lester et al., 2012).

Civilian Emergency Management System (EMS) personnel experience muscle fatigue and injury because of their work environment. Among EMS workers, sprains and strains account for over 40% of all injuries with the leading cause attributed to lifting, carrying and transferring patients and equipment (Reichard et al, 2017). The back is the body part most often injured during civilian EMS patient movement tasks (Maguire, 2005). Many back injuries reported by EMS personnel were related to the stretcher. Toivonen and Fagerstrom (2011) defined the impacts of lifting the stretcher off the ground, carrying the patient, installing auxiliary equipment, and loading everything into the ambulance. Furthermore, bending toward the patient, especially when standing or sitting on the edge of a seat, was one of the leading activities inside a moving ambulance that was shown to cause repetitive muscle strain and lead to the development of MSD (Deros et al., 2016). Analysis of injury and illness data from 2008 through 2013 found that the greatest portion of injuries involved overexertion of the upper and lower trunk (The National Institute for Occupational Safety and Health [NIOSH], 2013). More than half (62 percent [%]) of all prehospital provider back injuries resulted from lifting patients. Johnos (2011) found that force, repetition, and awkward postures experienced while performing EMS job tasks led to a variety of MSD, including epicondylitis, sciatica, low back pain, carpal tunnel syndrome, and rotator cuff injuries. Inadequate design of the ambulance interior would expose all occupants of emergency vehicles, providers, and patients to risk of injury (Brice et al, 2012).

The NIOSH and the Occupational Safety and Health Administration (OSHA) have developed assessment tools to reduce risk of injury on a job that involves manual material handling, or in this setting, patient handling (NIOSH, 2007, and United States Department of Labor, n.d). Risk factors under their standards include handling loads greater than 50 lb, poor footing, inadequate space, and requiring stressful body postures such as twisting, reaching, and bending while lifting. NIOSH's lifting equation recommends weight limits based on the weight of the object, distance lifted, position of weight relative to the body, frequency and duration, and the quality of grip on the object (NIOSH, 2007). Exceeding these recommendations may lead to injury or life-long MSD.

In ergonomic studies at four sites where people work in confined environments, MSD was identified as a significant and costly problem (Torma-Krajewski et al., 2009b; Steiner, 2004). Stobbe and Bobick (1986), looking at MSDs for miners, reported that strain and sprain

injuries accounted for almost 25% of all reported injuries for workers in confined environments. The study also indicated that the three most common overload conditions were: (1) bending forward, bending to the side, or twisting the neck or back; (2) unsupported abducted elbows, forearms resting on sharp edges, tossing motions at extremes of range of motion, working with elbows above shoulders; and (3) lifting more than 50 pounds (lb) unaided. The same study showed that at least 35% of workers in confined environments were potentially exposed to each of these three overload conditions.

MSD can result from sudden or improper lifting or handling of heavy loads, which can cause excessive stress and strain in certain parts of the musculoskeletal system. Such disorders can also occur because of musculoskeletal fatigue resulting from prolonged or repeated loading. The United States Army Aeromedical Research Laboratory (USAARL) conducted a study to assess fixed position litter loading on a MEDEVAC helicopter with a six litter configuration and found the receiving medic was often challenged to perform lifting of litter-patient packages at awkward angles (Kinsler & Barazanji, 2011). Test participants expressed general dissatisfaction with having to lift the litters to the heights required for fixed position loading. Another common observation was the tendency of the litter to become caught on the litter pan belts and other protruding structures, making it difficult to maneuver. The post-test evaluations, in general, indicated concern for the physical strain experienced by the medics and loading crews. Since fixed position litter loading causes concern, the Interim MEDEVAC Mission Support System (IMMSS) requires further, quantitative research and will be one of the systems used for the current study. In addition, subjects were asked to load/unload manikins onto a simulated movable litter pan system, the Basic Medical Interior (BMI), to draw comparisons between the two configurations.

Military Relevance

The Department of Defense (DoD) published lifting limits to aid in the design and development of military systems, equipment, and facilities. The weight limit recommended for a single male to lift an object off the ground with two hands and raise it up to a surface no greater than 3 feet (ft), is 87 lb (DoD, 2012). This is the maximum design weight limit and can be reduced by several factors. As height of the surface increases, the maximum weight limit decreases. If the frequency of lifting exceeds more than five lifts per minute or 20 lifts over 8 hours, the weight limit is reduced by the percent of 8.33 times the number of lifts per minute. If twisting is required, the body should not twist more than 30 degrees to the left or right of the centerline. If the body twists more than 15 degrees, the recommended weight should be reduced by 20% (DoD, 2012). In addition, these values assume there is sufficient space and no obstacles while performing these lifts. The USAARL conducted another study to evaluate the adequacy of space available for a Critical Care Flight Paramedic (CCFP) to perform advanced medical treatment scenarios on simulated critical care patients (manikins) in existing MEDEVAC aircraft, e.g., HH-60 and UH-60 (Barazanji et al., 2015). Findings showed that the medics' neck angles increased with shorter stature, up to 66 degrees for a stature of 4 ft 11 inches (in.) versus 37 degrees for a 6 ft 5 in. stature. The second height percentile, medic's neck angle, had more than a 30-degree flexion 94% of the time while completing medical tasks and scenarios. It was observed during this study that shorter medics tended to stand and lean over, while the taller medics knelt and then leaned over to perform tasks.

In 2019, the USAARL conducted a survey to investigate the painful postures and resulting injuries of enroute care providers while working in the confined space of common MEDEVAC platforms (Conti et al., 2019). The majority of the 60 respondents were CCFPs who performed their duties on the HH-60 and/or UH-60. The results of the survey highlighted that compartment configurability, the litter system, cabin ergonomics, compartment size, patient loading capability, and personal protective gear (PPG) were all found to negatively affect the mission according to over 60% of respondents. Patient loading and unloading was among the top causes of awkward postures assumed by bending, overextending, kneeling, squatting, and straining to lift a heavy weight. Lower back, knee, neck, shoulder, and upper back injuries were prevalent among respondents with 87% suffering lower back injuries. Awkward positions, especially bending, lifting patients, and flight gear/body armor were the leading causes of lower back injuries among respondents. The respondents reported that wearing their flight gear contributed to their injuries, such as the helmet contributing to neck injuries. To replicate operational conditions these medics face on the job, and to observe the postures required, the subjects in this study were outfitted in full combat gear. Furthermore, the survey revealed that 94% of respondents claim that increasing the number of patients increases the likelihood of painful postures (Conti et al., 2019). Identifying the negative aspects of patient loading and unloading is especially exigent given that future MEDEVAC operations will require caring for multiple patients.

As of October 2020, the U.S. Army implemented the Army Combat Fitness Test to assess the physical safety and readiness of all Soldiers. Specifically, the maximum deadlift event was designed to mimic movements required to lift heavy loads safely and effectively. The maximum deadlift is said to be a strong predictor of the Soldier's ability to lift and carry a casualty on a litter. Failed attempts or unsafe movements include knees buckling, hips raising above the shoulders, rounding or flexion of the back and shoulders, and losing balance (Department of the Army, 2020). These postures are commonly known to lead to injury and should be the criteria when looking at lifting and moving litter patients during MEDEVAC operations. Task specific research is needed to improve patient loading and unloading procedures as well as the design of future MEDEVAC platforms. Based on these Army guidelines, this study used motion capture technology to characterize the kinematics of the subjects, objectively and digitally, as they load and unload manikins on litters.

Objectives and Specific Aims

This project investigated the postures associated with patient loading and unloading on simulated or actual MEDEVAC platforms.

Specific Aims:

1. Collect motion capture data of simulated medics while they load and unload weighted manikins onto different MEDEVAC platforms.
2. Assemble position evaluations where subjects report any painful or awkward postures they were exposed to during the loading and unloading trials, which will offer insight as to what movements or MEDEVAC features may have caused pain to specific body parts.

3. Calculate peak and mean joint angles and the kinematics of major body segments and compare findings to U.S. Army and national occupational lifting standards that identify postures and movements that are known to lead to injury or MSD.

General Hypothesis:

Null hypothesis: Patient loading and unloading on a MEDEVAC platform does not subject CCFPs to postures that significantly exceed U.S. Army and National occupational lifting standards.

Hypothesis: The postures required of CCFPs to successfully load/unload litter patient onto a MEDEVAC platform significantly exceed U.S. Army and National occupational lifting standards.

Materials

A custom, modular, wooden HH-60/UH-60 medical evacuation interior simulator was built and used for this study. It was created with removable walls, so that the motion tracking cameras could view into the medical interior during testing. The simulator was modeled after actual HH-60 and UH-60 models aircraft's interiors and has accurate volume dimensions (Figure 1).



Figure 1. Wooden MEDEVAC simulator.

The OptiTrack motion tracking system by Natural Point was used for testing. Eight Prime 13W cameras were used to track subject motion during testing (Figure 2).

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Figure 2. OptiTrack Prime 13W motion tracking camera.

A sandbag manikin was used to simulate a litter patient. It weighed in the 95th weight percentile for the U.S. Army, 245 lb (Gordon et al., 2012). The manikin was strapped to standard U.S. Army decontaminable litters using litter straps. The subjects wore their Army Combat Uniform (ACU) during testing. The subjects also wore gloves, Head Gear Unit-56/Personal (HGU-56/P) flight helmet, plate carrier, armor plates, boots, and Air Warrior primary survival gear carrier, which were provided to them (Figure 3).

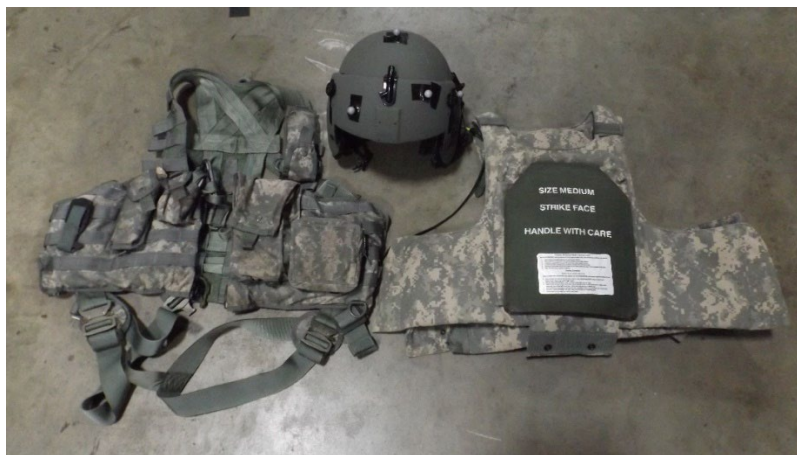


Figure 3. Helmet, plate carrier, armor plates, and survival gear carrier.

Methods

Subjects had to be a member of the U.S. Army, Reserves, or National Guard who met Army height and weight standards, in general good health, with no medical conditions that might be adversely affected by lifting. Individuals were denied participation if they had ongoing orthopedic injuries (especially back, neck, or head injuries), medical waivers affected by lifting, known severe skin sensitivities or allergies to adhesives, or who were pregnant. Refer to the medical history questionnaire for all excluding medical criteria (Appendix B).

Prior to data collection, the subjects were screened to ensure they understood proper lifting technique and were physically capable of lifting heavy loads. To evaluate the subject's lifting abilities, the subjects completed three repetitions of a kettlebell deadlift at 80 lb, holding a 40 lb kettlebell in each hand. Eighty pounds is the benchmark weight based off the approximate

weight the subject handled during testing. The kettlebells began on the floor and the subject bent at the knees and hips to reach down and grasp the handle of each kettlebell. With arms fully extended, the subject lifted the kettlebells by straightening their knees and hips until they reached a standing position. The subject then lowered the kettlebells and placed them back on the ground. Once the kettlebells touched the floor, they then could proceed with the next repetition. The subject repeated this movement consecutively until all three repetitions were completed. Lifting technique was evaluated by the study physician using requirements stated in ATP 7-22.01 for a deadlift. The study physician was looking for a shoulder's width distance between the subject's feet, a flat back, the head aligned with the spine, heels in contact with the ground, and bending at the knees and hips. Improper lifting form or failed attempts included rounding or flexing of the spine, knees collapsing inwards, hips raising above shoulders, and dropping or lowering the weight in an uncontrolled manner. All Soldiers should have been familiar with these measures as the U.S. Army implemented the deadlift into their fitness test in October 2020. At the completion of the three repetitions, the study physician determined whether the subject is safe to continue with this study. Refer to the lifting assessment for more details (Appendix C).

After the subject had donned all gear, the research team secured the reflective motion capture markers on to the subjects. Figure 4 shows the location of all the marker used in the study for the static trial.

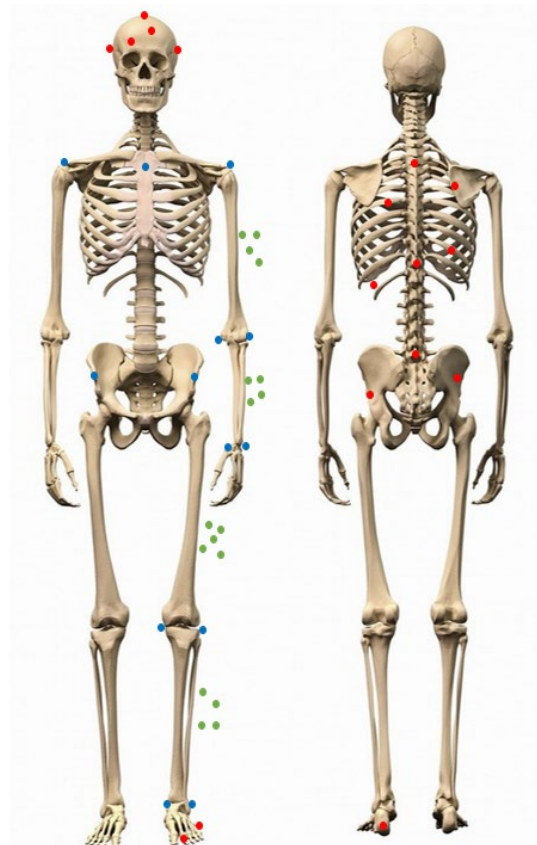


Figure 4. Reflective marker locations for static trial.

The lifting trials used most of the same markers, but the blue dots indicate anatomical landmark markers that were removed. The blue dots are markers that were used to create the skeletal model and were unnecessary for the lifting portion of the testing. The research team used elastic hook and loop straps and tape to secure marker plates (Figure 5) to major body segments (green dots). The marker plates held four to five markers and were used on the left upper arm, forearm, thigh, and shank. Only the left extremities were tracked. Due to the space constraints, collecting motion data from the right side was difficult. All the other markers were held in place using double-sided tape (blue and red dots).

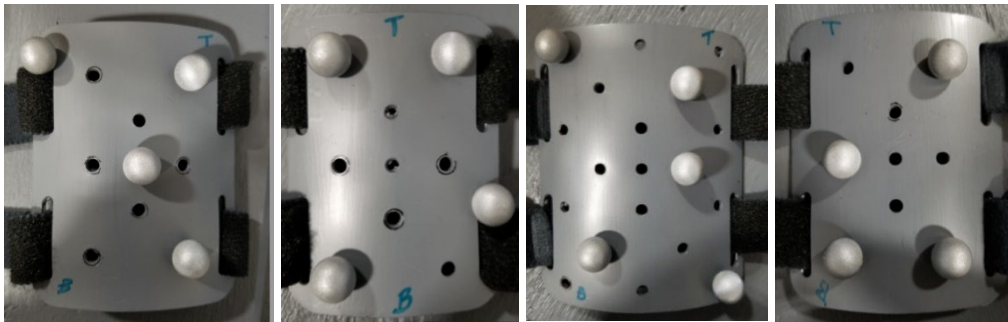


Figure 5. Marker plates from left to right: Upper arm, forearm, thigh, and shank.

After the lifting assessment, anthropometric measurements including height and weight were taken. The subjects were dressed in full combat gear (i.e., ACU, gloves, HGU-56P helmet, plate carrier, armor plates, boots, and Air Warrior primary survival gear carrier) (Figure 6).



Figure 6. Subject dressed in full gear for testing.

OptiTrack motion capture cameras were first setup and calibrated for the configuration shown in Figure 7, to capture the static trials for the subjects. The static trial was a standing T-Pose (feet shoulder width apart and arms extended out at shoulder height) and then an A-Pose (feet shoulder width apart and arms extended out at an angle to the sides).

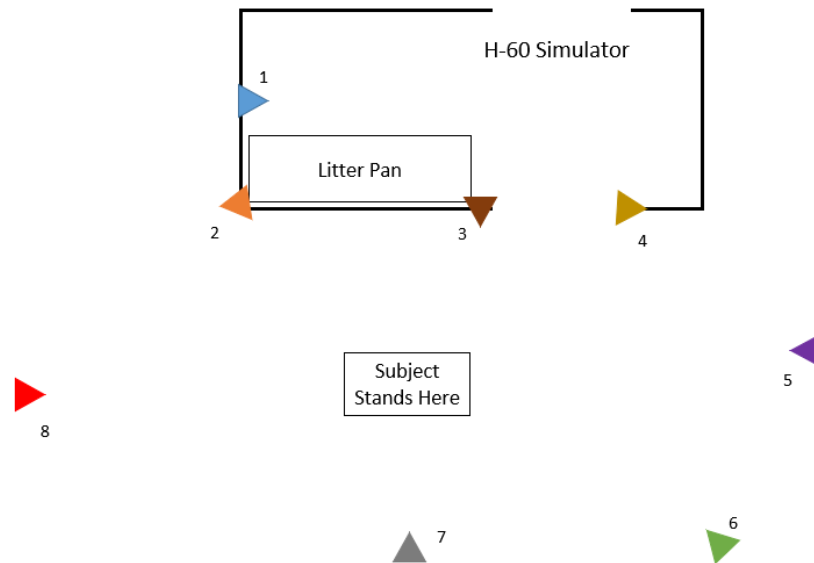


Figure 7. Camera setup for static trials (view from above).

Then the cameras were moved to the configuration for shown in Figure 8 and recalibrated for the lifting trials. Once all of the cameras were turned on and calibrated, they were not moved. If the cameras were bumped during testing the system was recalibrated before continuing data collection. Four digital video cameras were also set up in the space to capture reference video.

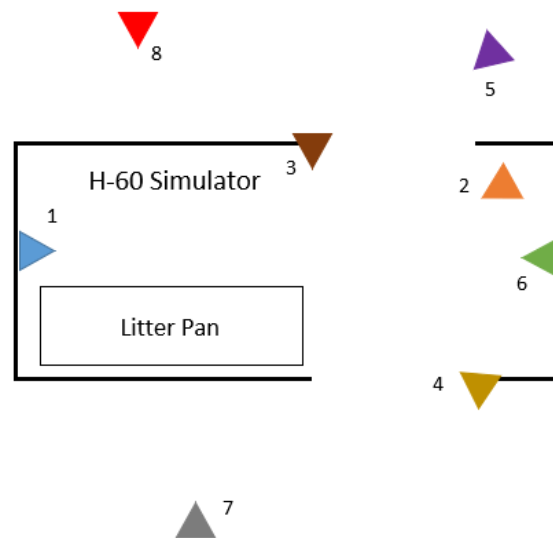


Figure 8. Camera setup for lifting trials.

A retired flight medic, who is a subject-matter expert on patient handling, then briefed and demonstrated proper loading and unloading procedures to the subject. The subject was able to do a dry run by loading and unloading an empty litter to get comfortable with the space and the procedures prior to data collection. Following the dry run, the motion trials began. The motion trials were split into two phases: the BMI phase and the IMMSS phase. Each subject completed both phases consecutively, with a break between each phase. To avoid skewing the data towards one configuration as fatigue progresses with each trial, subjects were alternately assigned their starting phase as either BMI or IMMSS. The BMI consisted of three litter positions (top), middle (mid), and bottom (bot) and the IMMSS consisted of two positions (top and bot). Each litter position consisted of two trials each, one loading trial and one unloading trial, totaling ten motion trials (Table 1).

Table 1. Lifting Trials

Testing Phase	Litter Pan Postion	Unload or Load
BMI	Top	Load
		Unload
	Mid	Load
		Unload
	Bot	Load
		Unload
IMMSS	Top	Load
		Unload
	Bot	Load
		Unload

Between each litter position, the study team presented the subject with a verbal position questionnaire regarding the trials (Appendix D). The subjects exited the simulator and were allowed to rest and recuperate while they were given the verbal position questionnaire. Subjects were asked to rate the difficulty of the trials on a scale from 1-5, 1 meaning that the trials were completed without any awkward positions and 5 meaning that the trials required constant awkward positions. The rating scale was explained prior to the motion trials and were referred to with each evaluation as needed. Subjects were asked to identify which body parts were negatively affected and any movements or MEDEVAC features that may have negatively affected their performance. Lastly, they had the option to provide their own comments or suggestions about the trials they completed.

In the BMI phase, the platform was set up in the HH-60M BMI configuration. On the testing side, all litter pans were lowered as they would be when preparing to load the first patient. On the opposite side, the litter pans were raised up to appropriate heights as if they were fully loaded with patients. Figure 9 shows the BMI setup for the top loading position.



Figure 9. BMI litter pan setup.

The subject climbed into the platform and prepared to receive the litter from the loading team. Four research team members acting as litter bearers then lifted, carried, and assisted the subject with loading a manikin on a litter onto the MEDEVAC platform. All trials were conducted loading the manikin's feet first. Accordingly, the manikin's head exited the platform first for the unloading trials. This phase consists of six motion trials which were performed as follows: load top litter position, unload top litter position, load middle litter position, unload middle litter position, load bottom litter position, unload bottom litter position. The loading trial begins once the subject makes first contact with the litter and concludes when the litter is on the litter pan. The unloading trial was followed by the subject removing the litter from the litter pan and passing it off to the litter bearers. The litter pan was then moved up to a height representative of a pan loaded with a patient before starting the next trial. This process was repeated until all three litter positions were loaded and unloaded. In this phase, each litter position was loaded and unloaded once for a total of six motion trials and three questionnaires.

In the IMMSS phase, the simulated platform or aircraft was set up in the UH-60A/L IMMSS configuration. All litter pans were set at their appropriate fixed heights on both sides of the platform. This phase consisted of four trials: two trials to load and unload the top litter position and two trials to load and unload the bottom litter position. All trials were conducted loading the manikin's feet first. In the first trial, the subject loaded the litter onto the top litter position. Similar to the BMI phase, the trial began when the medic received the litter from the litter bearers and ended once the litter was on the litter pan. The unloading trial followed suit for the top litter position. This process was repeated for the bottom litter position. In this phase, each litter position was loaded and unloaded once for a total of four motion trials and two evaluations. Figure 10 shows the litter pan in the IMMSS setup; in the figure the manikin has been loaded into the top litter position.



Figure 10. IMMSS litter pan setup.

Adequate breaks were given to the subjects and loading team after each trial and phase. Between each trial the study team verified that data were accurately captured and recorded. At the conclusion of the loading and unloading trials, all marker plates and markers were removed from the subjects. The study physician followed up with the subjects after test completion to see if any injuries occurred during testing.

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Results

Data from 17 subjects were collected during the study. Table 2 summarizes the subjects' height with their helmet on and the subjects' weight with their gear on; full anthropometric data can be found in Appendix E. This data was used when creating the skeletal models for motion tracking data, and to calculate the estimated force on the L5/S1 vertebral disk.

Table 2. Subject Anthropometrics

Subject Number	Height with Helmet (in.)	Weight With Gear (lb)
01	73.1	197.3
02	74.9	204.4
03	65.9	156.7
04	72.0	203.3
05	74.7	224.9
06	69.3	199.7
07	73.0	267.0
08	69.1	206.8
09	74.1	207.5
10	70.8	244.9
11	72.0	221.1
12	68.7	256.6
13	74.5	265.4
14	77.0	258.6
15	66.8	211.9
16	68.1	190.9
17	69.6	223.3

Data Preparation

The data was collected with the Motive: Body™ software from OptiTrack™. It was labeled and filtered in Motive™, then exported and moved into Visual3D™ 2021. In Visual3D a skeletal model was created for each subject from the static trial. The skeletal model was overlaid onto the motion tracking markers, from which joint angles could be calculated. Figure 11 shows the motion capture dots in Motive, and the skeletal overlay in Visual3D.

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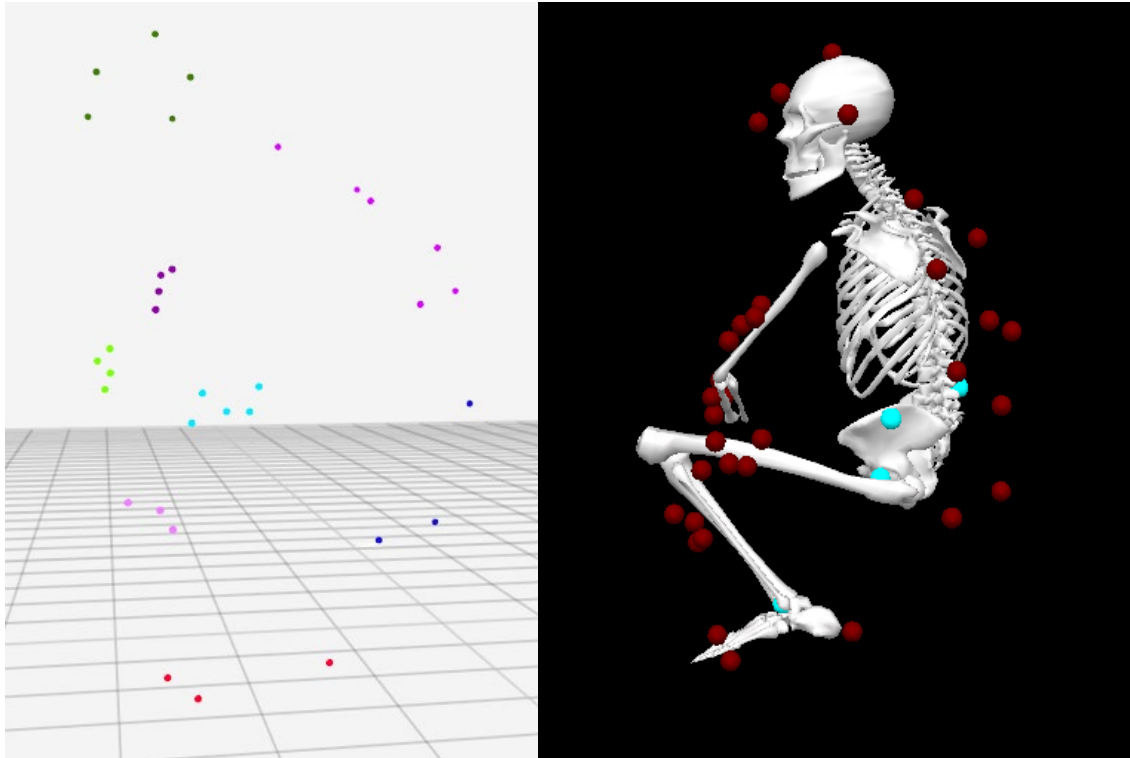


Figure 11. Labeled markers in Motive (left), skeletal overlay in Visual3D (right).

Table 3 shows the average ratings for each of the litter pan configurations in descending order from the position evaluation questionnaire. The subjects were asked to rate the difficulty on a scale from 1 to 5, with 1 being no awkward postures and 5 being constant awkward postures. The litter pan configuration with the highest rating was the IMMSS Top litter pan with an average score of 3.44, and a standard deviation of 1.00. The litter pan configuration with the lowest score was the BMI Top litter pan, with an average score of 2.65 and a standard deviation of 0.70.

Table 3. Litter Pan Configuration Average Awkward Posture Rating

Litter Pan Configuration	Average Rating (1 = No Awkward Postures, 5 = Constant Awkward Postures)	Standard Deviation
IMMSS Top	3.44	1.00
BMI Middle	3.32	0.98
BMI Bottom	3.27	1.28
IMMSS Bottom	2.79	0.92
BMI Top	2.65	0.70

The subjects were also asked if there were any movements that were painful or uncomfortable during the trials. The results by litter pan configuration can be seen in Figure 12.

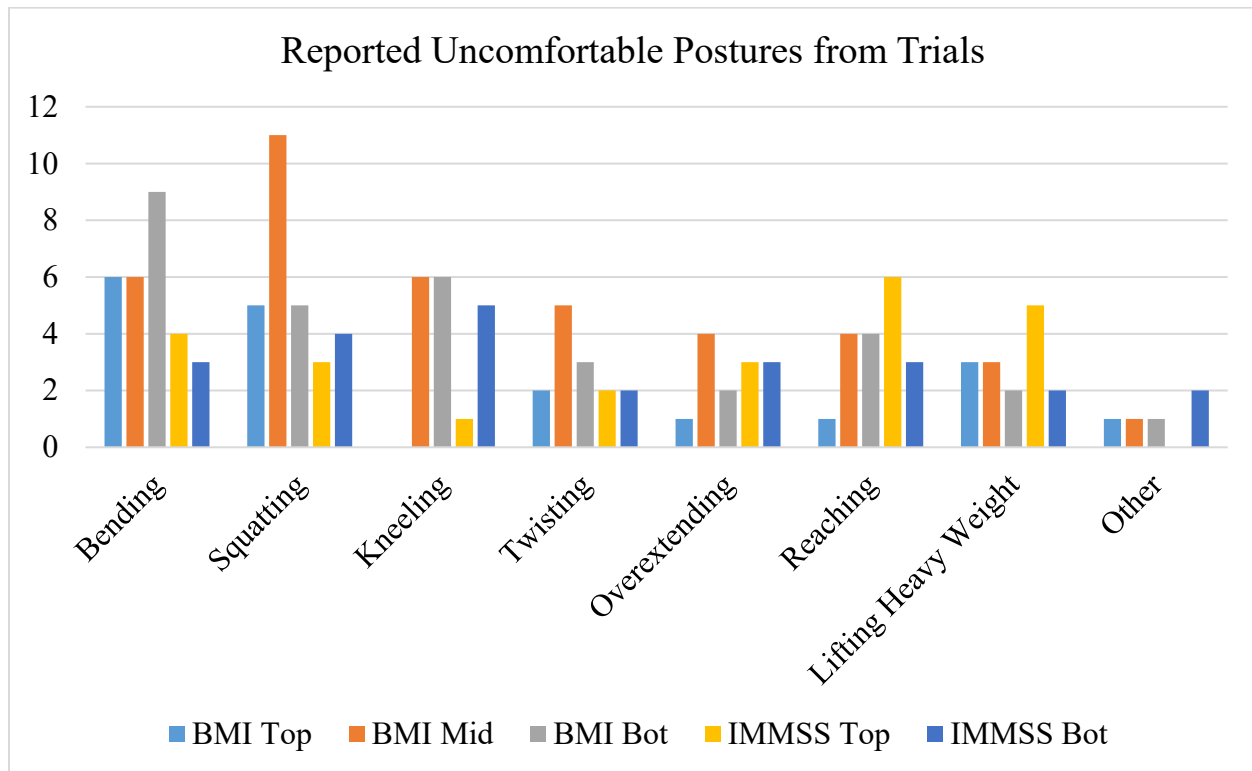


Figure 12. Uncomfortable postures reported during the trials.

Both bending and squatting were the most reported with a total of 28 instances over the five loading and unloading trials for all 17 subjects. During the entire study 83% of subjects reported bending causing discomfort, 65% reported squatting causing discomfort, and 53% reported kneeling causing discomfort.

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The third question on the evaluation asked the subjects what areas of their body were negatively affected during the trial (Figure 13).

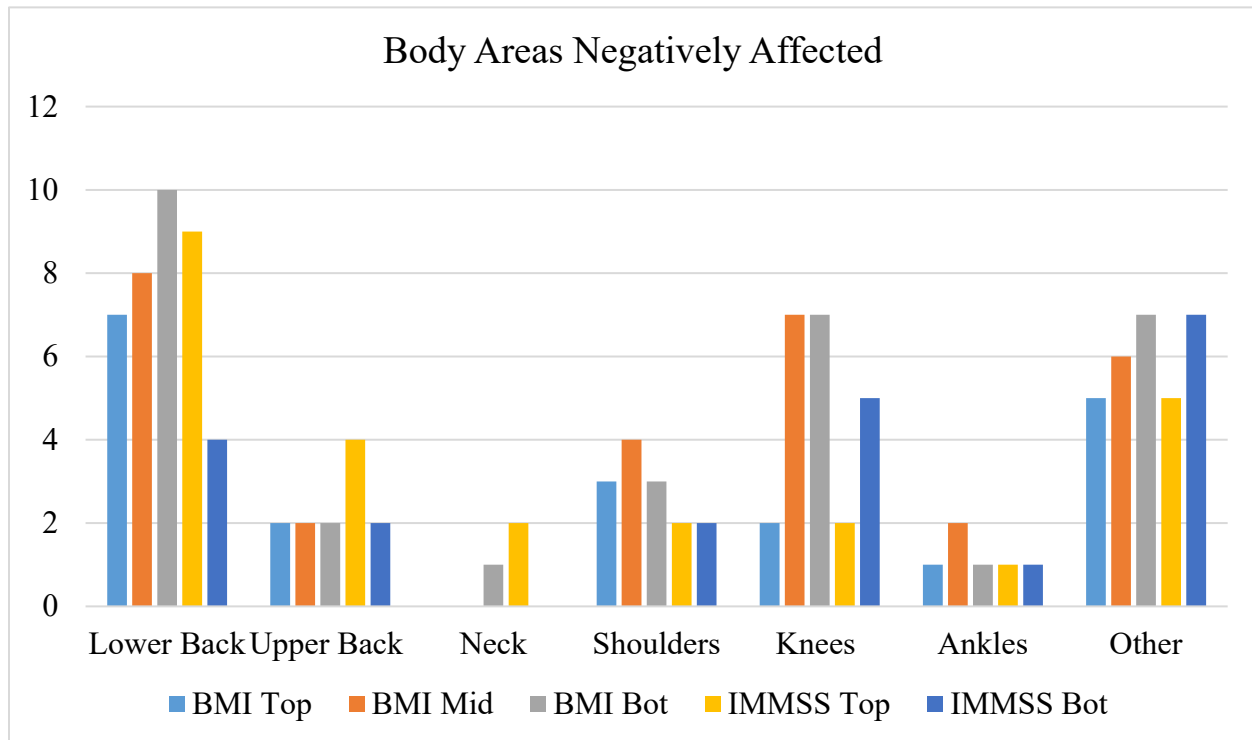


Figure 13. Body areas negatively affected by the trials.

For the BMI Top, BMI Mid, BMI Bot, and IMMSS Top litter configurations, the lower back was the most reported negatively affected area. During the study, 77% of subjects reported lower back discomfort, and 56% reported knee discomfort. The other areas affected include the hips, arms, gluteal and quadriceps muscles.

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Another question the subjects were asked was what MEDEVAC features negatively affected the trials (Figure 14).

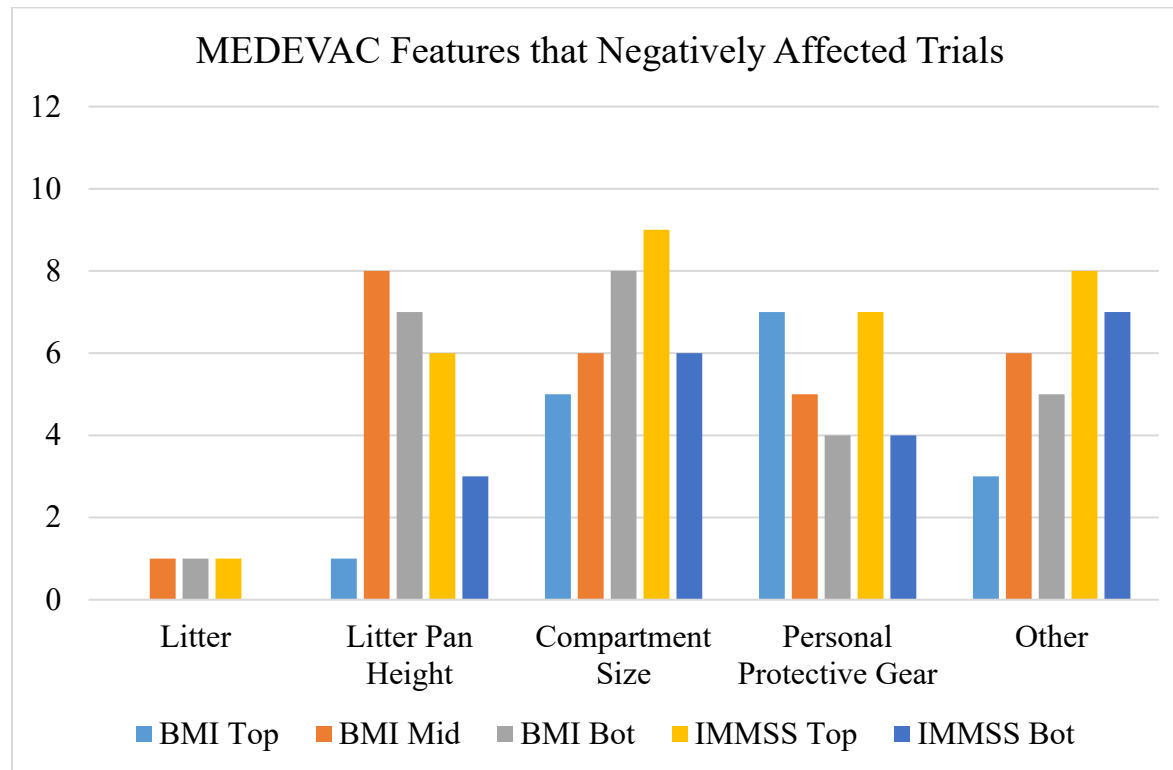


Figure 14. MEDEVAC features negatively affecting the trials.

The feature reported the most for negatively affecting the trial was the compartment size. The litter was only mentioned three times, but the litter pan height was mentioned a total of 24 times. During the study, 71% of the subjects reported litter pan height negatively affected the trial, 71% reported their personal protective gear affected the trial, and 65% of the subjects reported the compartments size affected the trial. The other MEDEVAC features mentioned included bumping the litter pans ($n = 16$), catching stirrup indents ($n = 4$), and hitting helmet on ceiling ($n = 3$).

The last question on the position evaluation asked if there were any other comments the subjects had about the study. Most of the responses were about loading on the floor compared to litter pans, the personal protective gear, or compartment size. Five subjects commented on how they found it easier to load on the floor compared to litter pans. Others mentioned that they found the personal protective gear cumbersome due to it catching on the litter pans or preventing full range of motion.

The subject posture data was analyzed for the back, hip, and knee angles. This analysis was completed by inspecting the data visually and pulling out instances in time where the skeletal model was complete. The overall average joint angles for all configurations and all the subjects were: back angle 61.0 degrees ($^{\circ}$), hip angle 51.8 $^{\circ}$, and knee angle 71.5 $^{\circ}$. Figure 15 shows an example of the average posture during loading and unloading.

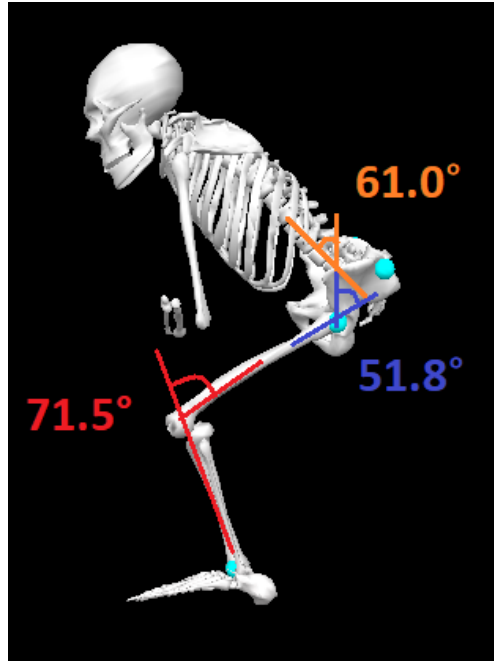


Figure 15. Average joint angle example.

Due to the nature of the data collection environment, dynamic data analysis was unfeasible for most of the trials. The instances of clear data that were analyzed for the minimum, maximum, mean, and standard deviations. Figures 16 and 17 show the minimum, maximum and mean for the back, hip, and knee angles. The average data for each subject can be found in Appendix F.

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Figure 16 shows the average back angle data for the x-axis or flexion in the frontal plane. For the BMI litter system, the average and maximum values were higher for the unloading versus the loading. The overall average for the back was 60.96°, the overall maximum was 71.30°, and the overall minimum was 50.01°. From a study on the joint kinetics during squat and stoop lifting, the expected value for the back angle is between 55° and 0° for a squat lift and 70° to 0° for a stoop lift (Hwang et al., 2009). The average value from this study indicate that the subjects favored a stoop position for the back angle.

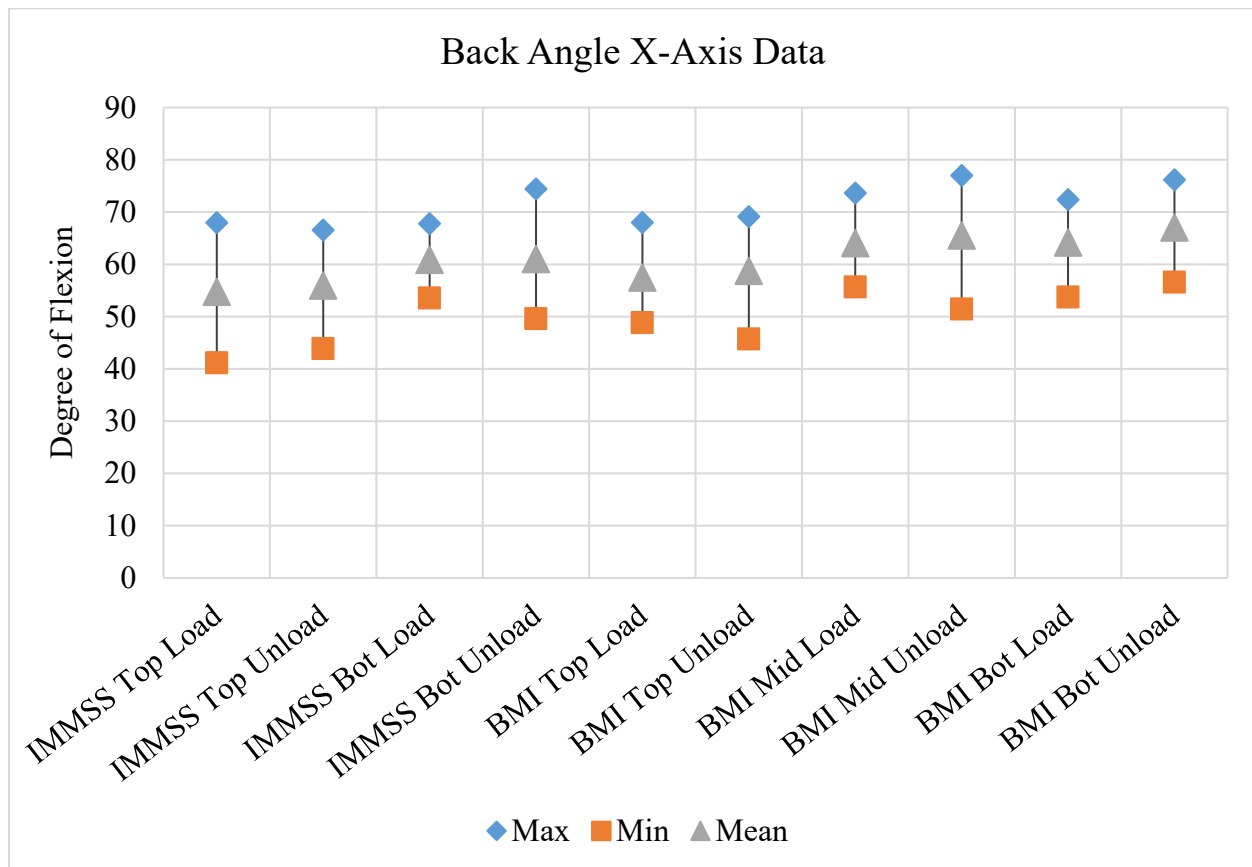


Figure 16. Back angle degree of flexion for all configurations.

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Figure 17 shows the average hip angle data for the x-axis or flexion in the frontal plane. The overall average was 60.96°, the overall average maximum was 71.30°, and the overall average minimum was 35.20°. The expected hip angles for a squat lift are 85° to -10° and 45° to -10° for the stoop lift.

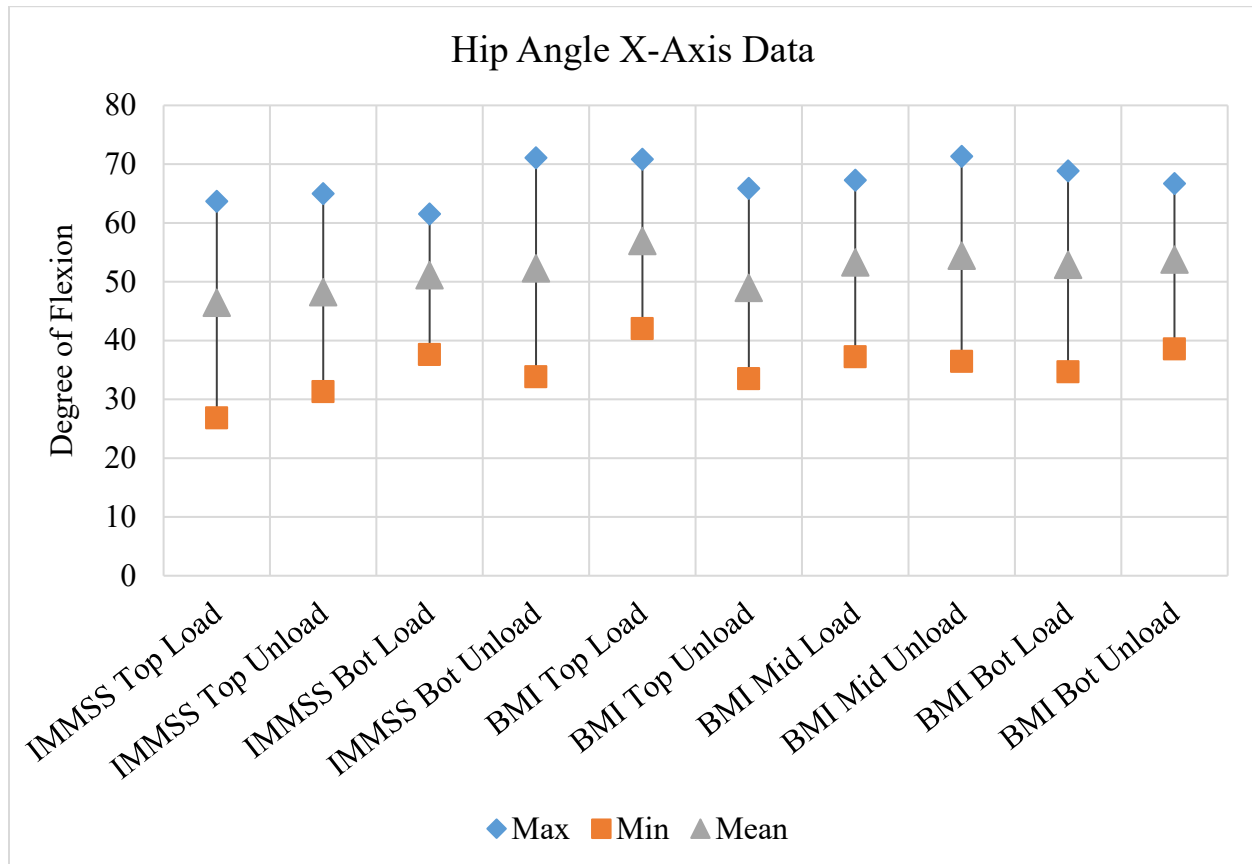


Figure 17. Hip angle degree of flexion for all configurations.

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Figure 18 shows the average knee angle data for the x-axis or flexion in the frontal plane. The overall average was 71.53°, the overall maximum was 106.61°, and the overall minimum was 36.51°. The expected knee angles for a squat lift are 130° to 0° and 5° to -5° for the stoop lift. From the values in Figure 18, the minimum knee flexion angle was never below 20° during the study.

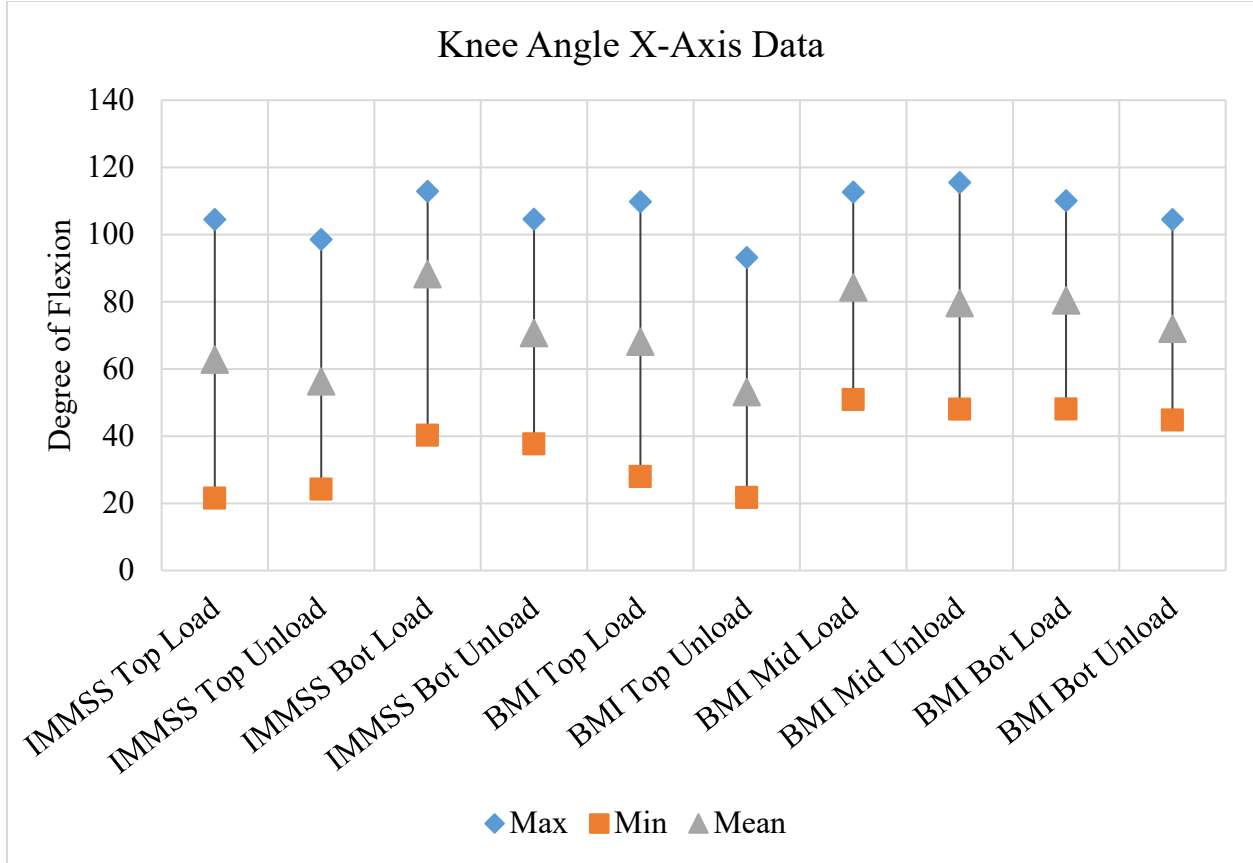


Figure 18. Knee angle degree of flexion for all configurations.

To gauge the estimated load on the subject's L5/S1 vertebral disk during loading, the compressive force was calculated using the following model (Merryweather et al., 2009):

$$F_c = 0.045(BW)(H) \sin(\theta) + \frac{L(HD)}{2} + 0.8 \left(\frac{BW}{2} + L \right)$$

where:

- F_c is the estimated compressive force (lb)
- BW is the subject body weight (lb)
- H is the subject height (in.)
- θ is the angle of the back (degrees)

- L is the weight of the load (lb)
- HD is the horizontal distance from the hand to the L5/S1 vertebral disk (in.)

For this study, the following assumptions were made to estimate the force on the L5/S1 vertebral disk. This equation does not address repeated lifts. The body weight of the subject included the weight of all gear worn during testing. The height of the subject was the height with helmet and boots on. The back angle was the average calculated angle for that specific litter position. Figure 19 shows the free body diagram for the equation.

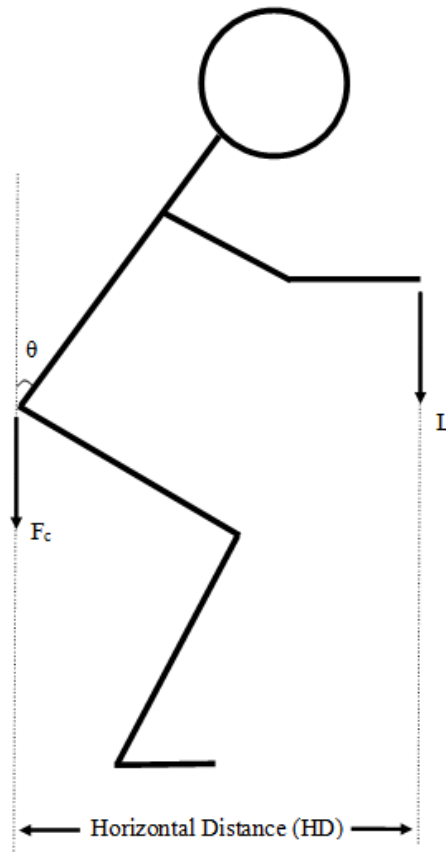


Figure 19. Compressive force free body diagram.

The horizontal distance was calculated by using the subject's elbow to wrist (EW) length, the shoulder to elbow (SE) length, and the shoulder to hip (SH) length, with the following formula:

$$HD = EW + SE * \cos(45^\circ) + SH * \sin(\theta)$$

Figure 20 shows a diagram indicating how the distances were calculated. The elbow angle was assumed to be 45°, and θ was the calculated average back angle for the litter position.

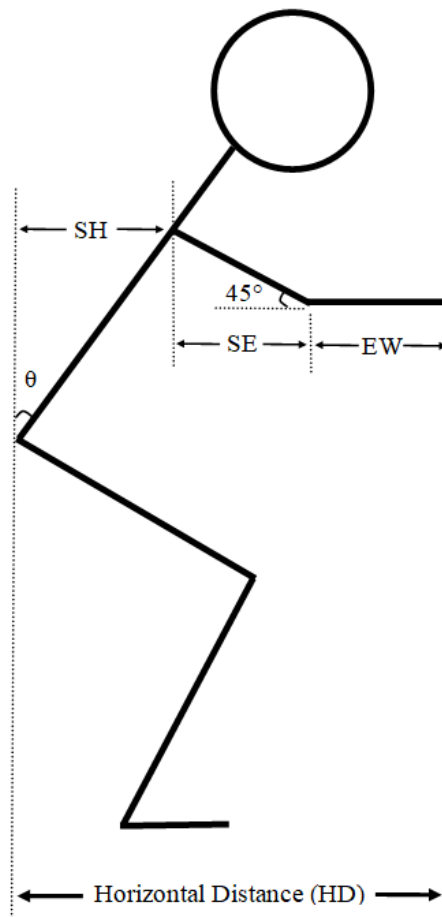


Figure 20. Horizontal distance used in force calculations.

For the load value in the compressive force calculations, two values were used. First, the force was estimated if the subject lifted half the load weight of 245 lb for a total of 122.5 lb. The second load value assumed the subject took a quarter of the load weight which was 61.25 lb. This was done because sometimes the subjects would take both handles from the litter bearers, while others allowed at least one litter stirrup to be placed on the litter position before taking the weight of the manikin.

Figures 21 through 30 show the estimated force values for the two load conditions. The half-load weight estimations are indicated by the blue triangles, and the quarter-load weight estimations are indicated by the orange squares. These values are estimations based on the assumptions made; they represent the compressive force in lb on the L5/S1 vertebral disk using the average back angles. There are also two lines on each graph. The lower grey line is at 770 lb, at which the NIOSH guidelines state there is low risk of back injury or pain under the line. The upper red line is at 1430 lb, at which there is high risk of back injury or pain to nearly all workers (Kohn & Bloswick, 1999).

For the IMMSS top load trial (Figure 21), if it was assumed that the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If it was

assumed that the subject only lifted one fourth of the manikin weight, five out of the 17 subjects were under the high-risk limit but still over the recommended safe lifting limit.

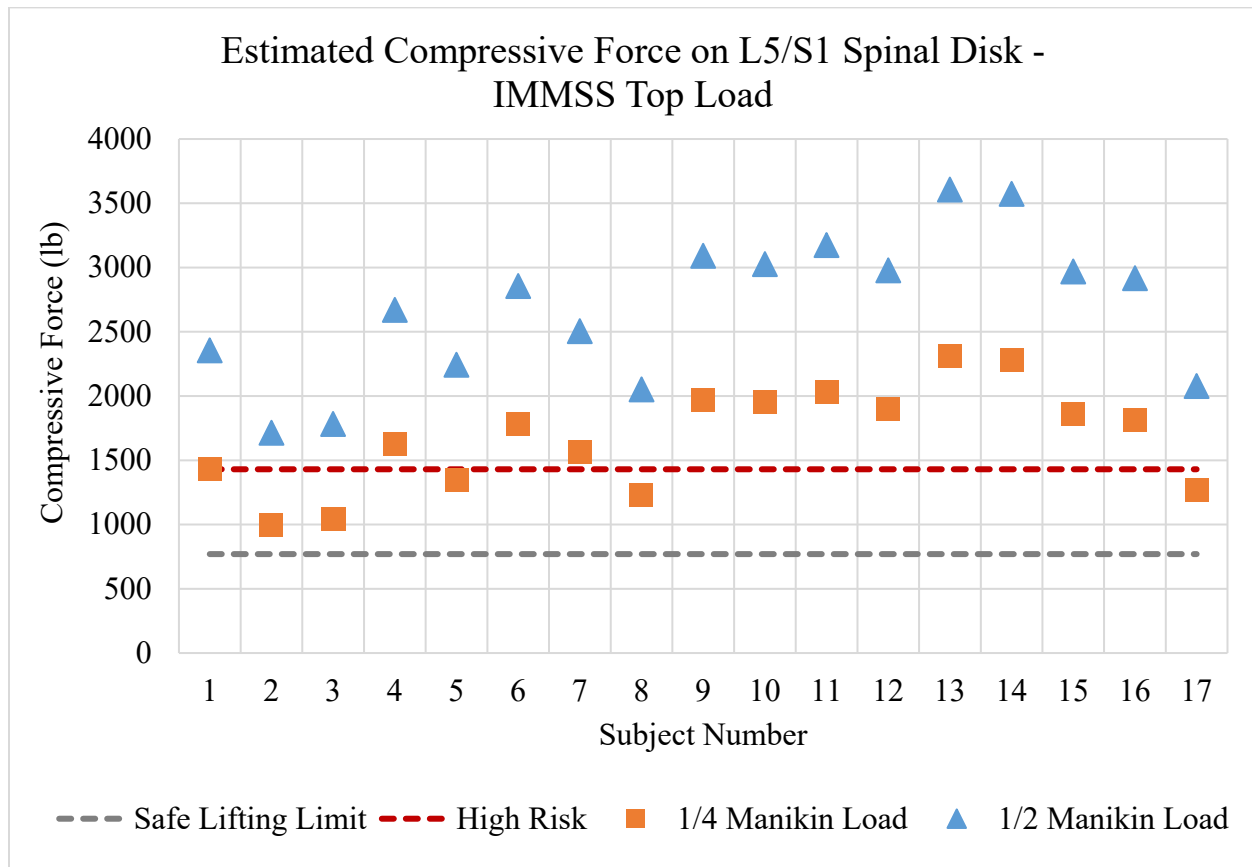


Figure 21. Estimated compressive force for the IMMSS top load trial.

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For the IMMSS top unload trial (Figure 22), Subject 7's data is not on the graph because no usable back angle data could be collected. For the other subjects, if they lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 16 subjects were under the high-risk limit but still over the recommended safe lifting limit.

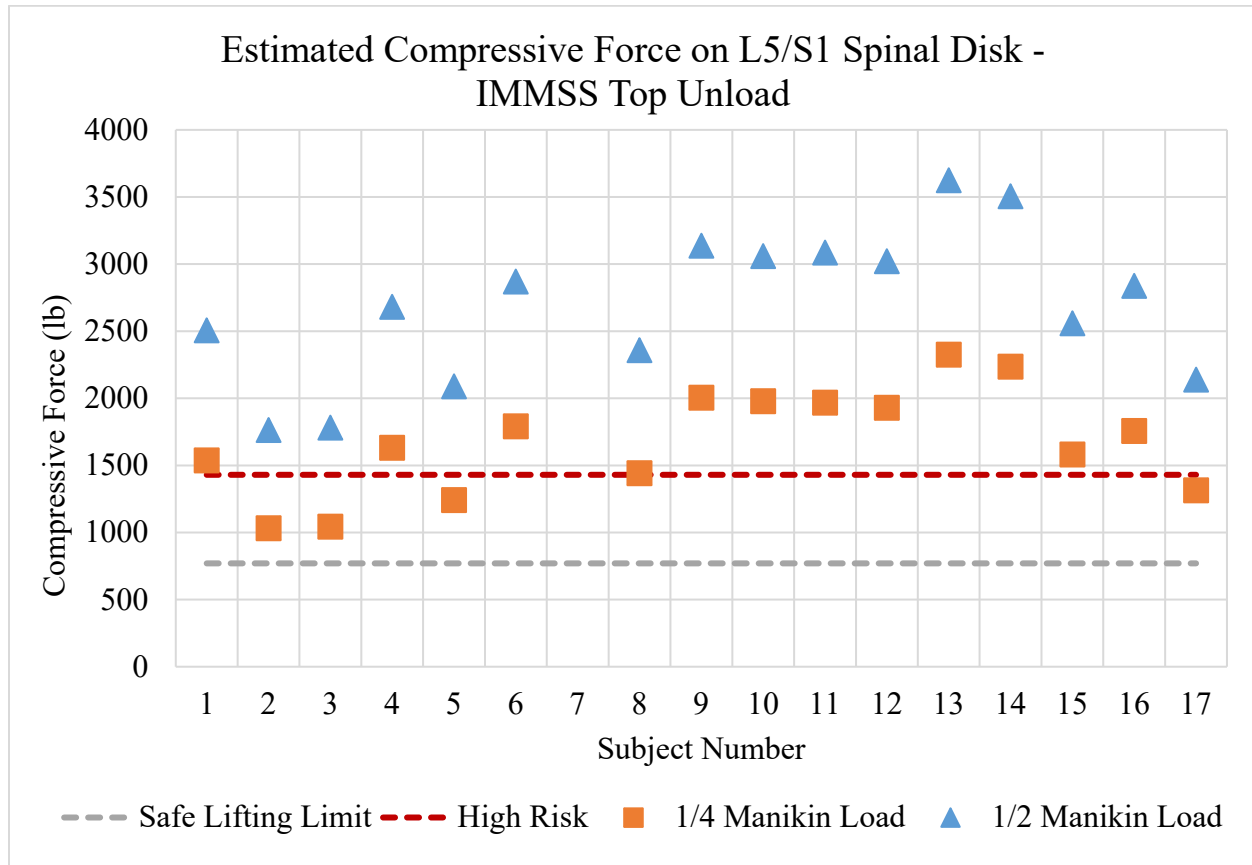


Figure 22. Estimated compressive force for the IMMSS top unload trial.

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For the IMMSS bot load trial (Figure 23), Subject 17's data is not on the graph because no usable back angle data could be collected. For the other subjects, if they lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, five out of the 16 subjects were under the high-risk limit but still over the recommended safe lifting limit.

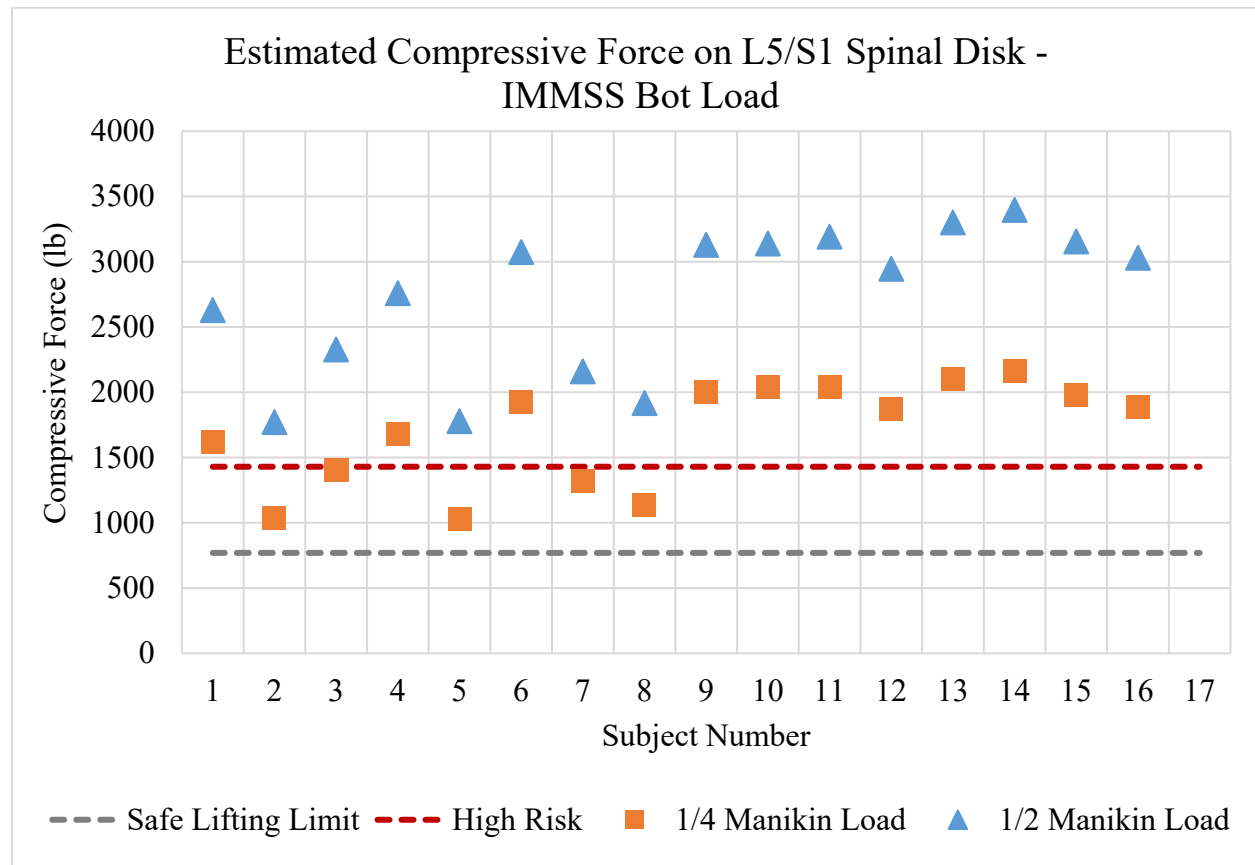


Figure 23. Estimated compressive force for the IMMSS bot load trial.

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For the IMMSS bot unload trial (Figure 24), estimated values for all 17 subjects could be calculated. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 17 subjects were under the high-risk limit but still over the recommended safe lifting limit.

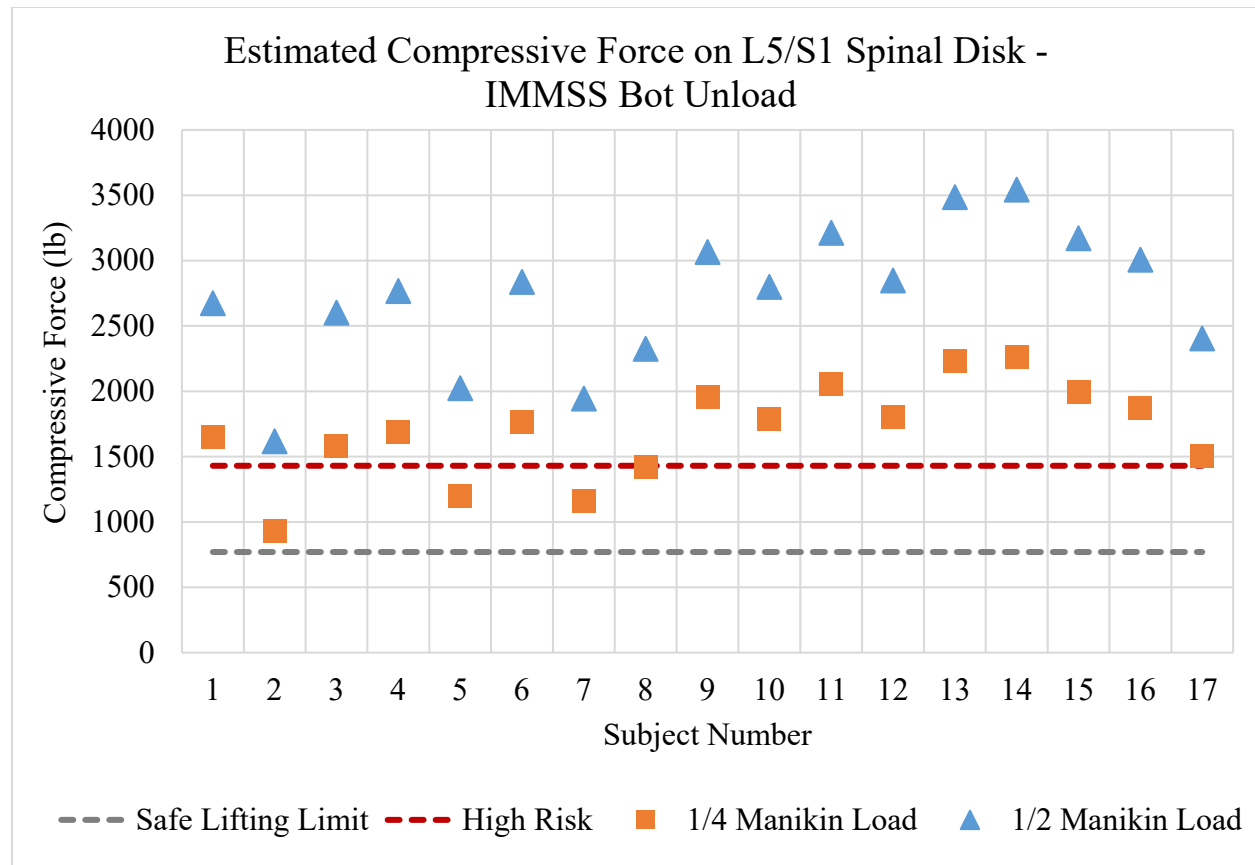


Figure 24. Estimated compressive force for the IMMSS bot unload trial.

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For the BMI top load trial (Figure 25), estimated compressive force values for all 17 subjects were able to be calculated. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, five out of the 17 subjects were under the high-risk limit but still over the recommended safe lifting limit.

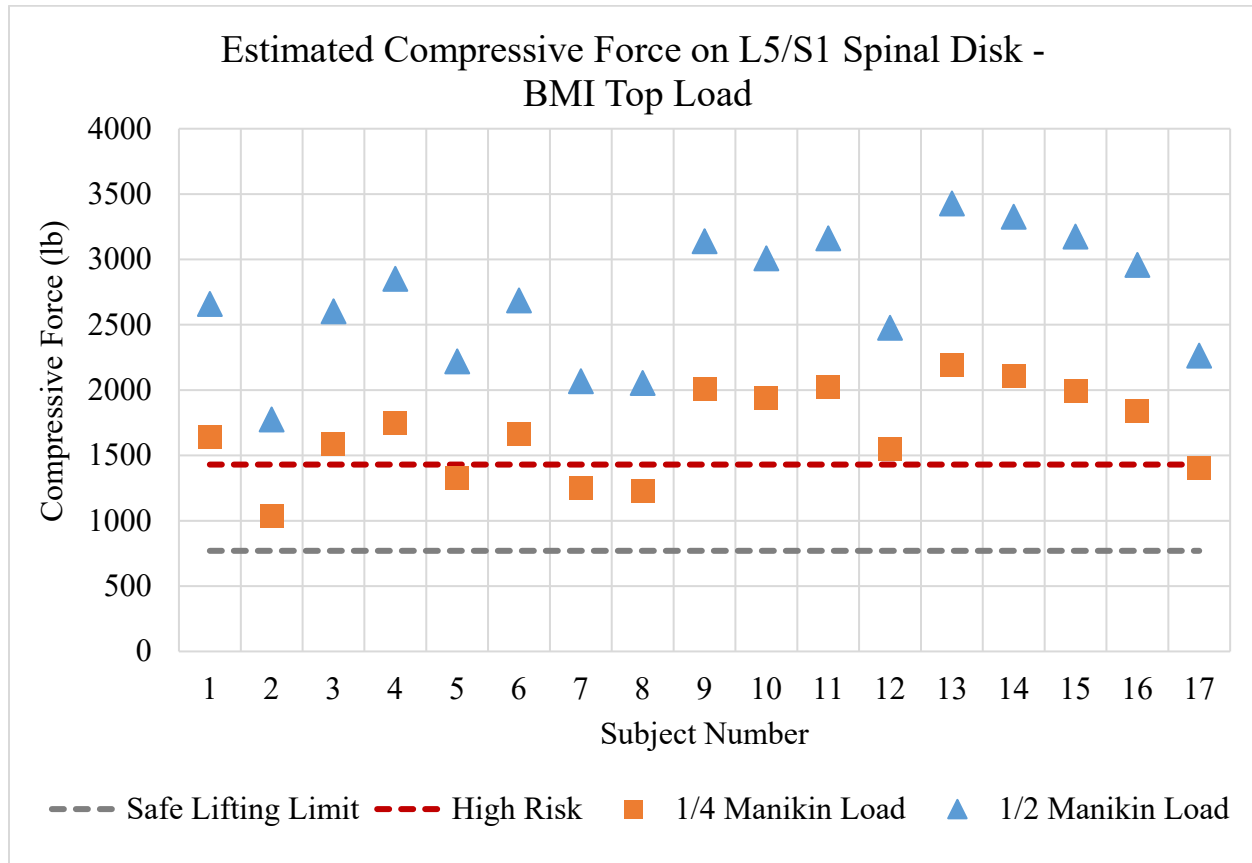


Figure 25. Estimated compressive force for the BMI top load trial.

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For the BMI top unload trial (Figure 26), estimated compressive force values for all 17 subjects were able to be calculated. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, five out of the 17 subjects were under the high-risk limit but still over the recommended safe lifting limit.

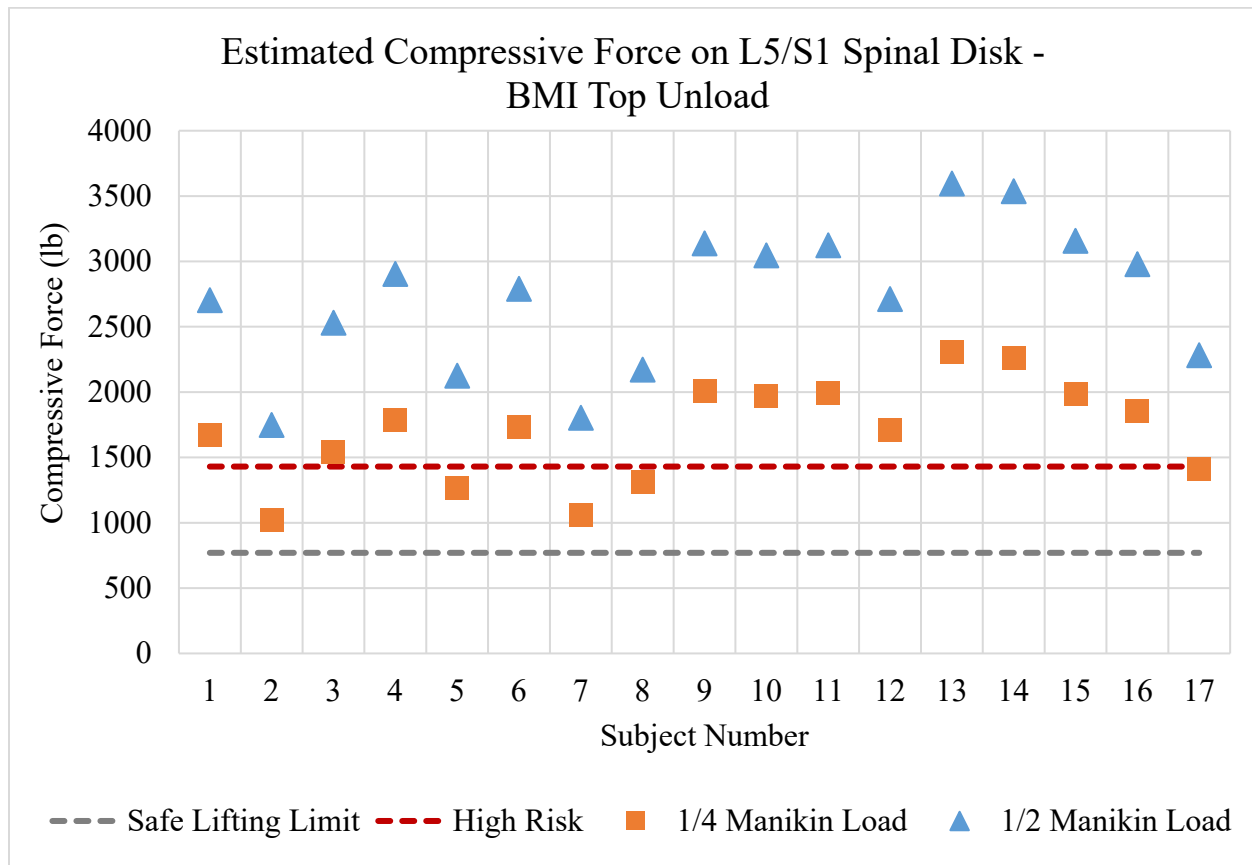


Figure 26. Estimated compressive force for the BMI top unload trial.

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For the BMI mid load trial (Figure 27), Subject 7's data is not on the graph because no usable back angle data could be collected. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 16 subjects were under the high-risk limit but still over the recommended safe lifting limit.

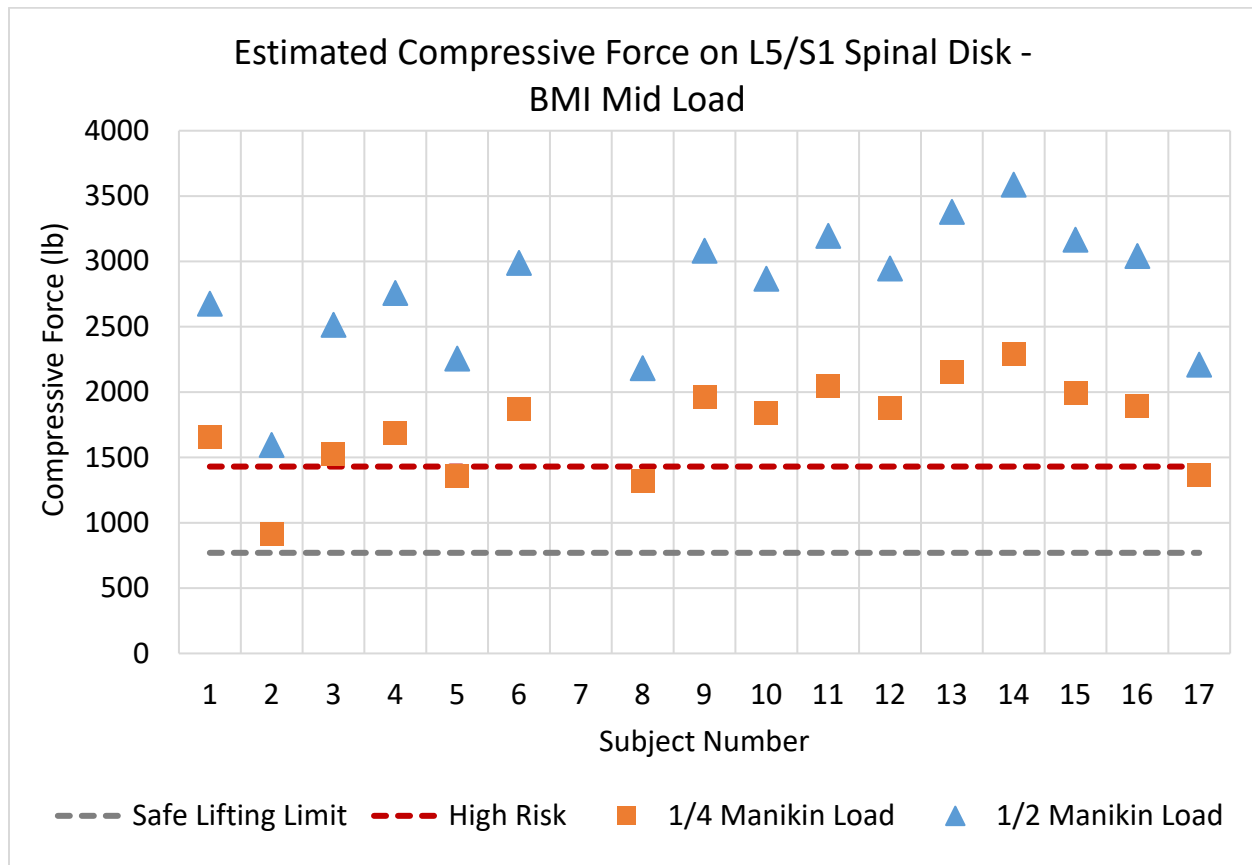


Figure 27. Estimated compressive force for the BMI mid load trial.

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For the BMI mid unload trial (Figure 28), Subject 3 and Subject 17's data are not on the graph because no usable back angle data could be collected. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 15 subjects were under the high-risk limit but still over the recommended safe lifting limit.

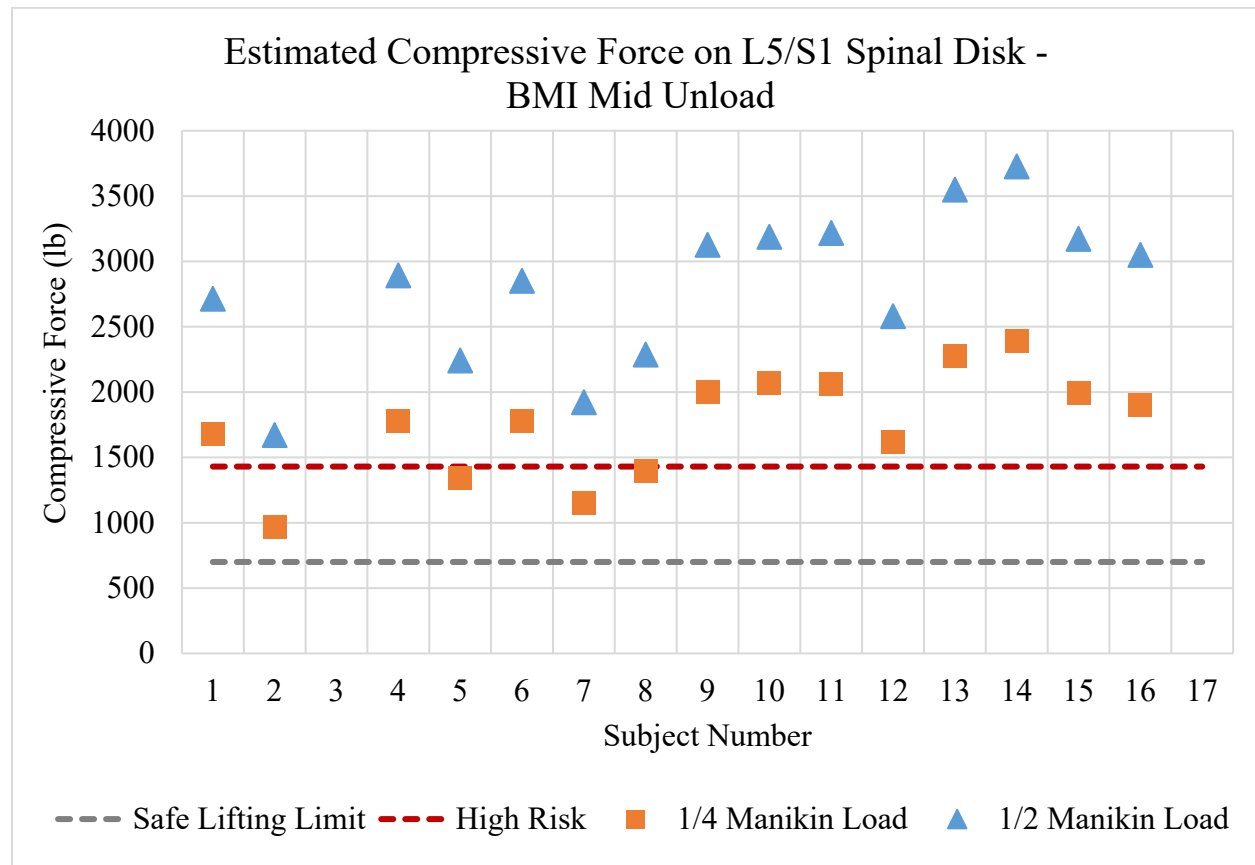


Figure 28. Estimated compressive force for the BMI mid unload trial.

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For the BMI bot load trial (Figure 29), Subject 7's data is not on the graph because no usable back angle data could be collected. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 16 subjects were under the high-risk limit but still over the recommended safe lifting limit.

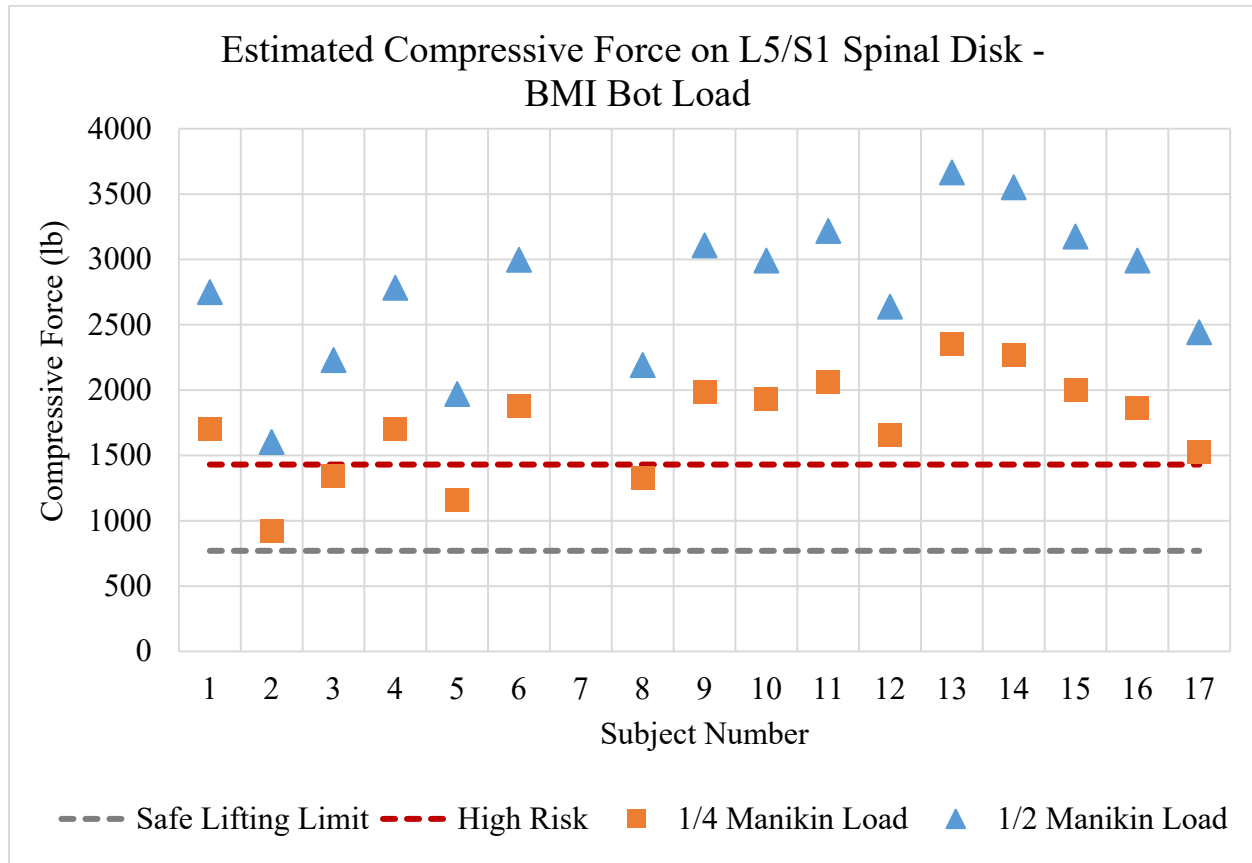


Figure 29. Estimated compressive force for the BMI bot load trial.

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For the BMI bot unload trial (Figure 30), Subject 3 and Subject 17's data is not on the graph because no usable back angle data could be collected. If the subject lifted one half of the manikin weight, all the estimated values were above the high-risk line. If the subject only lifted one fourth of the manikin weight, four out of the 15 subjects were under the high-risk limit, but still over the recommended safe lifting limit.

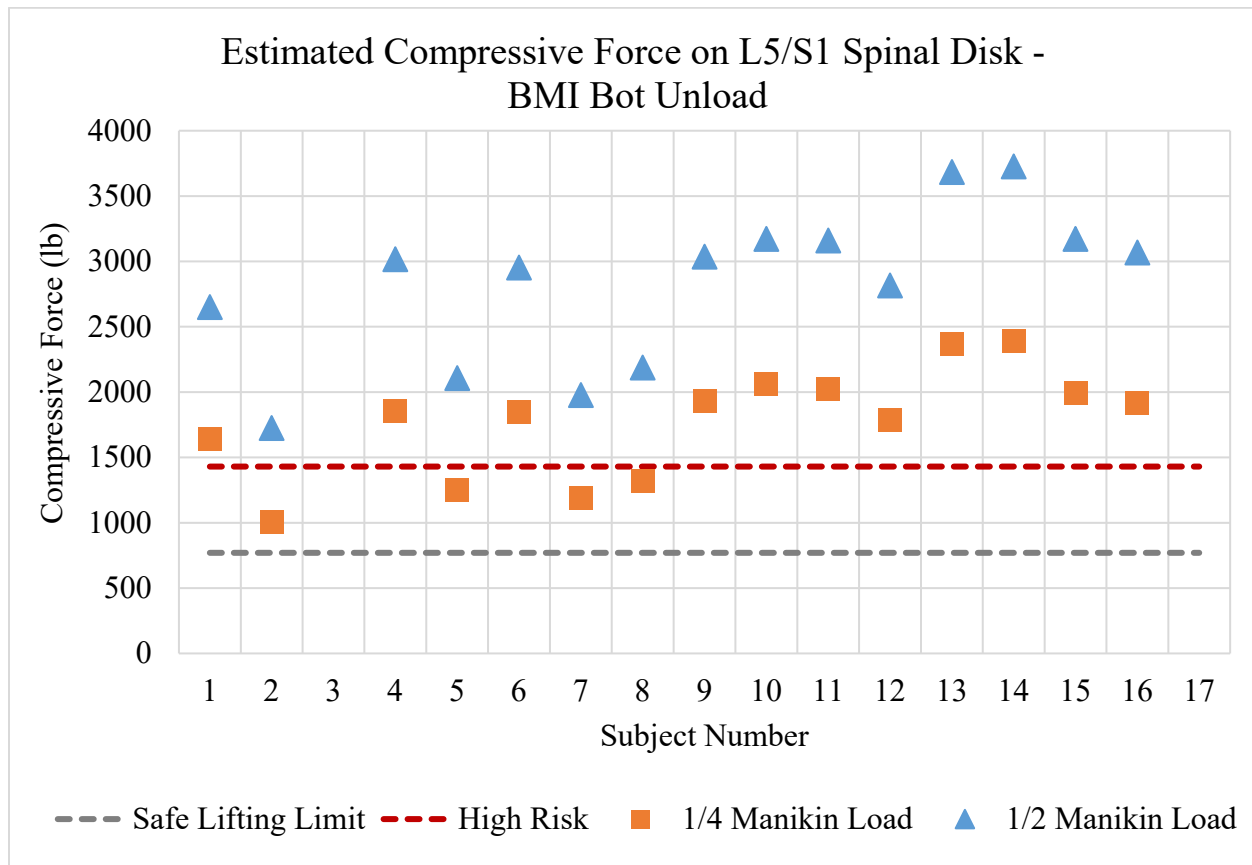


Figure 30. Estimated compressive force for the BMI bot unload trial.

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Discussion

En route care providers are reporting injuries from the painful postures during loading and unloading patients in the MEDEVAC environment. Based on the questionnaire data that was collected after each litter position, all subjects mentioned at least one posture and one area of the body negatively affected.

The MIL-STD-1427, which is the Department of Defense Design Criteria Standards, “establishes the general human engineering criteria for design and development of military systems, equipment, and facilities.” (Department of Defense, 2020) For lifting heavy weights (more than 30 lb) or large control displacements (more than 15 in. in a fore-aft direction) the MIL-STD-1427 directs that the person lifting should have enough space to move their entire body. For this study, the average height with the helmet of the subjects was 71.38 in. and the height of the MEDEVAC interior is 54.25 in. The minimum height for the subjects was 65.9 in., so none of the subjects were able to stand fully upright in the space.

The MIL-STD-1427 defines the maximum allowable weight for a single lifter is 51 lb for two handed lifting in the ideal condition. The weight of a 95th percentile Soldier is 245 lb without gear; if loading with a four-man litter team it can be assumed that subject was handling between one half (122.5 lb) to one fourth (61.25 lb) of the manikin’s weight. Both of these weights are over the recommended safe lifting limit.

The average back angle indicated a stooped lifting position, but the average knee angles indicated a squatting position. This means that no matter which posture the participants were using during the study, they were not completing the lifting tasks according to the general best practices. It is expected these motions could lead to injuries.

From the estimated compression force calculations, all the estimations were over the recommended safe compressive force limit of 770 lb. If it was assumed the subject took one half of the weight, every single subject was over the high-risk limit (1430 lb) for all positions and trials. If the subjects only took one fourth of the manikin weight, then around one third of the subjects were under the high-risk limit but still over the recommended safe limit. If it was assumed the subjects took only a quarter of the weight, then the force estimate was reduced an average of 40%. Other factors that affected the amount of load was horizontal distance from the hands to the back; the higher the average angle of the back increased this distance, which increased the compressive force.

The study has several limitations in the design and data analysis. The cramped environment and limited number of motion tracking cameras allowed only the data from the left arm and leg be collected. To pick up a marker, the software requires that three cameras have line-of-sight at all times. The medical interior simulator contains many obstacles that could disrupt the cameras line-of-sight, including the litter pans, litter with patient, litter pan support structure, and the subject’s own body.

Since the angle data represents discrete snapshots of the postures the subjects exhibited and not a dynamic examination of the postures, the data analysis will have some margin of error for the average data values.

Conclusion

The results from this study agree with the qualitative anonymous survey the USAARL provided to enroute care providers (Conti, 2019). In that study 87% of respondents ($n = 60$) reported suffering from lower back injuries, where the largest contributing factor was loading and unloading litters. In this study 77% ($n = 17$) of the subjects reported lower back discomfort from loading and unloading the litter. Also, from the USAARL survey, 60% ($n = 60$) of respondents reported at least one MEDEVAC feature negatively affected patient handling, and this study 94% ($n = 17$) reported at least one MEDEVAC feature negatively affecting the trial.

The estimated compressive force values were all over the safe lifting limit. When loading patients, the litter bearers should be sure to assist as much as possible to reduce the amount of weight to the medic, who is likely to be in an awkward posture. New technologies that may be able to help lift the litter into position without requiring awkward postures by the CCFP should also be considered, as well as perpendicular loading systems like the Carousel system. The Carousel is a discontinued U.S. Army MEDEVAC litter system that rotated for perpendicular loading and parallel travel. This reduced the amount of lifting the CCFP preformed, since the litter bearers could easily load the patient with minimal lifting by the CCFP. The IMMSS has a feature that allows the litter pan to swing out slightly to allow angled loading, but it is not always used. The design of the feature makes it difficult to move the pan into the load position and there is a possibility of discomfort to the patient after loading when securing back into the travel position due to jolting of the pan. The BMI only can be loaded parallel to the long axis of the helicopter, which means the CCFP must perform awkward postures to get the litter onto the litter pan.

These findings will contribute to the development of future MEDEVAC medical interiors and prevent injuries to the enroute care providers during patient loading and unloading procedures.

References

- Barazanji, K., Eslinger, A., Brown, D., Hildebrandt, G., Squire, C., Eddins, J., Oldorf, L., Bowers, B., Wilson, R. & Warren, J. (2015). *Aeromedical evacuation enroute critical care validation study* (Report No. 2015-07). U.S. Army Aeromedical Research Laboratory.
- Bloswick, D. S., & Villnave, T. (2000). Ergonomics. In: R. L. Harris (Ed.), *Patty's industrial hygiene* (5th ed., Vol. 4). John Wiley & Sons, Inc.
- Brice, J., Studnek, J., Bingham, B., Martin-Gill, C., Custalow, C., Hawkins, E., & Morrison, L. (2012). EMS provider and patient safety during response and transport: Proceedings of an ambulance safety conference. *Prehospital Emergency Care*, 16(1), 3 – 19.
10.3109/10903127.2011.626106
- Conti, S., Kroening, L., Kinsler, R., Lloyd, A., & Molles, J. (2019). *Optimal physical space for en route care: Medic posture and injury survey results* (Report No. 2019-18). U.S. Army Aeromedical Research Laboratory.
- Department of Defense. (2020) *Design criteria standards: Human engineering*. MIL-STD-1472H.
- Department of the Army. (2020). *Holistic health and fitness testing*. Army Techniques Publication No. 7-22.01.
- Department of Defense. (2012). *Protection of human subjects and adherence to ethical standards in DoD-supported research*. Department of Defense Instruction 3216.02.
- Deros, B., Darius, D., Thiruchelvam, S., Othman, R., Ismail, D., Rabani, N. F., Hatta, M., Hassan, A., & Zakaria, N. I. (2016). Evaluation on ambulance design and musculoskeletal disorders risk factors among ambulance emergency medical service personnel. *Iranian Journal of Public Health*, 43(1), 52–60.
- Gordon, C., Blackwell, C., Bradtmiller, B., Parham, J., Barrientos, P., Paquette, S., Corner, B., Carson, J., Venezia, J., Rockwell, B., Mucher, M., Kristensen, S. (2012). *2012 Anthropometric survey of U.S. Army personnel: Methods and summary statistics* (Report No. TR-15/007). U.S. Army Soldier Research, Development and Engineering Center.
- Hwang, S., Kim, Y. & Kim, Y. (2009). Lower extremity joint kinetics and lumbar curvature during squat and stoop lifting. *BMC Musculoskeletal Disorders*, 10, 15.
<https://doi.org/10.1186/1471-2474-10-15>
- Johnos, W. (2011). Prevalence of upper extremity musculoskeletal disorders. *Musculoskeletal Disorders*, 5(2), 187–190. 10.1155/2015/517346
- Kinsler, R. & Barazanji, K. (2011). *Assessment of fixed position litter loading in the HH-60M MEDEVAC helicopter (Technical Memorandum 2011-19)*. U.S. Army Aeromedical Research Laboratory.

- Kohn, J. P., Bloswick, D. S. (1999). Ergonomic task analysis and risk assessment. In J. P. Kohn (Ed.), *Ergonomic Process Management*. Lewis Publishers.
- Lester, J., Hsu, S., & Ahmad, C. (2012). Occupation hazards facing orthopedic surgeons. *American Journal of Orthopedics*, 41(3), 132–139.
- Maguire, B. (2005). Occupational injuries among emergency medical services personnel. *Prehospital Emergency Care*, 9(4), 405–411. 10.1080/10903120500255065
- Merryweather, A. S., Loertscher, M. C., Bloswick, D. S. (2009). A revised back compressive force estimation model for ergonomic evaluation of lifting tasks. *Work*, 34(3), 263–72. 10.3233/WOR-2009-0924. PMID: 20037241.
- Reichard, A., Marsh, S., Tonozi, T., Konda, S. & Gormley, M. (2017). Occupational injuries and exposures among emergency medical services workers. *Prehospital Emergency Care*, 21(4), 420–431. 10.1080/10903127.2016.1274350
- Steiner, T. (2004). Lifting the burden: The global campaign against headache. *Lancet Neurology*, 3, 204–205.
- Stobbe, T. & Bobick, T. (1986). Musculoskeletal injuries in underground mining. *Annual National Conference of Government Industrial Hygienists*, 14, 71–76.
- The National Institute for Occupational Safety and Health. (2007). *Ergonomic guidelines for manual material handling* (Publication No. 2007-131). Center for Disease Control and Prevention.
- The National Institute for Occupational Safety and Health. (2013). *Emergency medical services workers injury data*. Center for Disease Control and Prevention.
- Toivonen, R. & Fagerstrom, V. (2011). *The effect of patient transport stretchers on work ergonomics among paramedics*. Finnish Institute of Occupational Health.
- Torma-Krajewski, J., Wiehagen, W., Etcheverry, A., Turin, F. & Unger, R. (2009a). Using ergonomics to enhance safe production at a surface coal mine - A case study with powder crews. *Journal of Occupational and Environmental Hygiene*, 6(10), D55–D62.
- Torma-Krajewski, J., Wiehagen, W., Etcheverry, A., Turin, F. & Unger, R. (2009b). Ergonomics. *Journal of Occupational and Environmental Hygiene*, 6(10), D55–D62. 10.1080/15459620903146636.
- United States Department of Labor. (n.d). Safety and health topics: Ergonomics. <https://www.osha.gov/ergonomics>.

Appendix A. Acronyms and Abbreviations

BMI	Basic Medical Interior
CCCRP	Combat Casualty Care Research Program
CCFP	Critical Care Flight Paramedic
cm	Centimeter
DoD	Department of Defense
EMS	Emergency Management System
IMMSS	Interim MEDEVAC Mission Support System
in.	Inches
Kg	Kilogram
lb	Pounds
MEDEVAC	Medical Evacuation
MSD	Musculoskeletal Disorder
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PPG	Personal Protective Gear
ft	Feet
USAARL	U.S. Army Aeromedical Research Laboratory

Appendix B. Medical History Questionnaire

Medical History Questionnaire

GENERAL HEALTH:

Date of last physical examination: _____

Date last consulted a doctor: _____

Nature of consultation: _____

Are you currently in good health?

YES NO

If no, please explain: _____

Do you have any medical waivers?

YES NO

If yes, please explain: _____

Do you have any profiles that prevent lifting heavy weights, crouching in tight spaces or bending over?

YES NO

If yes, please explain: _____

Do you have or previously had any injuries/conditions in the following areas?

	YES	NO	If yes, please explain. (Injury, Condition, Procedure, Date, etc.)
Neck	☐	☐	
Upper Back	☐	☐	
Shoulder	☐	☐	
Arms	☐	☐	
Lower Back	☐	☐	
Knees	☐	☐	
Ankles	☐	☐	

Do you have any other known medical conditions that could be negatively affected by lifting/moving heavy objects?

YES NO

If yes, please explain: _____

Did you pass the Army Combat Fitness Test (ACFT)?

YES NO Did Not Test

If no, please explain: _____

Do you have any known severe skin sensitivities or allergies to adhesives? (glues, surgical tape, etc.)

YES NO

If yes, please explain: _____

Are you prone to claustrophobia?

YES NO

If yes, please explain: _____

Are you currently pregnant or trying to get pregnant?

YES NO N/A

Pregnancy Test Result:

Negative

Positive

Date of Test:

Signature of Verifying Physician:

To be completed by Study Physician.

Does the participant qualify for the study?

YES NO

Reason for disqualification:

Principal Investigator's Signature & Date

Study Physician's Signature & Date

Volunteer's Signature & Date

Appendix C. Lifting Assessment

Lifting Assessment

Subject Code: _____

- (1) A study team member will demonstrate proper lifting technique by performing a kettlebell deadlift.
- (2) The participant will complete three consecutive kettlebell deadlifts while holding one 40lb kettlebell in each hand, totaling 80lbs.
- (3) The study physician will assess technique and ability and determine if the participant is safe to continue with the study.

Proper lifting technique is demonstrated (with dumbbells) in Figure 1. Proper lifting form includes feet shoulder width apart, flat back, head aligned with the spine, heels in contact with the ground and bending at the knees and hips. Poor lifting is demonstrated (with deadlift bar) in Figure 2. Improper lifting form or failed attempts include rounding or flexing of the spine, knees collapsing inwards, hips raising above shoulders, and dropping or lowering the weight in an uncontrolled manner.

* The participant can choose to stop at any time or the study physician may halt testing for safety reasons.



Figure 1. Proper lifting technique.



Figure 2. Improper lifting technique.

Did the participant successfully complete three consecutive kettlebell deadlifts?

☐ YES ☐ NO

Did the participant exhibit proper lifting technique during the three kettlebell deadlifts?

☐ YES ☐ NO

If no to either, or the assessment was repeated, please explain.

Did the participant experience any discomfort in joints or any muscle groups during the assessment? (i.e. upper/lower back, shoulder)

☐ YES ☐ NO

If yes, please explain.

Is the participant physically fit to participate in this study?

☐ YES ☐ NO

Reason for disqualification: _____

Study Physician Signature

Date

Appendix D. Position Evaluation

Position Evaluation

Subject Code: _____

Configuration: ☐ BMI ☐ IMMSS

Litter Position: ☐ Top ☐ Middle (BMI only) ☐ Bottom

Question 1: “Can you rate the difficulty of the trials on scale from 1-5? 1 meaning that the trials were completed without any awkward positions and 5 meaning that the trials required constant awkward positions.” Rating: _____

Question 2: “Were any movements painful or uncomfortable during these trials? Please explain.”

Check off any movement(s) that were mentioned;

☐ Bending ☐ Squatting ☐ Kneeling ☐ Twisting ☐ Overextending

☐ Reaching ☐ Lifting heavy weight ☐ Other: _____

Question 3: “What areas of the body were negatively affected by these trials?”

Check off any body part(s) that were mentioned;

☐ Lower Back ☐ Upper Back ☐ Neck ☐ Shoulders

☐ Knees ☐ Ankles ☐ Other: _____

Question 4: “Did any MEDEVAC features (compartment size, litter system, helmet) negatively impact you in completing these trials?”

Check off any MEDEVAC feature(s) that were mentioned;

☐ Litter ☐ Litter Pan Height ☐ Compartment Size

☐ Personal protective gear ☐ Other: _____

Question 5: “Are there any other comments you would like to include about your ability to complete these trials?”

Notes: Provide any follow up questions and responses here or note if the trials were not completed.

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Appendix E. Anthropometric Measurements

Table E1. Subject Anthropometric Measurements

Subject	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15	S16	S17
Dominant Hand	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right	Right
Weight (kilograms [Kg])	76.0	79.2	58.1	78.7	88.5	77.1	107.5	80.3	80.6	97.5	85.6	102.8	105.6	102.6	82.5	73.1	87.8
Weight with Gear (Kg)	89.5	92.7	71.1	92.2	102.0	90.6	121.1	93.8	94.1	111.1	100.3	116.4	120.4	117.3	96.1	86.6	101.3
Stature (centimeter [cm]) with boots and helmet	185.7	190.2	167.4	183.0	189.7	176.0	185.5	175.6	188.2	179.9	182.9	174.4	189.3	195.5	169.6	173.1	176.9
Cervical Height (cm)	152.9	158.7	139.3	154.6	157.9	146.5	155.7	143.9	158.5	151.0	154.3	145.0	158.4	163.6	140.9	144.9	147.0
Shoulder-Elbow (cm)	35.2	34.6	32.4	38.3	35.8	30.7	34.3	35.6	39.3	36.2	33.4	32.5	36.2	38.8	30.8	33.4	33.5
Elbow-Wrist (cm)	28.6	27.8	25.5	30.8	29.6	26.8	30.6	28.2	29.2	28.3	26.9	29.4	29.8	29.4	26.7	27.8	26.7
Biacromial Breadth (cm)	42.5	42.0	40.7	41.1	43.6	42.1	44.1	38.8	35.9	41.8	41.6	44.2	45.4	44.0	44.3	39.3	40.6
Waist-Back Length (cm)	44.4	49.1	40.7	48.0	56.1	47.9	47.9	42.4	37.0	39.8	45.5	47.7	56.7	56.7	49.2	44.7	41.9
Chest Breadth (cm)	32.7	34.7	31.9	32.2	35.9	33.4	34.9	36.0	30.1	34.1	33.2	39.0	39.1	36.0	37.7	34.0	34.4
Acromion-Acilla (cm)	13.7	13.2	13.8	15.2	14.6	13.1	12.5	4.7	13.5	13.1	11.6	12.2	13.8	16.8	11.8	13.5	12.9
Bicristal Breadth (cm)	30.6	29.8	29.4	29.0	31.4	32.9	34.9	31.2	28.9	35.1	32.3	33.4	34.6	35.7	32.8	29.5	30.0
Pelvic Link (cm)	16.6	20.2	9.0	10.3	10.2	13.2	14.4	10.0	16.5	7.7	14.0	14.9	14.0	16.0	14.7	16.1	14.5
Thigh Link (cm)	35.3	39.9	29.1	37.5	44.2	43.5	39.7	38.7	40.5	48.7	34.6	36.0	33.9	46.6	31.1	36.8	34.5
Calf Link (cm)	38.9	42.4	33.4	40.6	35.6	39.6	43.6	40.2	42.5	41.4	40.7	37.1	40.2	41.5	32.9	36.9	40.3
Foot (Boot) Length (cm)	31.9	31.2	27.5	30.0	30.4	30.1	30.8	30.4	29.3	29.2	29.8	29.4	32.4	33.1	28.6	28.1	28.7

Appendix F. Body Angle Data

Table F1. IMMSS Top Load Average Angle Data per Subject

IMMSS Top Load												
Subject	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	18.89	41.75	31.09	6.15	38.87	24.54	30.55	4.60	73.82	29.32	48.16	13.67
S02	179.53	164.38	171.57	3.87	125.28	74.12	102.93	15.77	148.31	4.95	63.27	54.33
S03	26.18	8.19	18.35	7.43	107.31	19.66	69.08	25.38	102.44	6.86	50.40	37.09
S04	55.12	18.90	37.07	10.29	72.17	25.77	49.59	14.95	100.40	28.41	61.25	24.12
S05	26.84	8.98	20.30	5.25	108.06	58.76	90.24	14.41	137.82	13.89	71.37	40.07
S06	67.89	51.68	58.02	3.98	33.54	16.03	22.31	4.91	77.85	12.12	38.31	20.82
S07	53.40	4.27	28.73	18.56	70.42	30.09	53.76	10.24	140.60	22.98	99.73	33.39
S08	35.77	11.19	20.53	9.35	78.34	50.27	68.07	8.87	95.91	15.76	63.13	26.51
S09	84.95	64.45	75.95	6.66	30.56	0.39	19.87	7.62	14.72	0.08	5.09	4.06
S10	72.28	45.76	61.62	7.11	60.71	21.95	42.05	10.39	56.28	25.51	40.75	7.31
S11	89.69	58.97	77.39	7.01	39.62	21.08	27.07	5.03	151.36	52.36	129.22	36.18
S12	54.98	44.92	51.20	3.79	53.41	35.12	47.48	5.25	131.22	40.20	88.04	37.30
S13	107.30	57.13	66.27	11.33	43.72	14.98	34.01	7.17	58.82	22.65	43.45	11.26
S14	78.07	43.29	62.13	8.97	66.95	30.99	44.31	10.12	124.72	16.57	57.47	37.44
S15	75.83	7.06	62.54	18.20	55.56	19.64	30.44	9.18	126.94	32.40	58.04	22.29
S16	82.71	54.28	64.61	9.05	48.08	17.18	33.20	11.33	105.33	24.43	66.83	30.82
S17	45.94	14.49	23.28	6.96	113.26	58.92	85.28	13.20	129.96	17.38	82.34	43.16

*Note. “-” indicates no usable data was collected.

Table F2. IMMSS Top Unload Average Angle Data per Subject

IMMSS Top Unload												
Subject	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	46.07	20.48	37.16	7.00	47.87	19.03	30.88	8.63	69.11	31.11	49.99	10.70
S02	174.88	166.02	170.05	2.68	101.16	74.56	93.30	5.91	157.41	34.01	66.33	43.81
S03	27.43	6.93	18.28	7.44	89.52	46.24	68.87	13.72	90.86	3.70	41.02	31.62
S04	46.07	13.66	37.53	9.68	90.58	31.13	60.11	16.12	113.56	32.87	68.57	24.14
S05	24.62	3.68	15.87	7.93	141.96	81.10	108.80	17.28	158.21	11.26	86.23	45.07
S06	71.56	47.26	58.90	5.13	27.58	1.20	16.61	8.84	77.30	11.50	36.42	15.64
S07	-	-	-	-	-	-	-	-	140.79	61.38	106.48	21.28
S08	42.34	16.65	32.34	5.46	73.38	38.21	50.73	8.61	54.32	13.71	27.61	11.45
S09	92.94	84.37	87.65	2.52	25.90	13.43	17.84	2.96	7.45	0.11	2.88	2.45
S10	72.53	57.00	63.93	3.84	57.68	23.87	36.83	8.23	141.28	31.40	72.64	41.06
S11	80.01	56.93	67.90	7.01	56.82	9.79	33.28	11.91	76.27	11.59	46.31	18.08
S12	59.57	49.96	53.28	2.39	48.22	33.56	40.43	3.90	65.26	27.91	39.65	10.24
S13	71.94	62.75	67.42	2.50	49.93	26.41	40.33	6.41	86.39	28.75	48.17	13.05
S14	64.67	52.55	58.70	3.33	55.78	35.52	48.28	6.19	65.44	28.00	41.05	9.54
S15	74.97	0.10	41.46	30.51	36.69	0.13	20.28	12.59	131.28	32.26	90.67	30.56
S16	83.68	46.51	58.82	8.33	43.83	13.36	26.72	10.41	106.37	23.67	51.75	31.20
S17	31.68	16.99	25.51	4.70	93.13	53.16	78.45	11.31	133.91	28.21	81.34	39.27

*Note. “-” indicates no usable data was collected.

Table F3. IMMSS Bot Load Average Angle Data per Subject

IMMSS Bot Load												
Subject	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	32.09	47.46	42.54	3.56	24.18	46.13	36.10	5.60	176.67	1.14	123.13	73.98
S02	178.70	154.14	169.78	9.74	123.64	92.57	110.74	9.52	151.56	122.71	136.29	9.53
S03	65.67	37.05	43.76	6.83	75.21	29.83	69.07	12.36	92.73	8.93	76.96	20.34
S04	41.18	40.11	40.71	0.31	75.18	68.54	71.67	2.49	66.65	32.94	53.28	11.96
S05	11.74	3.30	7.27	3.01	106.51	38.72	64.87	23.21	147.39	79.19	120.69	23.45
S06	84.68	57.75	76.17	9.49	40.49	17.06	32.79	5.94	156.06	10.32	103.71	44.48
S07	23.06	9.91	18.15	3.75	48.84	30.30	40.30	6.26	121.42	110.19	116.71	3.41
S08	31.35	0.06	15.69	8.04	103.96	69.09	82.34	11.32	100.04	64.78	84.68	10.97
S09	98.15	93.09	96.20	1.22	39.67	24.94	31.30	5.11	12.33	0.35	5.53	3.89
S10	77.55	63.70	70.86	3.40	57.15	30.26	43.63	7.10	146.81	34.30	115.07	42.54
S11	87.45	76.03	80.27	2.69	42.79	28.76	38.05	2.93	149.46	45.90	133.61	30.96
S12	52.38	43.73	49.69	2.37	49.58	36.02	45.18	4.29	73.17	20.18	40.50	13.60
S13	76.87	34.99	51.28	12.65	58.30	17.85	43.06	14.74	128.22	19.82	79.21	31.35
S14	55.05	48.34	53.75	1.62	58.80	42.77	54.55	3.94	61.67	32.04	44.67	8.47
S15	83.31	74.43	81.61	2.16	40.53	8.43	23.48	6.39	154.92	23.14	130.45	41.58
S16	85.42	72.47	76.33	3.43	39.90	20.55	30.56	3.64	66.72	37.94	46.68	7.31
S17	-	-	-	-	-	-	-	-	-	-	-	-

*Note. “-” indicates no usable data was collected.

Table F4. IMMSS Bot Unload Average Angle Data per Subject

IMMSS Bot Unload												
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
Subject	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	63.92	38.15	44.55	6.54	50.57	23.95	35.18	6.68	81.76	0.38	37.11	27.83
S02	179.31	161.99	174.59	5.67	151.12	73.96	108.99	27.67	147.19	76.45	103.84	18.01
S03	75.29	43.76	61.68	8.34	88.82	50.84	66.48	9.83	137.41	38.12	82.07	32.41
S04	59.05	33.62	40.99	7.03	102.85	59.38	82.08	15.22	114.96	34.06	68.90	24.87
S05	28.22	4.58	14.05	6.27	103.35	37.84	85.38	22.53	139.53	32.57	56.28	33.03
S06	72.21	39.08	56.84	9.22	41.75	15.03	26.52	7.34	46.55	20.75	30.09	7.61
S07	37.51	0.29	11.81	11.15	46.17	9.76	34.33	7.74	145.03	104.63	125.49	8.66
S08	38.55	26.31	30.98	3.73	89.05	53.26	64.68	12.45	81.01	21.03	33.25	14.66
S09	109.25	104.88	107.53	1.24	27.75	18.36	24.74	2.96	10.93	2.12	6.41	3.16
S10	65.91	31.71	48.47	10.16	55.63	10.08	26.40	14.78	148.82	116.22	137.91	9.76
S11	90.52	79.01	85.25	2.74	55.43	23.39	40.70	13.18	135.14	39.74	98.75	36.19
S12	62.48	26.02	45.40	9.15	54.19	23.15	41.06	7.84	129.73	61.79	119.11	19.65
S13	77.82	35.97	59.52	14.53	64.76	32.96	49.34	11.01	93.77	17.98	57.20	25.84
S14	68.42	54.31	60.55	3.66	78.08	54.32	61.21	9.55	-	-	-	-
S15	95.82	79.97	86.16	5.05	37.58	10.22	16.27	7.94	124.76	40.45	91.88	32.78
S16	96.20	54.52	73.22	14.68	55.18	16.51	36.54	12.92	104.14	20.44	63.15	25.34
S17	44.58	29.10	35.88	3.87	106.39	61.99	88.90	13.96	137.14	13.78	90.21	45.55

*Note. “-” indicates no usable data was collected.

Table F5. BMI Top Load Average Angle Data per Subject

Subject	BMI Top Load											
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	50.52	38.39	43.91	2.86	45.22	31.08	35.50	3.70	73.65	22.05	44.88	20.83
S02	176.80	165.36	169.69	3.18	120.98	93.16	100.73	6.14	58.89	8.93	28.72	13.45
S03	84.17	51.18	61.86	10.47	62.87	28.11	46.25	8.78	111.64	10.62	50.18	37.17
S04	48.83	36.66	44.61	3.13	86.01	53.95	70.34	9.88	136.57	32.05	70.09	32.77
S05	23.64	14.91	19.60	2.46	122.34	94.55	111.76	6.77	131.36	26.52	72.00	34.64
S06	74.34	29.19	48.86	12.20	67.29	24.89	47.30	13.65	146.43	7.32	63.51	46.88
S07	21.20	8.13	15.40	3.16	75.90	58.50	65.09	5.28	114.12	101.01	107.60	3.38
S08	43.88	7.71	20.60	11.93	84.88	31.64	71.36	11.43	97.55	22.30	69.38	28.81
S09	95.03	86.38	89.84	2.71	37.84	17.07	21.60	4.79	35.30	0.10	3.81	8.22
S10	66.20	42.05	60.34	5.97	77.13	33.65	49.69	11.33	138.78	16.11	69.87	52.25
S11	87.19	68.68	75.55	4.24	35.17	10.38	27.34	5.00	153.20	40.33	120.61	44.61
S12	40.08	26.19	31.40	4.10	93.17	62.32	82.78	10.92	121.31	58.21	99.43	27.04
S13	66.61	48.24	56.77	4.97	60.35	46.26	55.03	3.38	110.60	17.02	82.87	32.68
S14	61.25	44.01	50.85	4.72	82.48	51.93	67.05	11.41	121.02	29.50	70.83	38.63
S15	95.11	81.71	89.20	4.10	24.39	6.03	13.48	6.10	126.68	36.95	97.49	34.30
S16	82.76	57.23	68.09	7.74	31.74	1.00	18.30	8.52	48.44	10.16	23.31	9.48
S17	38.39	24.25	30.25	3.32	96.29	69.72	84.31	7.93	140.55	36.27	83.05	38.93

*Note. “-” indicates no usable data was collected.

Table F6. BMI Top Unload Average Angle Data per Subject

Subject	BMI Top Unload											
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	52.05	37.25	45.98	4.38	55.37	34.33	41.87	5.51	70.12	19.78	45.02	11.93
S02	179.44	162.03	170.53	5.60	135.69	98.73	112.02	9.78	133.36	20.71	58.86	33.11
S03	63.00	52.75	56.28	3.29	48.05	27.01	40.07	5.02	49.57	0.77	19.27	18.40
S04	64.10	40.13	47.01	5.23	84.79	28.23	65.55	14.02	77.19	17.11	44.29	16.29
S05	24.76	7.14	16.92	7.46	97.52	55.38	82.32	13.00	130.13	40.67	78.05	40.29
S06	58.19	49.16	54.19	2.75	42.48	27.91	35.76	4.51	95.01	4.99	41.32	25.19
S07	21.20	0.54	7.78	5.36	41.10	15.43	31.10	7.95	142.23	104.28	126.18	10.90
S08	37.25	17.28	25.01	7.66	85.36	59.74	76.66	10.00	88.64	5.46	62.89	30.03
S09	95.99	90.75	91.61	1.63	25.48	20.21	21.47	1.07	5.41	0.01	0.49	1.27
S10	73.41	53.19	63.00	4.87	59.44	23.45	37.09	8.90	135.37	3.94	60.98	52.59
S11	84.30	5.01	71.33	25.10	95.28	17.09	35.12	22.70	135.94	28.91	53.93	24.97
S12	60.33	16.44	39.95	8.60	83.42	46.63	56.50	8.39	52.30	14.12	34.40	11.18
S13	80.03	48.61	65.62	8.18	49.88	17.51	31.54	7.87	40.16	15.21	30.57	7.14
S14	72.23	49.35	60.23	6.14	62.85	4.53	45.47	18.21	125.87	28.62	74.86	37.58
S15	92.20	75.98	82.05	5.52	21.45	8.81	14.47	3.58	120.23	24.43	56.45	30.08
S16	77.97	55.60	70.08	5.52	31.77	12.67	20.03	5.19	42.34	10.80	31.78	10.04
S17	38.53	16.05	30.93	6.12	100.39	71.73	85.25	9.01	139.82	29.76	83.13	42.30

*Note. “-” indicates no usable data was collected.

Table F7. BMI Mid Load Average Angle Data per Subject

Subject	BMI Mid Load											
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	54.30	36.73	44.67	4.57	61.69	27.94	37.46	9.36	79.06	53.01	62.81	7.36
S02	178.03	167.66	175.25	3.19	81.59	50.80	69.02	9.30	149.05	136.48	143.56	3.50
S03	60.62	47.27	55.11	4.63	72.93	32.81	50.41	15.52	101.64	100.23	100.74	0.44
S04	45.62	27.65	40.63	5.05	102.00	26.55	76.47	22.63	128.11	50.98	100.36	22.00
S05	24.61	14.84	20.65	3.90	123.61	76.72	103.91	13.58	138.58	14.49	82.56	42.40
S06	79.67	58.85	67.31	6.32	38.78	16.07	29.88	5.82	86.56	29.93	55.95	18.55
S07	-	-	-	-	-	-	-	-	145.17	116.74	128.35	8.03
S08	31.05	18.35	25.43	3.17	95.97	76.36	83.09	5.14	114.61	74.50	102.19	12.61
S09	112.98	95.24	105.43	4.45	39.14	15.60	30.01	6.31	-	-	-	-
S10	73.65	39.95	51.99	11.61	81.03	38.00	63.48	15.67	99.33	29.97	69.72	21.85
S11	96.48	72.90	80.73	5.86	43.59	20.62	31.15	9.10	140.09	37.13	87.40	41.39
S12	52.24	44.73	49.69	2.17	50.10	36.08	44.30	4.12	49.06	30.14	42.53	4.94
S13	72.79	42.30	54.56	11.79	64.26	45.35	53.75	5.62	92.43	16.95	62.77	30.67
S14	77.92	57.13	62.90	6.19	59.35	32.33	51.08	9.17	130.27	14.43	87.75	48.53
S15	88.54	77.03	84.64	3.39	27.75	14.85	21.48	3.41	131.88	30.19	83.01	39.16
S16	90.94	73.69	77.87	3.86	30.44	14.18	19.03	4.02	71.83	31.17	42.56	11.58
S17	38.64	16.13	28.16	4.81	104.06	71.29	87.92	8.83	144.12	47.72	95.54	37.09

*Note. “-” indicates no usable data was collected.

Table F8. BMI Mid Unload Average Angle Data per Subject

Subject	BMI Mid Unload											
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	58.76	23.50	46.47	10.72	48.61	12.52	31.73	9.60	85.44	36.38	48.22	11.09
S02	178.54	168.91	172.93	2.40	129.34	59.71	73.85	15.26	155.09	132.02	142.12	6.08
S03	-	-	-	-	-	-	-	-	55.26	15.42	38.28	13.01
S04	50.06	40.03	46.52	2.58	95.92	58.68	75.52	9.46	105.42	43.48	75.64	14.90
S05	25.40	11.32	20.23	3.54	130.89	66.33	106.25	14.37	131.90	28.67	71.58	36.27
S06	83.55	34.65	57.78	15.83	53.21	17.84	36.31	9.14	147.23	31.54	92.32	45.76
S07	32.78	0.24	11.19	9.89	53.11	11.32	38.91	10.11	133.30	109.60	117.76	6.75
S08	45.65	15.96	29.47	7.92	94.34	54.97	87.34	8.59	129.20	72.45	110.81	18.62
S09	118.93	50.45	97.00	19.65	54.09	17.25	31.97	10.84	-	-	-	-
S10	82.67	66.74	76.51	4.74	45.48	17.16	30.63	7.72	95.72	18.41	47.10	17.02
S11	106.24	76.69	88.00	7.25	41.02	0.72	24.68	14.30	156.05	28.22	104.18	48.20
S12	35.13	35.09	35.11	0.01	122.35	119.54	120.98	0.86	107.55	106.99	107.24	0.17
S13	66.82	59.16	62.86	1.46	57.65	30.56	53.77	6.65	41.52	19.95	37.75	5.10
S14	82.48	63.69	72.16	6.34	65.33	59.44	62.22	1.83	144.07	35.43	88.59	47.10
S15	95.79	74.84	87.04	7.10	39.57	2.20	16.03	9.13	134.06	18.85	63.38	43.53
S16	92.16	50.48	79.54	10.30	38.90	18.54	26.24	6.49	110.47	22.79	48.47	21.59
S17	-	-	-	-	-	-	-	-	-	-	-	-

*Note. “-” indicates no usable data was collected.

Table F9. BMI Bot Load Average Angle Data per Subject

Subject	BMI Bot Load											
	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	58.08	38.75	48.24	6.93	44.90	4.20	28.76	9.92	83.80	31.40	64.14	14.93
S02	179.45	166.43	175.01	4.17	97.13	38.60	65.06	16.15	-	-	-	-
S03	51.57	31.08	38.56	7.37	114.79	36.59	83.31	21.24	-	-	-	-
S04	47.44	28.54	41.65	5.69	73.63	46.96	65.21	9.32	133.84	54.11	94.68	22.32
S05	19.65	7.65	12.52	4.79	123.90	102.79	113.32	7.51	126.15	69.33	102.17	24.03
S06	77.07	50.00	68.12	8.88	56.83	27.32	41.52	8.74	85.83	15.11	47.10	22.05
S07	-	-	-	-	-	-	-	-	135.76	116.21	125.50	6.89
S08	31.57	16.91	25.76	3.50	105.13	80.06	88.20	6.14	117.65	53.65	91.96	21.48
S09	112.83	86.99	101.46	8.31	34.35	17.54	29.15	4.47	-	-	-	-
S10	72.41	43.64	59.21	8.29	89.01	15.35	59.44	27.11	132.61	46.42	95.50	28.11
S11	98.17	76.77	88.04	5.57	47.62	8.00	24.48	10.16	45.78	21.18	35.04	6.41
S12	39.66	33.34	37.17	2.04	-	-	-	-	-	-	-	-
S13	79.22	57.14	70.34	7.53	59.48	26.94	44.36	11.66	82.73	22.39	43.73	20.23
S14	64.28	59.32	61.05	1.47	16.33	7.91	13.24	2.65	114.86	93.06	109.24	6.06
S15	97.45	79.78	90.55	5.13	26.33	7.89	16.91	4.97	138.03	24.18	75.35	44.22
S16	88.42	48.28	71.42	13.91	49.12	27.31	36.91	8.31	98.92	36.89	70.20	20.73
S17	40.71	35.16	37.44	2.19	94.28	72.75	83.37	5.62	135.17	40.89	90.48	37.40

*Note. “-” indicates no usable data was collected.

Table F10. BMI Bot Unload Average Angle Data per Subject

BMI Bot Unload												
Subject	Back Angle - X-Axis Data				Hip Angle - X-Axis Data				Knee Angle - X-Axis Data			
	Max	Min	Mean	Std	Max	Min	Mean	Std	Max	Min	Mean	Std
S01	52.00	31.40	43.49	5.49	41.30	11.73	30.70	9.65	77.74	34.54	46.92	12.50
S02	179.68	164.72	171.23	5.35	138.80	76.42	107.03	20.83	163.63	80.23	125.67	22.03
S03	-	-	-	-	-	-	-	-	-	-	-	-
S04	60.64	41.93	52.48	6.07	93.72	64.05	80.03	9.12	133.01	50.70	87.02	24.25
S05	21.21	14.00	16.39	2.76	129.06	95.42	111.89	10.58	145.90	123.52	140.24	6.90
S06	68.03	61.91	64.57	1.88	31.37	12.39	24.80	4.69	64.23	4.23	27.44	14.25
S07	17.94	6.15	12.77	4.66	74.66	18.87	52.79	18.29	138.22	83.46	120.35	16.53
S08	36.27	12.85	25.60	8.57	82.63	49.25	65.32	11.66	103.90	12.09	57.61	34.67
S09	120.47	88.72	110.79	12.28	52.91	16.04	33.35	10.91	-	-	-	-
S10	90.88	69.45	74.37	5.84	47.72	33.30	43.52	3.30	72.71	30.12	46.97	14.03
S11	80.92	64.31	75.43	4.46	43.86	22.92	28.33	5.18	77.06	32.92	44.35	11.98
S12	50.16	41.07	44.07	2.73	62.08	55.48	59.14	2.26	58.45	53.07	56.96	1.60
S13	84.88	52.02	71.77	13.05	57.92	33.67	52.29	6.63	82.49	27.08	57.57	22.02
S14	82.74	67.78	72.22	4.30	75.38	53.68	64.09	9.30	-	-	-	-
S15	96.69	72.79	86.93	6.12	24.05	5.42	15.74	5.39	130.02	19.61	56.42	31.31
S16	100.05	59.37	83.83	14.17	44.93	29.98	37.59	4.37	111.07	30.32	68.30	26.23
S17	-	-	-	-	-	-	-	-	-	-	-	-

*Note. “-” indicates no usable data was collected.

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