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A Preliminary Study of the Effectiveness

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Intervention for Manual Scrap Metal Sorting.

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A Preliminary Study of the Effectiveness of a Safety and Health Ergonomic Intervention for Manual Scrap Metal Sorting.

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ABSTRACT

A tilting table was installed as an ergonomic intervention for a manual scrap metal sorting task at Puget Sound Naval Shipyard, in Bremerton, Washington. This was part of a larger shipyard ergonomics project. The scrap metal sorting task involves manually removing, sometimes heavy, pieces of scrap from a self-dumping hopper, and then placing or throwing the scrap into a larger container to be shipped off for recycling. Use of the tilting table allows for less strenuous removal of scrap items from the self-dumping hopper. This is accomplished by tilting the hopper until the discharge chute is nearly horizontal, and at approximately thirty inches above ground level. Relocation of the discharge chute results in lower spinal bending moments, and reduced lifting distance. This results in lower overall physical strain and reduced risk of injury, especially to the low back. This task was analyzed using the University of Michigan 3D Static strength Prediction Program, and the NIOSH Lifting Equation. The overall effect is an eventual reduction of injuries and all of the direct and indirect costs associated with those injuries.
ACKNOWLEDGEMENTS

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CHAPTER 1

Facility Background

"Plant Description: Puget Sound Naval Shipyard is located adjacent to the city of Bremerton, Washington, one hour west of Seattle by ferry, and approximately 30 miles north of Tacoma. The shipyard proper encompasses 344 acres of land, with additional non-adjoining property totaling 1,558 acres. The shipyard facilities include approximately 400 separate buildings, nine permanent piers including 12,310 feet of deep water space, and six drydocks. This shipyard is the Pacific Northwest’s largest Naval Shore Activity, and one of the largest industrial installations in the State of Washington.

Products: Puget Sound Naval Shipyard performs overhauls and repairs on all sizes and types of U.S. Navy ships as well as being home port for six active ships. Approximately 41% of the workload of the shipyard involves the inactivation, reactor compartment disposal, and recycling (IRR) of nuclear-powered submarines and surface vessels. Approximately 12 surface vessels and 88 submarines have been recycled in the past 12 years.

Age of Plant: Puget Sound Naval Shipyard was established in 1891 as a U.S. Naval Station. A number of small buildings from that era still survive on site.

Number of Employees, etc: Approximately 8,200 civilian employees, of which 3,500 are production workers. Average age of production workers is approximately 42 years of age." (Hudock, Wurzelbacher, 2000a)
Project Background

The domestic ship building, ship repair, and ship recycling industries have historically had much higher injury/illness incidence rates than those of general industry, manufacturing, or construction. For 2000 the Bureau of Labor Statistics reported that shipbuilding and repair (SIC 3731) had a recordable injury/illness incidence rate of 22.0 per 100 full-time employees (FTE). By contrast, the manufacturing sector reported a rate of 9.0 per 100 FTE, construction reported a rate of 8.3 per 100 FTE, and all industries reported a rate of 6.1 injuries/illnesses per 100 FTE. When considering only lost workday cases, shipbuilding and repair had an incidence rate of 11.7 per 100 FTE, compared to manufacturing at 4.1, construction at 4.0, and all industries at 2.8 lost workday injuries/illnesses per 100 FTE.

When comparing shipbuilding to the manufacturing sector for injuries to specific parts of the body, shipbuilding is higher in at least three instances. For upper extremity injuries and illnesses, for the year 1999, shipbuilding reported 73.1 cases per 10,000 FTE while manufacturing reported 67.5 cases. For back injuries for the same year, shipbuilding reported 94.4 cases per 10,000 FTE while manufacturing reported 48.2 cases. For the lower extremity, shipbuilding reported 111.6 cases per 10,000 FTE to manufacturing’s 38.2 cases.

"For the entire Puget Sound Naval Shipyard (PSNS), for the five-year period 1994 to 1998,
there were 10,259 injuries and illnesses recorded onto the OSHA 200 Logs for an average annual incidence rate of 22.8 per 100 FTE. In 1997, the PSNS incidence rate was 23.9 compared to a rate of 21.4 for the shipbuilding industry, 12 per cent higher than the industry average. In 1998, the PSNS incidence rate was 20.1 compared to a shipbuilding industry rate of 22.4, 10 per cent below the industry average. Similar declines in the incidence rates for days away from work cases and restricted or light duty cases also occurred recently at the shipyard.

When considering only the production workers at PSNS, for the period 1994-1998, there were 8,029 injuries and illnesses recorded for an annual incidence rate of 41.5 per 100 FTE. From 1994 to 1998 there was a decline in both the total incidence rate (22 per cent) and in the days away from work incidence rate (32 per cent). When focusing solely on musculoskeletal disorders (MSD) among production workers, MSD represented 54 percent of the total number of cases and 67 percent of the days away from work cases. Occupations with the highest incidence rates and numbers of MSD include pipefitter, welder, marine mechanic, shipfitter and electrician.

Beginning in 1995 the National Shipbuilding Research Program (NSRP) began funding a project, looking at the implementation of ergonomic interventions at a domestic shipyard as a way to reduce Workers’ Compensation costs and to improve productivity for targeted processes. That project came to the attention of the Maritime Advisory Committee for Occupational Safety and Health (MACOSH), a standing advisory committee to the Occupational Safety and Health Administration (OSHA). The National Institute for Occupational Safety and Health (NIOSH) began an internally funded project in 1997 looking at ergonomic interventions in new ship construction facilities. In 1998, the U.S. Navy decided to fund a number of research projects
looking to improve the commercial viability of domestic shipyards, including projects
developing ergonomic interventions for various shipyard tasks and processes. Project personnel
within NIOSH successfully competed in the project selection process. The Institute currently
receives external project funding from the U.S. Navy through the NSRP.

**Project Specifics**

The primary portion of the work being performed at PSNS is in the IRR activity. This work
includes the decommissioning of the vessel, the inactivation and removal of pertinent and viable
systems, the isolation of the nuclear reactor compartment and the dismantling or recycling of the
contents and structure of the vessel. Primary means of dismantling the vessel include either
torch cutting or cutting with an electrically powered reciprocating saw. The dismantling
process ranges from 8-10 months for each submarine.

When PSNS was visited in October 1999, IRR activity was taking place in 2 drydocks. One
drydock contained the hull of a nuclear-powered cruiser and another drydock contained four
nuclear-powered submarine hulls. Vessels are brought to PSNS under their own power and are
moored at the docks. While at the docks, initial IRR work is done, dismantling non-essential
systems and storing components and scrap for future removal. When drydock space becomes
available, the drydocks are flooded and vessels are floated into place onto supports.
Bin Emptying at Drydock Sorting Pad Process

As the surface vessels and submarines are being dismantled as part of the IRR activity, hundreds of bins of scrap metal are generated. Each bin measures approximately 5 feet by 3 feet by 3 feet. The bins hold a variety of materials: stainless steel, painted steel, unpainted steel, aluminum, and other metal components. Each bin is filled during the “cut and carry” dismantling process for the vessel or vessels within the drydock. The scrap bins are moved from the vessels to the sorting pad area by forklifts. The sorting pad is surrounded by large shipping containers (approximately 8’ x 20’), each for a specific type of metal." (Hudock, Wurzelbacher, 2000b)

The sorting pad worker removes the individual pieces of metal from the scrap bin by hand. The worker makes a determination of the type of metal in hand and then carries the item to the appropriate shipping container. The worker then places or throws the item into the shipping container and returns to the scrap bin for the next item. Each bin requires approximately 20 minutes to empty and sort. Individual items can weigh anywhere from a few grams to more than fifty kilograms, for high-pressure valve assemblies. Common items are high-pressure couplings that weigh approximately thirty kg (Hudock, Jaszkowiak, 2002).

Research Objective

The objective of this research project is to quantitatively compare the ergonomic risks of the current scrap metal sorting workstation to a revised workstation set-up. Currently the workstation consists of a self-dumping hopper placed on the floor of the sorting slab. Material
is removed from this hopper manually. The hopper is not dumped out upon the surface of the sorting slab. Instead the workers bend over the edge of the hopper to reach in and grasp items of scrap (Figure 1). Pieces of scrap are then lifted out of the hopper, carried to the shipping containers, which are placed around the outside of the sorting slab and then either thrown, or placed into the appropriate shipping container. Many of the pieces of scrap material are heavy, in excess of 30 kg. The revised workstation is much the same, except that the self dumping hopper is now placed upon a tilting table which allows the discharge chute to move to a nearly horizontal position. This eliminates the need for excessive bending to grasp and lift heavy objects from the hopper.

**Project Overview**

Currently the worker encounters significant risk of injury in three phases of the sorting task: lifting, carrying and lowering/throwing. The new workstation equipment addresses the risk associated with the lifting portion of the task. The other two phases remain unchanged.
Figure 1. Worker reaching deep into sorting bin (Hudock, Wurzelbacher, 2000a).

Figure 2. Worker lifting heavy valve assembly from sorting bin (Hudock, Wurzelbacher, 2000a).
CHAPTER 2

Selected Manual Materials Handling Research

Researchers have been studying the physical effects of manual materials handling for many years. There is an ongoing effort to develop tools and methods for quantifying and analyzing the biomechanical, physiological and ergonomic effects of manual materials handling in the workplace. This research is the result of the economic costs associated with musculoskeletal injuries in the workplace.

Injuries in the workplace are costly to both individuals and industry. There are many safety and health costs associated with workplace injuries. These costs include direct medical costs and disability costs associated with the injury and a multitude of indirect costs. These indirect costs include, but are not limited to compensation insurance premiums, injured worker replacement and training, retraining of injured workers, and the resulting loss of productivity.

The majority of manual materials handling research has focused on reducing the risk of musculoskeletal injuries. The most prevalent and costly of these are injuries to the lumbar spine. These are collectively known as low back disorders (LBD). Most of the research on LBD has focused on injuries to the lumbar spine caused by strenuous and/or repetitive lifting.
A smaller portion of the research has focused on the other aspects of manual materials handling, namely lowering, pushing, pulling and carrying.

The results of this research have been the development of many different methods to assess the risk of workers in a given job developing LBD. These assessment methods range from checklists that quantify the physical strain associated with a job, to complex, computerized, static and dynamic biomechanical models (Waters et al, 1998).

Low back disorder risk assessments utilize three basic types of data. These are biomechanical, physiological and psychophysical data. Biomechanical data is collected empirically from laboratory experiments, or derived from mathematical modeling of the human body and the forces acting upon it. Physiological data is collected empirically, or is estimated using a variety of estimation techniques, such as heart rate and oxygen consumption. Psychophysical data is determined by subjective measures of experimental subjects. Psychophysical data is based upon the level of exertion that an experimental subject thinks they can maintain for a given period of time, without becoming, overly exhausted, tires or winded. Many assessment tools have been incorporated into software packages for use by industry. One such package is UGS Jack®, which combines ergonomic analysis with workplace simulation software.
The biomechanical assessment tools can be divided into two classifications: 1) those that derive results from statically determinate models and, 2) those with results derived from dynamic models. Of the static models, the most widely used is 3DSSP, a static strength prediction program developed at the University of Michigan. The static models are generally older and simpler, and therefore are much more widely used, whereas the dynamic models are more recent developments, and not as widely used.

Dynamic models of lifting mechanics are much more complex than static models. The dynamic models generally require many more inputs than the static models, and those inputs are often more difficult to obtain. Dynamic models usually require significant computing power to utilize effectively, whereas static models can often be computed manually. Also, static models such as 3DSSP and NIOSH Lifting Equation are often contained in many current software packages. Easy to use dynamic models are not as available, in easy to use packages.

The structures that have been most widely studied in conjunction with LBD are the intervertebral disks of the lumbar spine, and the lumbar vertebrae. The NIOSH lifting equation (Appendix 1) set a limit of 3400N compression for the lumbar vertebrae as a limit below which most of the working population could consistently function without significant risk of developing lifting related LBD (Waters et al, 1993). Other, similar research by (Stambough et al, 1995), suggest even lower limits. Both of these models are static models.
Dynamic biomechanical models tend to better predict risk of LBD than static models (Granata, Marras, 1999). Dynamic modeling introduces inertial forces that have been shown to be significant components of spinal compressive forces (Bush-Joseph et al, 1988), (Milburn, Barrett, 1999), (Lindbeck, Arborelius, 1991), (Chaffin, Page, 1994). Likewise, speed of lift increases the contribution of dynamic forces to total spinal forces (Bush-Joseph et al, 1998), (Dolan et al, 1994), (Marras et al, 1993), (Marras et al, 1995), (Lindbeck, Arborelius, 1991). Thus, if all else is equal, the faster lift will have the greater risk of injury.

As the speed of lift decreases, the inertial and acceleration components of the lift also decrease. As the acceleration components of a lift decrease, their value approaches zero, and thus approximates a static posture. For this reason slow lifts can be analyzed more accurately with static models than can faster lifts (Waters et al., 1998).

**Choice of Analysis Tools**

This experiment utilized two different assessment methods, 3DSSP (University of Michigan, 1997) and revised NIOSH Lifting Equation (Waters et al, 1993). These were chosen because of the applicability to the task and ease of use. The NIOSH Lifting Equation and 3DSSP are static analysis tools that do not include any measures of dynamic load. Both tools are included in the UGS Jack® ergonomic analysis software.
Static methods of analysis were deemed to be sufficient for this experiment because of the limitations in scope. The experiment has been limited to a worst-case scenario of lifting a heavy load from the bottom of the bin. In this case a heavy load is between 10 and 50 kg. Lifts with loads of 50 kg tend to be slow lifts, and require more than 1s to complete. As mentioned earlier, slow lifts can approximate static measures because the acceleration component is relatively small (Lindbeck, Arborelius, 1991). That same study also mentioned that the maximum forces occur very near lift-off. Therefore, the frame of video nearest the point of lift-off was chosen for analysis.

**Jack 3DSSP Differences**

The standard 3DSSP program calculates spinal compression forces at the L5-S1 interspace. Some of the research calculates spinal forces at this point, and some calculates forces at L4-L5 interspace. These are generally considered to be equivalent (Raschke, Chaffin, 1996), but there has been some research pointing to differences of approximately 13% in compressive strength of adjacent spinal motion segments (Adams et al, 1994).
CHAPTER 3: Task and Workstation

Task Definition

The sorting task consists of removing material from the self-dumping hopper, determining the type of material, carrying the material to the large scrap bins, and either placing or throwing the material into the large bin, then returning to the hopper for another piece of scrap.

Pre-intervention Workstation Set-up

The sorting pad workstation consists of a raised platform approximately 24’ X 24’ with a ramp leading up from the floor of the drydock. Around the perimeter of the raised platform are four to six 8’ X 20’ shipping containers, each one for a different type of scrap material (Figure 3). The self-dumping hopper is placed upon the surface of the sorting slab by a forklift, and then removed after it has been emptied.
Chosen Solution for Workstation Modification

Several possibilities were considered for modification of the sorting slab workstation: A light-duty crane that could move heavy items from the hopper to the shipping containers, a rotating table upon which the hopper would be emptied, and then unloaded manually, a tilting platform upon which to place the self-dumping hoppers and complete elimination of the sorting slab, by moving the sorting operation to the ship being dismantled. After much consideration, the tilting table was chosen.

The tilting table was deemed to be the most versatile and mobile solution, with the least amount of administrative and material cost. The crane system was not as mobile, and thus not easily
moved from one drydock to another. It also carried a high administrative cost, because it would require certified riggers to operate. The rotating table was considered too large to operate safely on the current sorting slab, and was not highly mobile. Elimination of the sort slab carried high administrative cost due to training of numerous people to identify and sort scrap material. It was also, not as feasible due to limited space aboard the vessels.

**Post-Intervention Workstation set-up**

The post-intervention workstation is identical to the pre-intervention workstation, except for the addition of a tilting table to assist unloading of the self-dumping hoppers. A forklift is used to load the self-dumping hoppers onto the tilting table, at which point they are slowly and incrementally tilted to a maximum of 30 degrees. At maximum tilt the discharge chute functions as a horizontal work surface, at a height of approximately 30.5 inches. By limiting rotation to 30 degrees, the discharge chute of the hopper will not pass a horizontal position, and material in the hopper will not inadvertently fall out onto the segregation platform.

No off the shelf products with the required specifications previously existed on the market. Only one vendor was found that was willing to modify an existing platform with the proper >2600 kg capacity, to the shipyards specifications. Vestil Manufacturing, Angola, Indiana supplied a modified table as a test model for the project. This table was 30-degree tilt, pneumatically powered, with a guarded remote foot pedal control, and was welded to the raised segregation platform (Hudock, Jaszkowiak, 2002).
CHAPTER 4: Experiment

Laboratory

The lab is equipped with a motion capture system by Peak Performance Technologies. This system consists of six cameras placed around the perimeter of the room, and aimed at the subject. Cameras were Philips LCT0500 Digital black and white surveillance units equipped with 40mm lenses and infrared filters. Each camera was equipped with an infrared light source aligned with the lens. All cameras are linked to a central processor, which records the digital signals for future processing.

Cameras were placed on the walls, on horizontal sliding mounts. This allowed each camera to be moved laterally to achieve the best possible position to have an unobstructed view of as many reflective markers as possible throughout each trial.

Mock-Up

A mock-up of the self-dumping hopper was used to compare the initial condition of a hopper placed on the ground to the resulting condition of the same hopper set on an elevated, tilting platform. The Peak Motus® motion capture system was used to collect data for the comparison.
The mock-up was constructed of 2” x 2” lumber and ¼” plywood. The overall dimensions were 56” x 48” x 38”, in the original unmodified position, and 56” x 48” x 44” after being placed on a tilting mechanism. The mock-up was reduced in the width dimension due to space constraints in the laboratory. The width of the actual self-dumping hopper is 65”, compared to the 48” used for the mock-up. The tilting platform for the mock-up adds approximately six inches to the initial height of the hopper. As the table tilts forward, the hopper lip is lowered to a final height of approximately 30.5”.

Figure 4. Pre-intervention mock-up
A wire frame type of construction was used for the mock-up, and utilized 2” X 2” lumber for the perimeter of the hopper. The bottom surface of the hopper was covered with ¼” plywood. The base of the hopper was constructed of 2” X 2” frame covered with plywood surface. This was then attached to a 2” X 4” frame with hinges at the front edge, and support struts on each side. The support struts allowed for the hopper to be fixed with varying degrees of tilt, to allow for data collection. After completion the entire assembly was painted flat black to eliminate as much reflective interference, with the video capture system, as possible.
NIOSH conducted an instrumented biomechanical evaluation of the tilting table (Figure 5). This evaluation was carried out, in the laboratory, utilizing the Peak Motus® motion capture system and UGS Jack® ergonomic analysis software.
Video footage of the scrap metal sorting task was used to construct a laboratory experiment to compare the biomechanical loads of the sorting task without the tilting table, and with the tilting table in place. This experiment utilized a framed mock-up of the self-dumping hopper. The analysis of this experiment was constrained to a worst-case scenario, namely, the removal of a heavy object, from near the bottom of the bin.

During on-site evaluation, several heavy objects were weighed. A common type of scrap, such as valves and flanges from high-pressure steam lines weigh upwards of 27 kg, and one object was weighed at 50 kg. According to the workers, similar heavy objects weighing in excess of 45 kg are not uncommon, and have been encountered many times in a single day.

The mock-up was first placed flat on the floor, and multiple trials were run using the Peak Motus® motion capture system. Each trial consisted of about three to four seconds of motion, as the subject stepped up to the front of the hopper, bent forward, reached in and picked up an object from near the bottom of the bin, and then turned to take the object to the nearby shipping containers. A piece of foam rubber weighing less than 1 kg, and approximately 12” x 8” x 4” was used to simulate a piece of scrap metal.
A single frame of video was chosen from each trial for biomechanical analysis. This frame corresponded to the lift-off point of each bend-lift-carry sequence. That is the point at which the object is no longer being supported by the bin, and is fully supported by the human.

The second phase of the experiment involved the same process, but this time with the mock-up elevated and tilted forward to the same position, as it would be if mounted on the tilting table, and moved to the maximum inclination of 30 degrees. For both conditions, the ten cleanest trials were utilized, and a single frame corresponding to the lift-off point was chosen for analysis.

UGS Jack® ergonomic analysis software was used to evaluate the biomechanical loads associated with this sorting task. Three load levels were used for all of the calculations: 5 kg/hand, 15 kg/hand and 25 kg/hand. Then the results from the pre-intervention trials, and post-intervention were compared. Load levels are subsequently referenced by either total load for two hands: 10 kg, 30 kg, 50 kg, or single hand load: 5 kg, 15kg, 25 kg/hand.

**Experimental Procedure**

This experiment simulated the sorting task before any ergonomic intervention, and after the tilting table intervention had been installed. The pre-intervention condition consisted of the self-dumping hopper being placed directly on the surface of the sorting slab, and then emptied
manually. The post-intervention condition consisted of the self-dumping hopper being placed upon an elevated platform that could then tilt up to thirty degrees. At a thirty degree tilt the inclined surface of the self-dumping hopper is approximately horizontal, and at a height of 30.5 inches.

The subject performed fifteen trials of the simulation for each condition. The data was collected and analyzed using one frame from each trial. The data set chosen for analysis of each trial corresponds to the lift-off point of each lift from the bottom of the hopper. As mentioned earlier, this experiment was constrained to a worst-case scenario, namely the removal of a heavy object, of irregular shape, from the bottom of the hopper.

**Data Collection**

Data collection was accomplished through the use of reflective markers placed at key points on the subject (Figure 5). These reflective markers reflect back the infrared light, from the units mounted to each camera. The infrared filters allow the system processor to record the infrared signals digitally and then track each signal throughout the duration of the trial.

The experimental subject wore twenty-seven reflective markers for each trial. Markers were placed such that the system could record movement with six degrees of freedom. Markers were
constructed of foam balls covered with reflective tape, and ranged in size from 0.5” to 1.5” diameter. Each reflective marker was attached to subject using double side tape.

Four markers were placed on the head, two at the front and two at the rear. One marker placed on the spinous process of the C7 vertebrae. Four markers were placed on the hip/waist area: one on each iliac crest, and one on each side of the sacrum. Each arm/hand had five markers: acromion process of each shoulder, lateral epicondyle of each elbow, center of carpal area of wrist, distal end of second metacarpal and distal end of fifth metacarpal. Each leg/foot had six markers: lateral side of each knee joint, lateral malleolus of each ankle, calcaneal process at each heel and one at the distal end of first phalanx (Figure 6, Table 1).
Figure 6. Linked spatial model from Peak Motus®
Table 1. Peak Motus® Anatomical Marker Legend

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<th>Marker No.</th>
<th>Marker Label</th>
<th>Anatomical Position</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>LFHD</td>
<td>Left front of head</td>
</tr>
<tr>
<td>2</td>
<td>RFHD</td>
<td>Right front of head</td>
</tr>
<tr>
<td>3</td>
<td>LBHD</td>
<td>Left back of head</td>
</tr>
<tr>
<td>4</td>
<td>RBHD</td>
<td>Right back of head</td>
</tr>
<tr>
<td>5</td>
<td>C7</td>
<td>Spinous process, cervical 7</td>
</tr>
<tr>
<td>6</td>
<td>LSHO</td>
<td>Acromion process, left shoulder</td>
</tr>
<tr>
<td>7</td>
<td>LELB</td>
<td>Lateral epicondyle, left elbow</td>
</tr>
<tr>
<td>8</td>
<td>LW</td>
<td>Top center of left wrist</td>
</tr>
<tr>
<td>9</td>
<td>LHRA</td>
<td>Distal end of 2nd metacarpal, left hand</td>
</tr>
<tr>
<td>10</td>
<td>LHRB</td>
<td>Distal end of 5th metacarpal, left hand</td>
</tr>
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<td>RSHO</td>
<td>Acromion process, right shoulder</td>
</tr>
<tr>
<td>12</td>
<td>RELB</td>
<td>Lateral epicondyle, right elbow</td>
</tr>
<tr>
<td>13</td>
<td>RW</td>
<td>Top center of right wrist</td>
</tr>
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<td>Lateral surface of left knee</td>
</tr>
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<td>LANK</td>
<td>Lateral malleolus, left ankle</td>
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<tr>
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<td>LHEE</td>
<td>Calcaneal process, left heel</td>
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<td>Lateral surface of right knee</td>
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<td>25</td>
<td>RANK</td>
<td>Lateral malleolus, right ankle</td>
</tr>
<tr>
<td>26</td>
<td>RHEE</td>
<td>Calcaneal process, right heel</td>
</tr>
<tr>
<td>27</td>
<td>RTOE</td>
<td>Distal end of first phalanx, right foot</td>
</tr>
</tbody>
</table>

Analysis

With the analysis tools available in the UGS Jack® software it was possible to compare several measures of biomechanical stress. The Low Back Analysis tool in UGS Jack® gave measurements for spinal disc compression, anterior/posterior shear, lateral shear, and muscle tension of several major muscle groups of the torso region. The disc compression and shear
measurements were calculated for the L4/L5 joint. The 3DSSP calculations use the University of Michigan 3D Static Strength Prediction protocol. This tool gave results for the percentage of the male industrial population that would be capable of doing this task without risk of injury, partitioned into categories based on major body joints. For this task the Torso, Hip, Knee and Shoulder joints were reviewed. The NIOSH lifting equation protocol gave values for the Lifting Index and the Single Task Recommended Weight Limit (STRWL).
CHAPTER 5

Results

Biomechanical data obtained from the mock-up using the Peak system was analyzed using UGS Jack®. The results of this analysis show that the tilting table is an improvement over the old system, of a self-dumping hopper set upright at ground level. Comparison of the biomechanical loads before using the tilting table and afterwards, shows that the loads placed on the worker doing this task are much reduced, with the tilting table in place. Below are the summarized results of the biomechanical analysis of the tilting table using UGS Jack® ergonomic analysis software. Pre and post-intervention values were compared using a paired-t test for statistical significance. Nearly all results were statistically significant at (P=<.001) (Appendix 2).
Summary of Results: 3DSSP

Analysis using the University of Michigan 3D Static Strength Prediction protocol, within the UGS Jack® software, shows that this sorting task was made significantly easier, as measured by the percentage of the population capable of accomplishing the task. Post intervention analysis shows that approximately 97% of the male industrial population could perform this task at the 10 kg load level, approximately 90% at the 30 kg load level, and approximately 75% at the 50 kg load level. This compares favorably to the pre-intervention analysis which showed that this task could be accomplished, without serious risk of injury, by approximately 75% of the
population at the 10 kg load level, by approximately 35% of the population at the 30 kg load level, and by only about 2-5% of the population at the 50 kg level.

Table 2. SSP for SHOULDER JOINT: Percentage of population capable of performing task at given loads (average of values for left and right joints).

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Mean % Capable N = 10)</th>
<th>POST-INTERVENTION (Mean % Capable N = 10)</th>
<th>DIFFERENCE (Improvement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>98.8%</td>
<td>100.0%</td>
<td>1.1%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>45.6%</td>
<td>98.5%</td>
<td>53.0%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>0.9%</td>
<td>86.0%</td>
<td>85.1%</td>
</tr>
</tbody>
</table>

Table 3. SSP for TORSO (Spinal Joints): Percentage of population capable of performing task at given loads.

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Mean % Capable N = 10)</th>
<th>POST-INTERVENTION (Mean % Capable N = 10)</th>
<th>DIFFERENCE (Improvement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>86.1%</td>
<td>98.1%</td>
<td>12.0%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>39.5%</td>
<td>89.5%</td>
<td>50.0%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>5.4%</td>
<td>69.6%</td>
<td>63.3%</td>
</tr>
</tbody>
</table>
Table 4. SSP for HIP JOINT: Percentage of population capable of performing task at given loads (average of values for left and right joints).

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Mean % Capable N = 10)</th>
<th>POST-INTERVENTION (Mean % Capable N = 10)</th>
<th>DIFFERENCE (Improvement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>73.8%</td>
<td>95.7%</td>
<td>21.9%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>30.6%</td>
<td>87.0%</td>
<td>56.5%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>6.6%</td>
<td>72.3%</td>
<td>65.7%</td>
</tr>
</tbody>
</table>

Summary of Results: LowBack Analysis

The Low Back Analysis toolkit in UGS Jack® calculated the intervertebral disk compression forces for the L4/L5 joint, muscle tension in the erector spine muscle group, anterior/ posterior shear at the L4/L5 joint and lateral shear at L4/L5. Post intervention analysis shows approximately 60% improvement for the disk compression forces, over pre-intervention values. Erector Spine muscle tension and anterior/posterior shear both showed a similar 60% improvement over pre-intervention values. Values for lateral shear, at the L4/L5, joint showed an approximately 80% improvement.

Of these four measures the disk compression forces and muscle tension in the erector spine group appear to have the greatest significance for this task, while the anterior/posterior shear and lateral shear appear to have much less significance for this particular sorting task. This is
probably due to the symmetry of the lifting task. Both of the spinal shear measures maintained values below the NIOSH action limits throughout the experiment. Thus the contribution of these two measures to the overall risk of injury associated with this task appears to be small. These measures could become more significant for non-symmetrical lifts, or single hand lifts. The measures for L4/L5 compression and erector spine muscle tension appear to contribute the majority of the injury risk. Both measures exceed the NIOSH action limit (3400N) and NIOSH maximum limit (6400N), in several instances.

Table 5. LOW BACK ANALYSIS: L4/L5 COMPRESSION

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Newtons), (N = 10)</th>
<th>POST-INTERVENTION (Newtons), (N = 10)</th>
<th>DIFFERENCE (Newtons)</th>
<th>IMPROVEMENT (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>4260.7 N</td>
<td>1686.3 N</td>
<td>2574.4 N</td>
<td>60.4%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>7084.5 N</td>
<td>2922.1 N</td>
<td>4162.4 N</td>
<td>58.8%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>9912.3 N</td>
<td>4164.7 N</td>
<td>5747.6 N</td>
<td>58.0%</td>
</tr>
</tbody>
</table>
### Table 6. LOW BACK ANALYSIS: ERECTOR SPINE MUSCLE TENSION

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Newtons), (N = 10)</th>
<th>POST-INTERVENTION (Newtons), (N = 10)</th>
<th>DIFFERENCE (Newtons)</th>
<th>IMPROVEMENT (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>2006.5 N</td>
<td>781.9 N</td>
<td>1224.6 N</td>
<td>61.0%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>3328.1 N</td>
<td>1362.7 N</td>
<td>1965.4 N</td>
<td>59.1%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>4652.8 N</td>
<td>1939.2 N</td>
<td>2713.6 N</td>
<td>58.3%</td>
</tr>
</tbody>
</table>

### Table 7. LOW BACK ANALYSIS: ANTERIOR/POSTERIOR SHEAR

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Newtons), (N = 10)</th>
<th>POST-INTERVENTION (Newtons), (N = 10)</th>
<th>DIFFERENCE (Newtons)</th>
<th>IMPROVEMENT (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>739.4 N</td>
<td>294.4 N</td>
<td>445.0 N</td>
<td>60.2%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>1233.7 N</td>
<td>510.9 N</td>
<td>722.8 N</td>
<td>58.7%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>1726.6 N</td>
<td>725.5 N</td>
<td>1001.2 N</td>
<td>8.0%</td>
</tr>
</tbody>
</table>
Table 8. LOW BACK ANALYSIS: LATERAL SHEAR Absolute Value

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (Newtons), (N = 10)</th>
<th>POST-INTERVENTION (Newtons), (N = 10)</th>
<th>DIFFERENCE Newtons</th>
<th>IMPROVEMENT (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>27.5 N</td>
<td>5.9 N</td>
<td>21.6 N</td>
<td>78.4%</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>49.7 N</td>
<td>9.5 N</td>
<td>40.2 N</td>
<td>80.8%</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>69.6 N</td>
<td>12.1 N</td>
<td>57.5 N</td>
<td>82.6%</td>
</tr>
</tbody>
</table>

Summary of Results: NIOSH Lifting Equation

The NIOSH lifting equation, as it applies to this task, before the intervention was installed, is probably an overestimation of the severity of the task. This is because the equation assumes a complete vertical lift, which is not the case in this instance. This task is actually a less than vertical lift, because a heavy object would slide up an incline. The reduction in biomechanical loading due to the incline is partially offset by the friction force resisting the upward motion along the incline.

The NIOSH lifting equation is much more accurate for the Post intervention situation. In this instance the lift is a complete vertical lift beginning at approximately thirty inches above the ground.
The single task lifting index was above 1.8 for all three load levels, in the pre-intervention phase. Only the 10 kg load level was less than 2.0, a level that has been shown to pose a significant risk of injury. Post intervention analysis showed that the 10 kg load level and the 30 kg load level were both below 2.0. Only the 50 kg level remained above 2.0.

The Single Task Recommended Weight Limit (STRWL) demonstrates the effectiveness of the tilting table as an ergonomic intervention. As mentioned previously, the NIOSH lifting equation is overestimating the severity of this task before the intervention, but still demonstrates significant improvement. In this experiment, the STRWL was increased threefold by the tilting table intervention.

Table 9. NIOSH Lifting Equation: Single Task Lifting Index

<table>
<thead>
<tr>
<th>LOAD</th>
<th>PRE-INTERVENTION (N = 10)</th>
<th>POST-INTERVENTION (N = 10)</th>
<th>IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kg/hand</td>
<td>1.8</td>
<td>0.6</td>
<td>1.2</td>
</tr>
<tr>
<td>15kg/hand</td>
<td>5.4</td>
<td>1.9</td>
<td>3.5</td>
</tr>
<tr>
<td>25kg/hand</td>
<td>9.1</td>
<td>3.2</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Table 10. NIOSH Lifting Equation: Single Task Recommended Weight Limit

<table>
<thead>
<tr>
<th>PRE-INTERVENTION kg, (N = 10)</th>
<th>POST-INTERVENTION kg, (N = 10)</th>
<th>IMPROVEMENT kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>16.1</td>
<td>10.6</td>
</tr>
</tbody>
</table>

On site summary

This test table was in use for several months, and received favorable reviews from the segregation slab workers. The workers generally liked the tilting table, in that it made the sorting task less strenuous, by reducing the amount of bending, and the overall effort required to segregate a hopper of scrap material. They felt that the pace of the task was not significantly changed by the use of the tilting table. They also mentioned a few problems with the table, and suggested modifications to increase the device’s usefulness and durability. All suggested modifications were implemented as described later in the text.

1. Tilt table platform is not large enough to easily accommodate the self-dumping hopper. The loading platform needs to be larger to allow more space within which to place a full hopper. This makes the task of the forklift driver easier.

2. Construction of tilt table is not heavy enough to be durable over long-term use. It should be made of heavier gauge material to reduce flexure and increase durability, in the interest of reduced repairs.
3. Tilt-table needs to be more mobile, or there needs to be more units to allow for more than one hopper at a time on the sort-slab. Instead of being rigidly welded to the sort slab, it should be mounted on a heavy platform that could be easily moved by a forklift.
CHAPTER 6

Conclusion

The tilting table intervention that has been put in place has a variety of benefits to ease the sorting task. The first benefit is the reduction of biomechanical stress on the worker. The tilting of the scrap bin moves the front surface to a nearly horizontal position. This eases the process of disentangling oddly shaped pieces of scrap from within the bin. Instead of having to lift a piece of scrap vertically, it can now be pulled in a horizontal direction toward the worker. Once a piece of scrap is disengaged from the others in the bin, it can be lifted vertically and carried to the shipping containers.

The resultant lift occurs from a position that is much closer to the body, and causes much smaller spinal compression forces. This result is expected from the studies by (Ferguson, et al, 2002), (Granata, Marras, 1999) which stated that spinal loading was much greater when lifts occurred from bottom or rear of a bin/pallet, as opposed to lifts from the upper front portion of a bin.

Another very significant benefit of moving the lift toward the front of the bin is the ability to more easily perform tandem lifts with very heavy objects. A tandem lift performed from the lip
of a bin that has been tilted to the horizontal position would greatly reduce the spinal
compression in the sagital plane, for a single worker, while slightly increasing the lateral shear
component of the spinal stress. The overall risk of injury would probably be greatly reduced,
compared to a single person lifting the same heavy load.

Task analysis using the NIOSH Lifting Equation shows a substantial reduction of LBD risk with
the tilting table in place. Given that the results from the pre-intervention analysis are probably
an overestimate of the actual risk, the differences between the two situations are probably much
too great to not signify an actual reduction of risk.

Some curious phenomena have been noticed with difficult tasks like the pre-intervention bin
sorting. Researchers have noticed what has been called the healthy worker effect, and survivor
populations (Waters et al, 1999). This effect is likely occurring in this job. Healthy worker
effect is the trend for difficult jobs to self-select workers that can cope with the physical
demands of the job. This creates a population of workers that can consistently work in these
conditions without injury. Use of the tilting table will result in the task being suitable to a much
larger percentage of the workforce. This is evidenced by the results in tables 1-4. Use of the
tilting table resulted, in a significant change in the percentage of the population capable of
performing the task without risk of injury. For the torso body segment, the change for a 50 kg
load was approximately 6% capable to 70% capable (Table 3).
Based on the results of the laboratory experiment, and worker reaction to the experimental tilting table, more such tables have been purchased. The new tables are improved over the original test table in several ways. They are made of heavier material so as to be more durable. The loading platform is larger to allow easier loading of the hoppers onto the table. The exterior of the tilt-table, around the edges of the loading platform, is enclosed in an expandable skirt to minimize pinch point hazards. The new tables will also be made mobile by mounting them on a large ballast plate that can be moved via forklift. These mounting plates will be made of 1.5-2” steel. The shipyard has purchased two more tilting tables, for use on the segregation slab. Total cost of these tilting tables is $4025 each plus the cost of installation, and construction of mounting plates, which will be carried out by the shipyard. Up to six more tables have been purchased for use in different areas and processes throughout the shipyard.

CHAPTER 7

Future Research

The ergonomic intervention in this research study should be considered an initial preliminary workplace improvement. There are still problems to be corrected. For example, this improvement only accounts for the risk associated with one portion of the task. There are two other portions that may contribute significantly to risk of injury for workers, as confirmed by (Mital, Ramakrishnan, 1999). The carrying portion and the lowering/throwing portion of the
task should be analyzed. There is a variety of research suggesting methods of performing such analysis (Wright, Metal, 1999 b.), (Shoaf et al, 1997), (Mital et al, 1997).

The carrying and lowering/throwing portions of the task may also contribute significantly to the physiological stress of the job. Physiological stress could become very important during times of high or low temperature. These environmental conditions may be large contributors to the overall stress of this job, since it is performed exclusively out of doors. High physiological stress could add to the risk of injury with this job, and adversely affect the workers' overall health.
BIBLIOGRAPHY


Unigraphics Solutions Inc., Jack® version 2.4, 10824 Hope Street, Cypress, CA 90630, Copyright 2001.

University of Michigan Software, 3D Static Strength Prediction Program Version 4.0, 3003 State Street, #2071, Ann Arbor, MI 48109-1280, Copyright 1997, The Regents of the University of Michigan.


APPENDIX 1: NIOSH Lifting Equation

ERGONOMICS, 1993, VOL. 36, NO. 7, 749–776

Rapid Communication

Revised NIOSH equation for the design and evaluation of manual lifting tasks

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¶ Department of Industrial and Systems Engineering, University of Wisconsin–Milwaukee, WI 53201, USA

Keywords: Low back pain; Prevention and control; Evaluation methodology; Lifting.

In 1985, the National Institute for Occupational Safety and Health (NIOSH) convened an ad hoc committee of experts who reviewed the current literature on lifting, recommend criteria for defining lifting capacity, and in 1991 developed a revised lifting equation. Subsequently, NIOSH developed the documentation for the equation and played a prominent role in recommending methods for interpreting the results of the equation. The 1991 equation reflects new findings and provides methods for evaluating asymmetrical lifting tasks, lifts of objects with less than optimal hand–container couplings, and also provides guidelines for a larger range of work durations and lifting frequencies than the 1981 equation. This paper provides the basis for selecting the three criteria (biomechanical, physiological, and psychophysical) that were used to define the 1991 equation, and describes the derivation of the individual components (Putz-Anderson and Waters 1991). The paper also describes the lifting index (LI), an index of relative physical stress, that can be used to identify hazardous lifting tasks. Although the 1991 equation has not been fully validated, the recommended weight limits derived from the revised equation are consistent with or lower than those generally reported in the literature. NIOSH believes that the revised 1991 lifting equation is more likely than the 1981 equation to protect most workers.
APPLICATIONS MANUAL
FOR THE REVISED NIOSH LIFTING EQUATION

Thomas R. Waters, Ph.D.
Vern Putz-Anderson, Ph.D.
Arun Garg, Ph.D.

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Biomedical and Behavioral Science
Cincinnati, Ohio 45226

January 1994
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FOREWORD

This Manual was developed to provide users of the revised NIOSH lifting equation (1991 version) with methods for accurately applying the lifting equation to a variety of lifting tasks. All necessary terms, definitions, and data requirements for the revised equation are provided in Section 1. Procedures for analyzing single-task and multi-task lifting jobs are described in Section 2. A series of ten lifting tasks is included in Section 3 to illustrate application of the procedure. For each task, a brief job description is provided, followed by a job analysis, and a hazard assessment, including a completed worksheet. Suggestions for redesign of the task are also provided.

The rationale and supporting criteria for the development of the revised NIOSH lifting equation are described in a journal article, Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks, by T. Waters, V. Putz-Anderson, A. Garg, and L. Fine, Ergonomics 1993. [See Appendix I]. The revised equation reflects research findings published subsequent to the publication of the original NIOSH equation (1981) and includes consideration of additional components of lifting tasks such as asymmetrical lifting and quality of hand-container couplings as well as a larger range of work durations and lifting frequencies than did the 1981 equation. It must be noted that application of this equation is limited to those conditions for which it was designed. It does not, for example, address such task factors as one-handed lifting, lifting extremely hot or cold objects, or factors that may increase the risk of a slip or fall and other non-lifting components of job tasks. A complete list of work conditions which are not covered by the 1991 equation is presented in Section 1.2 on page 9 of this Manual. Finally, it should be recognized that all methods require validation. Appropriate studies for the validation of this equation must be conducted to determine how effective these procedures are in reducing the morbidity associated with manual materials handling.
The equation was designed to assist in the identification of ergonomic solutions for reducing the physical stresses associated with manual lifting. It is our hope that this Manual (1) will assist occupational safety and health practitioners in evaluating lifting tasks and reducing the incidence of low back injuries in workers, and (2) also serve to stimulate further research and debate on the prevention of low back pain, one of the most costly occupational health problems facing our nation.

Janet C. Haartz, Ph.D.
Director, Division of
Biomedical and Behavioral Science
APPENDIX 2: Statistical Analysis

Paired t-test:

Single task recommended weight limit:

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 ( \frac{T}{L} )</td>
<td>10</td>
<td>0</td>
<td>5.499</td>
<td>0.198</td>
<td>0.0628</td>
</tr>
<tr>
<td>Col 2 ( \frac{\Delta T}{\Delta L} )</td>
<td>10</td>
<td>0</td>
<td>16.081</td>
<td>2.568</td>
<td>0.812</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-10.582</td>
<td>2.634</td>
<td>0.833</td>
</tr>
</tbody>
</table>

Difference: -10.582, 2.634, 0.833

\[ t = -12.703 \text{ with 9 degrees of freedom. (} P < 0.001 \) \]

95 percent confidence interval for difference of means: -12.466 to -8.698

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (\( P < 0.001 \))

Power of performed test with alpha = 0.050: 1.000

Single task lifting index 10 kg load: (Normality Failed, See p.65)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 ( \frac{T}{L} )</td>
<td>10</td>
<td>0</td>
<td>1.819</td>
<td>0.0617</td>
<td>0.0195</td>
</tr>
<tr>
<td>Col 2 ( \frac{\Delta T}{\Delta L} )</td>
<td>10</td>
<td>0</td>
<td>0.642</td>
<td>0.142</td>
<td>0.0448</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>1.177</td>
<td>0.166</td>
<td>0.0523</td>
</tr>
</tbody>
</table>

Difference: 1.177, 0.166, 0.0523

\[ t = 22.485 \text{ with 9 degrees of freedom. (} P < 0.001 \) \]

95 percent confidence interval for difference of means: 1.059 to 1.295

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (\( P < 0.001 \))

Power of performed test with alpha = 0.050: 1.000
Single task lifting index 30 kg load: (Normality Failed, See p.66)

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Failed (P = <0.001)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>5.461</td>
<td>0.183</td>
<td>0.0578</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>3.536</td>
<td>0.497</td>
<td>0.157</td>
</tr>
</tbody>
</table>

Difference 3.536 0.497 0.157

t = 22.495 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 3.180 to 3.892

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Single task lifting index 50 kg load: (Normality Failed, See p.66)

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Failed (P = <0.001)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>9.100</td>
<td>0.306</td>
<td>0.0967</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>5.891</td>
<td>0.830</td>
<td>0.263</td>
</tr>
</tbody>
</table>

Difference 5.891 0.830 0.263

t = 22.434 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 5.297 to 6.485

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
L4/L5 Compression 10kg load:

Paired t-test:  

Data source: Data 1 in Notebook

Normality Test:  
Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>4260.740</td>
<td>240.531</td>
<td>76.063</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>1686.344</td>
<td>322.377</td>
<td>101.945</td>
</tr>
</tbody>
</table>

Difference  
2574.396  
341.870  
108.109

t = 23.813 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 2329.837 to 2818.955

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

---

L4/L5 Compression 30kg load:

Paired t-test:  

Data source: Data 1 in Notebook

Normality Test:  
Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>7084.465</td>
<td>428.055</td>
<td>135.363</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>2922.061</td>
<td>548.107</td>
<td>173.327</td>
</tr>
</tbody>
</table>

Difference  
4162.404  
639.620  
202.265

t = 20.579 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 3704.848 to 4619.960

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
L4/L5 Compression 50kg load:

Paired t-test:
Data source: Data 1 in Notebook
Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 p / h/h</td>
<td>10</td>
<td>0</td>
<td>9912.319</td>
<td>616.044</td>
<td>194.810</td>
</tr>
<tr>
<td>Col 2 f / h/h</td>
<td>10</td>
<td>0</td>
<td>4164.749</td>
<td>785.934</td>
<td>248.534</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>5747.569</td>
<td>918.102</td>
<td>290.329</td>
</tr>
</tbody>
</table>

Difference 5747.569 918.102 290.329
\[ t = 19.797 \] with 9 degrees of freedom. (P = <0.001)
95 percent confidence interval for difference of means: 5090.799 to 6404.340
The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Erector spine muscle tension 10kg load:

Paired t-test:
Data source: Data 1 in Notebook
Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 p / h/h</td>
<td>10</td>
<td>0</td>
<td>2066.483</td>
<td>47.312</td>
<td>14.961</td>
</tr>
<tr>
<td>Col 2 f / h/h</td>
<td>10</td>
<td>0</td>
<td>781.862</td>
<td>123.923</td>
<td>39.820</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>1224.621</td>
<td>129.111</td>
<td>40.828</td>
</tr>
</tbody>
</table>

Difference 1224.621 129.111 40.828
\[ t = 29.994 \] with 9 degrees of freedom. (P = <0.001)
95 percent confidence interval for difference of means: 1132.261 to 1316.981
The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
Erector spine muscle tension 30kg load:

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>3328.122</td>
<td>92.786</td>
<td>29.342</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>1362.710</td>
<td>225.124</td>
<td>71.191</td>
</tr>
</tbody>
</table>

Difference 1965.412 244.938 77.456

t = 25.375 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 1790.194 to 2140.630

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Erector spine muscle tension 50kg load:

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>4652.820</td>
<td>137.840</td>
<td>43.589</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>2713.580</td>
<td>357.369</td>
<td>113.010</td>
</tr>
</tbody>
</table>

Difference 2713.580 357.369 113.010

t = 24.012 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 2457.934 to 2969.226

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
Anterior/posterior shear 10kg load:

**Paired t-test:**

Data source: Data 1 in Notebook

Normality Test: Passed \( (P = 0.164) \)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1↓↑ /↓↑</td>
<td>10</td>
<td>0</td>
<td>739.409</td>
<td>49.230</td>
<td>15.568</td>
</tr>
<tr>
<td>Col 2 /↓↑</td>
<td>10</td>
<td>0</td>
<td>294.419</td>
<td>83.560</td>
<td>26.424</td>
</tr>
<tr>
<td>Difference</td>
<td>444.990</td>
<td>66.098</td>
<td>20.902</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( t = 21.289 \) with 9 degrees of freedom. \( (P = <0.001) \)

95 percent confidence interval for difference of means: 397.707 to 492.274

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change \( (P = <0.001) \)

Power of performed test with alpha = 0.050: 1.000

Anterior/posterior shear 30kg load:

**Paired t-test:**

Data source: Data 1 in Notebook

Normality Test: Passed \( (P > 0.200) \)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1↓↑ /↓↑</td>
<td>10</td>
<td>0</td>
<td>1233.708</td>
<td>96.029</td>
<td>30.367</td>
</tr>
<tr>
<td>Col 2 /↓↑</td>
<td>10</td>
<td>0</td>
<td>510.917</td>
<td>126.177</td>
<td>43.063</td>
</tr>
<tr>
<td>Difference</td>
<td>722.791</td>
<td>119.902</td>
<td>37.916</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( t = 19.063 \) with 9 degrees of freedom. \( (P = <0.001) \)

95 percent confidence interval for difference of means: 637.018 to 808.564

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change \( (P = <0.001) \)

Power of performed test with alpha = 0.050: 1.000
Anterior/posterior shear 50kg load:

**Paired t-test:**

**Data source:** Data 1 in Notebook

**Normality Test:** Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>1726.635</td>
<td>138.029</td>
<td>43.649</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>725.471</td>
<td>196.964</td>
<td>62.286</td>
</tr>
<tr>
<td>Difference</td>
<td>1001.164</td>
<td>167.789</td>
<td>53.059</td>
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<td></td>
</tr>
</tbody>
</table>

\[ t = 18.869 \] with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 881.135 to 1121.192

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Lateral shear 10kg load:

**Paired t-test:**

**Data source:** Data 1 in Notebook

**Normality Test:** Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>-27.503</td>
<td>30.972</td>
<td>9.784</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>-33.435</td>
<td>39.416</td>
<td>12.464</td>
</tr>
<tr>
<td>Difference</td>
<td>-33.435</td>
<td>39.416</td>
<td>12.464</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ t = -2.682 \] with 9 degrees of freedom. (P = 0.025)

95 percent confidence interval for difference of means: -61.631 to -5.238

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.025)

Power of performed test with alpha = 0.050: 0.602
Lateral shear 30kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (\mu \neq \mu )</td>
<td>10</td>
<td>0</td>
<td>-49.711</td>
<td>51.482</td>
<td>16.280</td>
</tr>
<tr>
<td>Col 2 (\mu \neq \mu )</td>
<td>10</td>
<td>0</td>
<td>9.527</td>
<td>33.648</td>
<td>10.640</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-59.238</td>
<td>64.594</td>
<td>20.427</td>
</tr>
</tbody>
</table>

Difference: -59.238 64.594  20.427

t = -2.900 with 9 degrees of freedom. (P = 0.018)

95 percent confidence interval for difference of means: -105.446 to -13.030

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.018)

Power of performed test with alpha = 0.050: 0.683

Lateral shear 50kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (\mu \neq \mu )</td>
<td>10</td>
<td>0</td>
<td>-69.639</td>
<td>72.067</td>
<td>22.790</td>
</tr>
<tr>
<td>Col 2 (\mu \neq \mu )</td>
<td>10</td>
<td>0</td>
<td>12.116</td>
<td>47.745</td>
<td>15.098</td>
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<td></td>
<td>10</td>
<td>0</td>
<td>-81.755</td>
<td>90.490</td>
<td>28.615</td>
</tr>
</tbody>
</table>

Difference: -81.755 90.490  28.615

t = -2.857 with 9 degrees of freedom. (P = 0.019)

95 percent confidence interval for difference of means: -146.487 to -17.022

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.019)

Power of performed test with alpha = 0.050: 0.668
3DSSP shoulder joint 10kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>98.837</td>
<td>0.292</td>
<td>0.0924</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>99.970</td>
<td>0.0462</td>
<td>0.0146</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
<td>-1.133</td>
<td>0.302</td>
<td>0.0954</td>
</tr>
</tbody>
</table>

\[ t = -11.878 \text{ with 9 degrees of freedom. (P = <0.001)} \]

95 percent confidence interval for difference of means: -1.349 to -0.917

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

3DSSP shoulder joint 30kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>45.580</td>
<td>9.040</td>
<td>2.859</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>98.548</td>
<td>2.538</td>
<td>0.803</td>
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<tr>
<td>Difference</td>
<td></td>
<td></td>
<td>-52.967</td>
<td>9.522</td>
<td>3.011</td>
</tr>
</tbody>
</table>

\[ t = -17.590 \text{ with 9 degrees of freedom. (P = <0.001)} \]

95 percent confidence interval for difference of means: -59.779 to -46.156

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
3DSSP shoulder joint 50kg load:

Paired t-test:

Data source: Data 1 in Notebook

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>0.880</td>
<td>0.558</td>
<td>0.271</td>
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<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>86.007</td>
<td>18.546</td>
<td>5.865</td>
</tr>
</tbody>
</table>

Difference: -85.127 18.484 5.845

t = -14.564 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -98.350 to -71.904

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

3DSSP torso 10kg load:

Paired t-test:

Data source: Data 1 in Notebook

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>86.173</td>
<td>1.782</td>
<td>0.563</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>98.138</td>
<td>0.925</td>
<td>0.292</td>
</tr>
</tbody>
</table>

Difference: -11.965 1.660 0.525

t = -22.786 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -13.153 to -10.777

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
3DSSP torso 30kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (\neq )/</td>
<td>10</td>
<td>0</td>
<td>39.452</td>
<td>4.863</td>
<td>1.538</td>
</tr>
<tr>
<td>Col 2 (\neq )/</td>
<td>10</td>
<td>0</td>
<td>89.460</td>
<td>6.615</td>
<td>2.092</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-50.007</td>
<td>6.468</td>
<td>2.045</td>
</tr>
</tbody>
</table>

Difference -50.007 6.468 2.045

t = -24.450 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -54.634 to -45.381

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

3DSSP torso 50kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (\neq )/</td>
<td>10</td>
<td>0</td>
<td>5.389</td>
<td>1.826</td>
<td>0.577</td>
</tr>
<tr>
<td>Col 2 (\neq )/</td>
<td>10</td>
<td>0</td>
<td>68.642</td>
<td>17.530</td>
<td>5.480</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-63.253</td>
<td>16.767</td>
<td>5.302</td>
</tr>
</tbody>
</table>

Difference -63.253 16.767 5.302

t = -11.930 with 9 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -75.247 to -51.259

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = <0.001)

Power of performed test with alpha = 0.050: 1.000
3DSSP hip joint 10kg load:

**Paired t-test:**

**Data source:** Data 1 in Notebook

**Normality Test:** Passed \((P > 0.200)\)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (p)</td>
<td>10</td>
<td>0</td>
<td>73.782</td>
<td>7.092</td>
<td>2.243</td>
</tr>
<tr>
<td>Col 2 (\Delta)</td>
<td>10</td>
<td>0</td>
<td>95.693</td>
<td>2.131</td>
<td>0.674</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-21.911</td>
<td>7.824</td>
<td>2.474</td>
</tr>
</tbody>
</table>

**Difference**  
-21.911 \(7.824 \) 2.474

t = -8.856 with 9 degrees of freedom. \((P < 0.001)\)

95 percent confidence interval for difference of means: -27.508 to -16.314

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change \((P < 0.001)\)

Power of performed test with alpha = 0.050: 1.000

3DSSP hip joint 30kg load:

**Paired t-test:**

**Data source:** Data 1 in Notebook

**Normality Test:** Passed \((P > 0.200)\)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 (p)</td>
<td>10</td>
<td>0</td>
<td>30.566</td>
<td>13.862</td>
<td>4.384</td>
</tr>
<tr>
<td>Col 2 (\Delta)</td>
<td>10</td>
<td>0</td>
<td>87.045</td>
<td>8.842</td>
<td>2.796</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>-56.480</td>
<td>16.830</td>
<td>5.322</td>
</tr>
</tbody>
</table>

**Difference**  
-56.480 \(16.830 \) 5.322

t = -10.612 with 9 degrees of freedom. \((P < 0.001)\)

95 percent confidence interval for difference of means: -68.519 to -44.440

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change \((P < 0.001)\)

Power of performed test with alpha = 0.050: 1.000
3DSSP hip joint 50kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Passed (P > 0.200)

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>N</th>
<th>Missing</th>
<th>Mean</th>
<th>Std Dev</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 -</td>
<td>10</td>
<td>0</td>
<td>6.582</td>
<td>8.888</td>
<td>2.811</td>
</tr>
<tr>
<td>Col 2 +</td>
<td>10</td>
<td>0</td>
<td>72.327</td>
<td>18.490</td>
<td>5.847</td>
</tr>
</tbody>
</table>

Difference -65.744 19.154 6.057

\[ t = -10.854 \text{ with 9 degrees of freedom. (P }< 0.001 \]

95 percent confidence interval for difference of means: -79.446 to -52.042

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P < 0.001)

Power of performed test with alpha = 0.050: 1.000

Wilcoxon Signed Rank Tests

Single task lifting index 10kg load:

Paired t-test:

Data source: Data 1 in Notebook

Normality Test: Failed (P < 0.001)

Test execution ended by user request, Signed Rank Test begun

Wilcoxon Signed Rank Test

Data source: Data 1 in Notebook

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Missing</th>
<th>Median</th>
<th>25%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1 -</td>
<td>10</td>
<td>0</td>
<td>1.830</td>
<td>1.810</td>
<td>1.850</td>
</tr>
<tr>
<td>Col 2 +</td>
<td>10</td>
<td>0</td>
<td>0.575</td>
<td>0.570</td>
<td>0.630</td>
</tr>
</tbody>
</table>

\[ W = -55.000 \quad T+ = 0.000 \quad T- = -55.000 \quad P(\text{est})= 0.006 \quad P(\text{exact})= 0.002 \]

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference (P = 0.007)
Single task lifting index 30kg load:

Paired t-test:  
**Data source:** Data 1 in Notebook  
Normality Test: Failed \( (P < 0.001) \)

Test execution ended by user request, Signed Rank Test begun

**Wilcoxon Signed Rank Test**  
**Data source:** Data 1 in Notebook  

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Missing</th>
<th>Median</th>
<th>25%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>5.490</td>
<td>5.430</td>
<td>5.550</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>1.730</td>
<td>1.710</td>
<td>1.890</td>
</tr>
</tbody>
</table>

\[ W = -55.000 \quad T^+ = 0.000 \quad T^- = -55.000 \quad P(\text{est.}) = 0.006 \quad P(\text{exact}) = 0.002 \]

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference \((P = 0.002)\).

---

Single task lifting index 50kg load:

Paired t-test:  
**Data source:** Data 1 in Notebook  
Normality Test: Failed \( (P < 0.001) \)

Test execution ended by user request, Signed Rank Test begun

**Wilcoxon Signed Rank Test**  
**Data source:** Data 1 in Notebook  

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Missing</th>
<th>Median</th>
<th>25%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>10</td>
<td>0</td>
<td>9.145</td>
<td>9.060</td>
<td>9.250</td>
</tr>
<tr>
<td>Col 2</td>
<td>10</td>
<td>0</td>
<td>2.885</td>
<td>2.840</td>
<td>3.150</td>
</tr>
</tbody>
</table>

\[ W = -55.000 \quad T^+ = 0.000 \quad T^- = -55.000 \quad P(\text{est.}) = 0.006 \quad P(\text{exact}) = 0.002 \]

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference \((P = 0.002)\).
APPENDIX 3: Analytical Software Contact Information

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