Investigation of Avionics Box Precision Placement Using Motion Capturing and Thermal Imaging Techniques

Damon Stambolian, Moataz Eltoukhy, Shihab Asfour, Stephanie Bonin

Abstract— There have been an abundance of lifting studies performed throughout the history of biomechanical analysis however, there are few studies that have looked at the biomechanics of placing a box on a target or within a restricted space. Of those studies, none have looked at the human's ability to precisely place the box, and none have considered precise placement in restricted space. Furthermore, the human lifting capabilities and limitations is lacking in the design standards used for avionics box and shelf arrangements, and past avionics box and shelf arrangements developed for the Space Shuttle have led to hardware damage during avionics box installations. Thus, the focus of this study is to use motion capture along with thermal imaging techniques to explore and describe the kinematics, EMG, and thermal variations during the lifting and precise placement of an avionics box in restricted space.

Index Terms— Avionic Box Placement, Kinematics, EMG, Thermal Imaging, Motion Capturing, Biomechanics, Lifting.

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1 Introduction

THERE has been many biomechanical analysis performed for lifting activities, but few of these studies have looked at the activity of placing a box precisely on a target or within restricted space. Wang (1989), Mital (1989) investigated inserting a box into a shelf with restrictions on the sides and on top. A later study looked at the biomechanics of placing a box with no restrictions to the top of the box but with limited clearance on each side of the box target, simulating putting a box between two boxes on a shelf with limited clearance (Kumar, 1996). More recently, Davis (2001) looked at the biomechanics of placing a box within a target space of ½" larger than the box and Beach (2006) also looked at placing a weight within the same ½" target space clearance, however, the accuracy of placing the box within the target was not analyzed. Of these few studies, none have looked at the human's ability to precisely place the box, and none have analyzed precise placement in restricted space.

Additionally, the ARNIC-404A standards used to design avionics box and shelf arrangements, and the Federal Aviation Administration Human Factors Design Standards (FAA-HFDS) do not include the human lifting capabilities and limitations for precise placement in restricted space. The ARNIC standard provides weights for different size boxes, but does not provide any human factors advice for designing the avionics box/shelf for safe lifting. The FAA-HFDS does provide analysis methods for maximum lifting and anthropometric measurements for arm clearance separately, but does not provide standards to design for precise or non-precise placement of a box in restricted space.

Furthermore, in the Space Shuttle Orbiter, where precise placement in restricted space is required, there has been a history of cold plate damage (NASA Engineering Network Lessons Learned entry 3696, 2010), as depicted in Figure-1 More recently, because of the importance for improving designs for avionics box installations, the NASA Constellation Program performed studies using physical mockups to analyze the avionics box locations and spacing for electrical cables, fluid lines and tools (Dippolito, 2011).

Thus, the focus of this study is to use motion capturing and thermal imaging to explore and describe the kinematics, kinetics, and EMG of the human trunk during lifting and precise placement of an avionics box in restricted space.

It is expected that heavier boxes placed in restricted space and on the lower shelf will result in less accurate placement and higher stresses to the human.

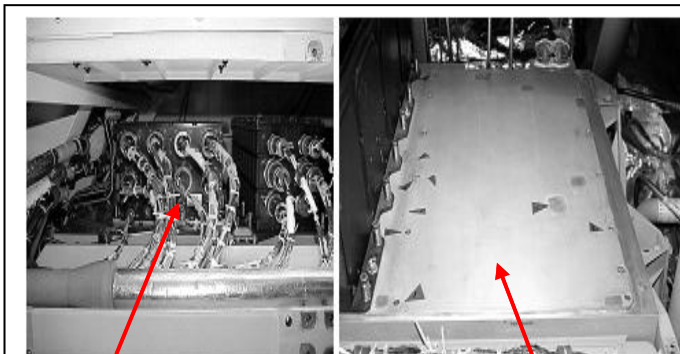

Fig. 1. Avionics Boxes and Damages to Cold Plate

- *Moataz Eltoukhy currently works as a postdoctoral associate in industrial engineering in University of Miami, USA. E-mail: meltoukhy@gmail.com*
- *Shihab Asfour is currently the associate dean of the college of engineering in University of Miami, USA. E-mail: sasfour @miami.edu*
- *Damon Stambolian is pursuing his Ph.D. degree in industrial engineering in University of Miami, USA. E-mail: d.stambolian@umiami.edu*
- *Stephanie Bonin is pursuing her Ph.D. degree in industrial engineering in University of Miami, USA. E-mail: stephbonin@yahoo.com*

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Thermal images show the natural superficial heat emission of the skin and represents it's temperature. The temperature of the skin is influenced by small blood vessels which are regulated by the autonomic nervous system. It is also affected by larger blood vessels and the metabolic characteristics of deeper tissues. This energy is then reflected on the skin surface and seen in the thermal image taken.

When muscle tissue is strained or torn it causes increased heat. The heat patterns indicate the source of the probable injury

Noncontact thermal imaging is a valid and reliable measurement of skin surface temperature (Selfe et al., 2006). Thermography, when used in a clinical setting, is a diagnostic imaging procedure that detects, records, and produces images of the patient's skin surface temperatures. In this procedure equipment is used which provides both qualitative and quantitative representations of these temperature patterns.

IR thermography visualises characteristic, unusual or pathogenic temperature patterns on the surface of the skin. Areas of increased heat indicate increased blood flow, which can be correlated with inflammation, infection or malignancies. Cold spots show decreased circulation pointing to nerve damage, blood clot or scar tissue (Kastberger et al., 2003; Krumova et al., 2008; Ng, 2009). In human medicine, thermography has already been effectively used for non-invasive assessment of disease activity in osteoarthritis of the knee, hands and the tempomandibular joint (Fikackova and Ekberg, 2004; Selfe et al., 2006; Spalding et al., 2008).

Relation to other imaging methods: The imaging methods of Ultrasound, Xray, MRI, and CT send some sort of electronic vibration or radiation into the patient, with unpredictable and variable patient risk. Telethermography is non-invasive. It uses an infrared detector to pick up the signals emitting from the patient, based on changes to the skin surface microcirculation. It does not send any form of electronic vibration or radiation into the patient. Ultrasound, Xray, MRI, and CT expose the patient to some part of the electro-magnetic spectrum, with obvious effects.

Ultrasound, Xray, MRI, and CT look at anatomical /structural features, and will provide insight to damage, or structural alteration, as a result of disease processes and trauma. They will not show the neurovascular activity associated with any physiological conditions and healing processes, whereas TG is able to provide this vital information.

The nervous system has a great effect on the processes involved in the human body, and TG can provide a very good monitoring system without harm to the subject. A baseline clearly has to be established, as with all imaging methods, and progress or deterioration can be measured effectively with TG. Establishing symmetry and return of function to a region can be quickly evaluated as a result.

The aim of the study is to use motion capture along with thermal imaging techniques to explore and describe the kinematics, EMG, and thermal variations during the lifting and precise placement of an avionics box in restricted space.

2 Methods

2.1 Experimental Setup

A simulated avionics shelf was constructed with an adjustable shelf height of 30″ to 60″. There were 3 different boxes, identical in size and weighing 25, 35 and 45 pounds (Figures 2 and 3). As seen in Figure 4, above the placement shelf there was a second removable upper shelf which when installed simulates the restricted space above the box, and there were two extra boxes on the shelf to simulate having a box to the left and right of the placement box. In addition, markers were used to record the three-dimensional location of the box relative to the shelf to analyze the accuracy of placement.

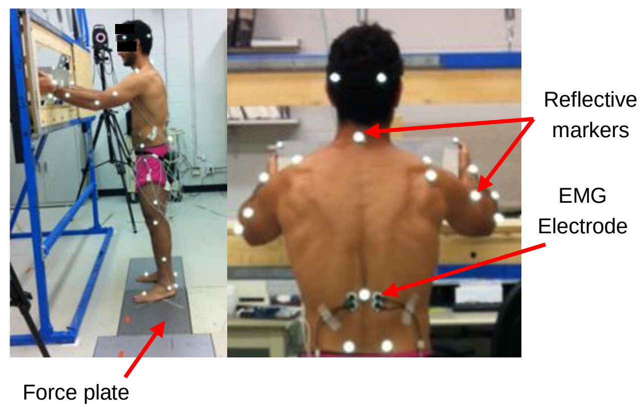

Fig. 2. Restricted and Un-Restricted Shelves

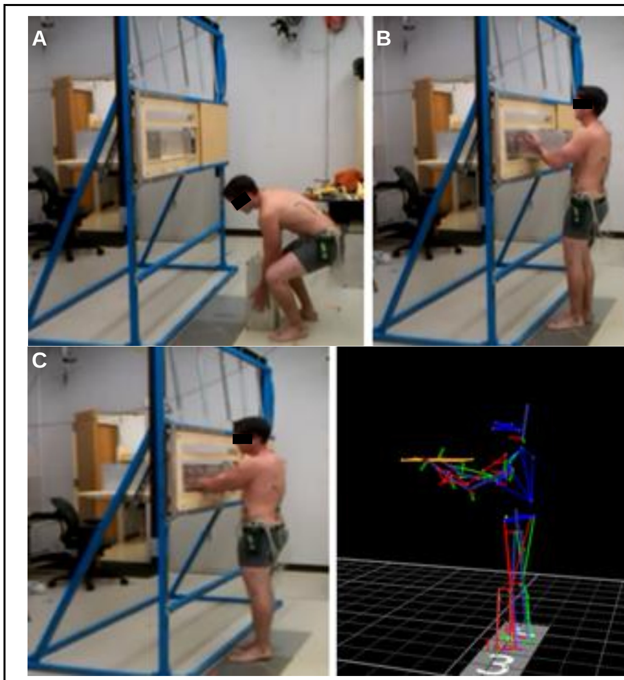

Fig. 3. Physical and Computer Simulation of Placing Avionics Box in Avionics Shelf

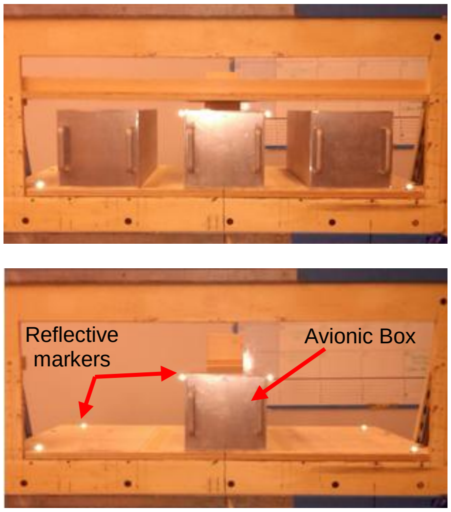

Fig. 4. Restricted and Un-Restricted Shelves

2.2 Biomechanics and Thermal Imaging

Kinematic data were captured and recorded at the University of Miami's Biomechanics laboratory with the Vicon (Oxford Metrics, United Kingdom) Nexus software version 1.6.1.57351 and 10 MX cameras providing 1024 x 1024 pixel resolution, sampling rate 120 Hz. Force data were collected with Kistler force plates (Model: 9253B, sampling rate: 2400 Hz) and EMG with a Noraxon Telemyo System (Noraxon USA., Inc., Scottsdale, Arizona), which are synchronized and integrated into the Vicon Nexus system. (Eltoukhy, 2010, Lisman, 2011). The EMG raw data signal processing was performed using the MyoResearch XP (Master Edition 1.07.41).

The Signal processing included ECG Reduction, Rectification, Smoothing, and Normalization. The kinetic and EMG mean values were derived using Master Edition 1.07.41. The biomechanics model was created in Vicon Nexus. Similar human computer models have been reported as an effective method for analyzing aerospace ground human activities such as handling boxes (Jeffrey, 2010, Stambolian, 2009).

Fluke thermal imager unit with IR-Fusion technology (Fluke Corporation, WA, USA) was used. Ambient temperature was controlled at 22-24 °C. Baseline images were taken; the subjects then performed the lifting tasks described, and another thermogram was taken immediately afterwards. Thermograms were taken over 1280x1024 pixels on the subject's back. Mean readings were recorded before and after lifting.

The first priority is to establish whether there's symmetry either in the horizontal or vertical axis in the region of interest. It's then important to identify any focalized hot or cold spots within that region that may contribute to any asymmetry, and relate that to the anatomical location.

The subjects were instructed to remove any jewelry prior to the test and not wear restrictive clothing. Also, subjects were advised to avoid getting sunburnt prior to the test, or use topical creams.

2.3 Procedures

Six college age subjects were recruited in this study. They were educated on the purpose of the study and the activities which he would perform during the study.

EMG electrodes were placed on the subject's left and right erector spinae, latissimus dorsi, external obliques, internal obliques, and rectus abdominis. The subject performed two 3-second maximal voluntary contractions (MVC) for each of these muscles. Then the reflective markers were placed on the subject using the Vicon Plug-In-Gait marker configuration.

The subject initially performed two practice lifts, and then began the experimental lifts. Twelve different lifts were performed twice, which resulted in a total of 24 lifts. The different configurations were a combination of 25 (light) and 45 (heavy) pound boxes, and restricted or un-restricted space. The subjects were instructed to place the box as accurately as possible in the outline on the shelf.

2.4 Box Placement

An exact outside dimension outline of the box was drawn on the shelf for the subject to aim for a precise placement. In order to get accurate measurements for analyzing the difference in precise placement, four markers were placed on the table and four were placed on the box. Although the lift activity began by lifting the box from the floor, the start of the lift for this study was selected when the box was 2/3 of the box length distance into the shelf. The end of the lift (placement) was determined by observing the smallest distance between the Z axis of the shelf and box markers, which confirmed that the box was flat on the shelf.

3 RESULTS

3.1 Box Placement

For each box placement, the difference between the desired placement location and the actual placement was recorded in both the X and Y directions. The following sections show the X (side to side) gap measurement, Y (front to back) gap measurement, and there is also a graph for the time it took to place the box, starting at 2/3 box length distance away from final placement. The first and second lift is shown for comparing the intra-subject variability.

For the side to side gap measurement the majority of the placements were closer to the target on the first lift as compared to the second lift. There were only three cases where the placements improved on the second lift. Only the 45-lb box in restricted spaces in both 30″ and 60″ height exceeded the 0.5″ target space used in Beach (2006), Davis (2004). For the most part, most of the measurements in the first placement were close to the second placement.

For the front to back gap measurement there were only three lift cases exceeding the 0.5″ threshold used in previous studies. The restricted 45-lb box in the 30″ shelf was the only configuration where both placements were above 0.5″. Eight lifts improved on the second placement, and four lifts were worse on the second lift. The gaps were much higher for the 25-lb box in the restricted 30″ shelf and the 45-lb box in the

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restricted 30″ shelf.

For the time to place the box, the time increased as the weight increased in the un-restricted 60″ shelf. For the restricted 60″ shelf the time to place the 25-lb box for the first lift took less time, and for second lift took more time, than the 35-lb and 45-lb box, and the time to place the 35-lb and 45-lb box is almost identical.

For the 30″ shelf, the 25-lb box in the un-restricted space took the longest time, the 45-lb box in the restricted space took the least time, and the rest of the cases were about the same. When comparing the times between the first and second lifts, they were fairly close except the 25-lb box in the 60″ restricted shelf. In the restricted 60″ shelf most of the cases took more time than in the un-restricted shelf, but in the restricted 30″ shelf most of the cases took less time than in the un-restricted shelf (Figure 5).

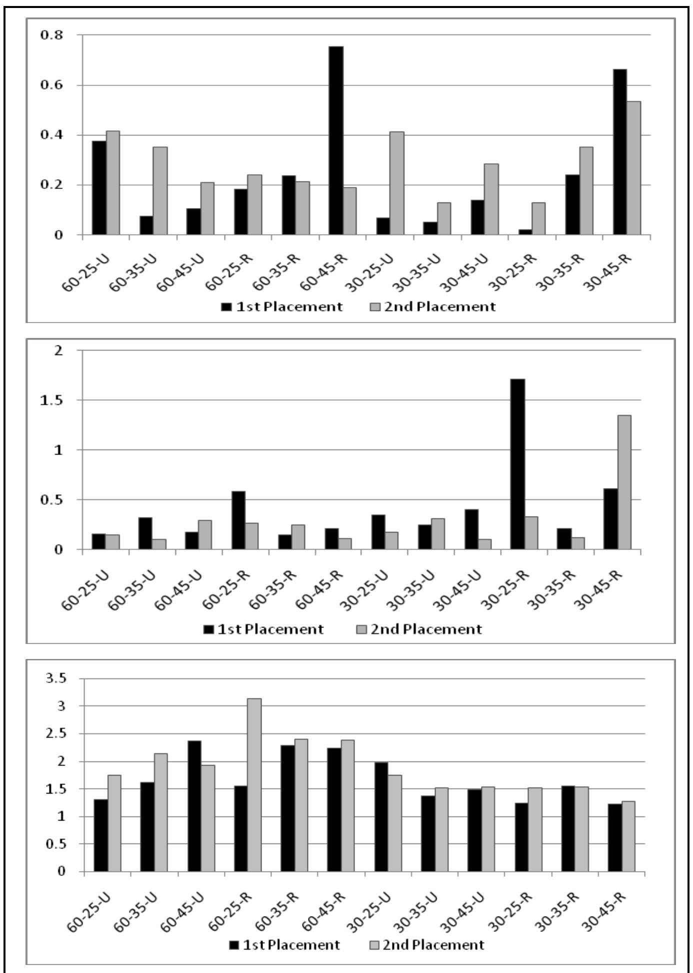

Fig. 5. Side to Side Gap, Front to Back Gap, and Time to Place Box

3.2 Thermal Imaging

Thermograms were taken for the lifting tasks of both the light (25lbs) and heavy (45lbs) boxes. Figure 6 depicts the thermograms taken for two subjects (subject # 1 (S1) and subject # 2 (S2)). As shown in the figure the lifting of the heavy box resulted in more thermal activity throughout the entire subject's back as an indication of the stresses resulted from the lifting task of the heavy box.

In case of S1, the following can be noticed; there is a central mid-line heat stripe. Arms are relatively symmetrical. Also, there are multiple focal heat spots throughout the trapezius and surrounding areas. Also, to the right of the thoracic spine, focal heat patterns can be seen (Active Trigger point irritation), and in the right scapula (muscle strain). Sprain strain is from in the focal heat patterns in the upper left trapezius. An increased zone of thermal activity in cervical region is evident. S2 on the other hand showed a slight increase of heat emission patterns of the T1 through T3 region. Also, a winged pattern effect at mid thoracic on both sides with increased thermal activity over left trapezius region is noticed.

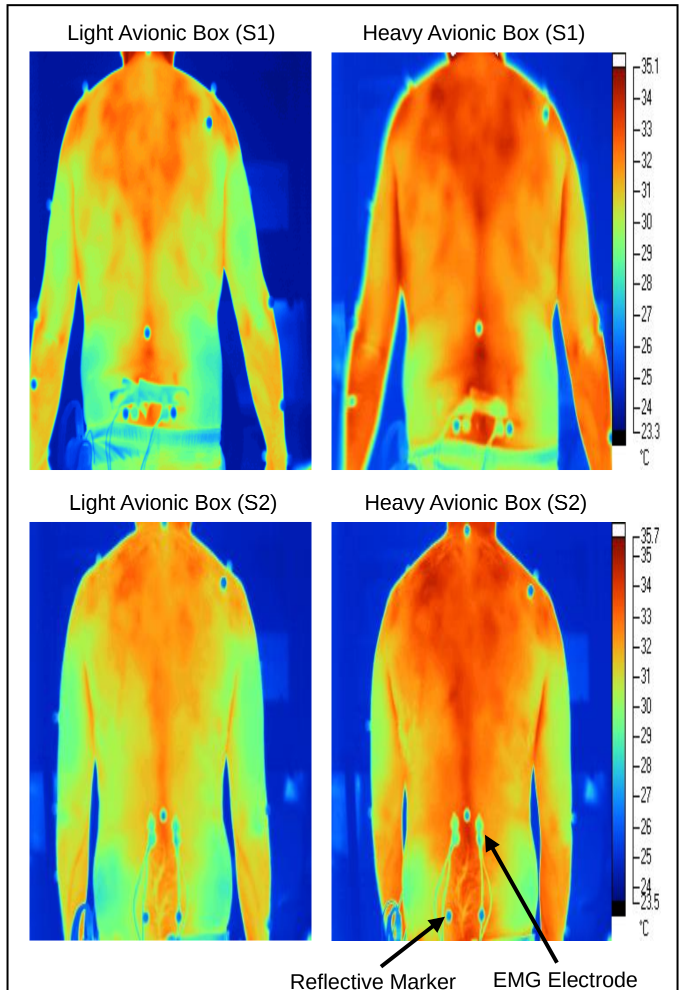

Fig. 6. Thermal images of the subject's back

3.3 Electromyography (EMG)

The muscles EMG studied were the mean normailzed activity for the erector spinae (ES), latissimus dorsi (LD), external obliques (EO), internal obliques (IO), and rectus abdominis (RO). Because this was a saggital lift, symerty was used in the analysis and only one side was used in the following analysis.

The ES muscle activity increased as the weight of the boxes increased in each configuration. The muscle activity for the 30″ shelf was higher than the 60″ shelf. The muscle activity for 30″ 45-lb un-restricted and restricted configuration was almost the same at 80% MVC. The activity between the first and second lift were for the most part close.

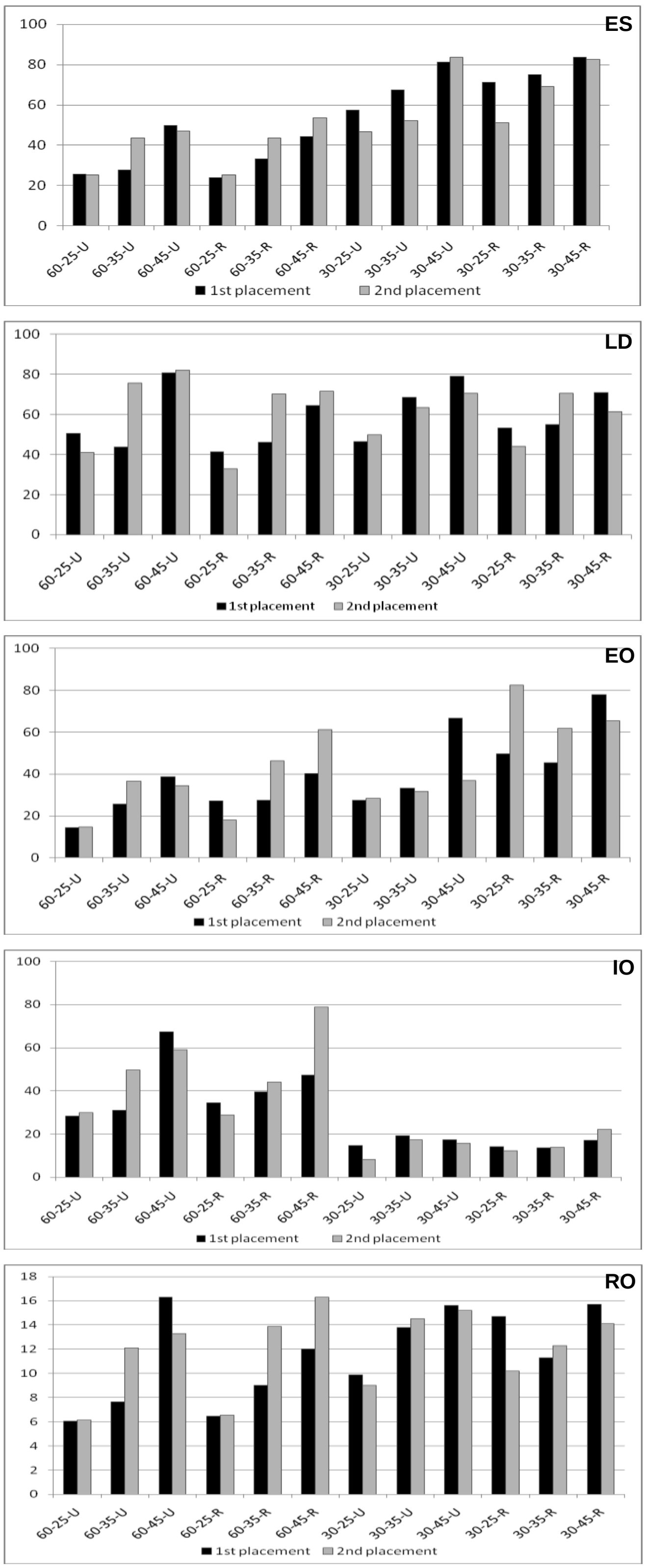

Fig. 6. Erecta Spinae, Latissimus Dorsi, External Oblique, Internal Oblique, and Rectus Abdominis

For most of the cases the activity of the LD muscle increased as the weight of the box increased, and the muscle activity was higher for the un-restricted 60″ shelves as compared to the restricted 60″ shelf. When comparing the restricted to un-restricted space in the 30″ shelf the muscle activity; for the 25-lb box was higher for the first lift but lower for the second lift, for the 35-lb box was lower for the first lift but higher for the second lift, and for the 45-lb box was lower for both lifts.

For most of the cases the EO muscle activities were higher for the 30″ shelf as compared to the 60″ shelf, and the muscle activity was higher for the restricted 30″ and 60″ shelves as compared to the un-restricted shelves.

The IO showed more activity in the 60″ shelf than the 30″ shelf. The activity increased with the weight of the box, except the 30″ 45-lb un-restricted case was slightly less than the 30″ 35-lb un-restricted case for both lifts, and the 30″ 25-lb restricted case was slightly higher than the 30″ 35-lb restricted case for the first lift.

For most of the cases the RO muscle activity increased as box weight increased, and was higher for the 30″ shelf as compared to the 60″ shelf. The RO activity was slightly higher for the 25-lb box in restricted space for both 30″ and 60″ shelves. The 35-lb box in the 30″ un-restricted shelf showed higher activity than in the restricted shelf.

The muscle activity for the 45-lb box in the 60″ restricted shelf decreased for the first lift but increased in the second lift, and for the 30″ restricted shelf the muscle activity increased for the first lift but decreased in the second lift. The activity for the RO was the lowest of all the muscles as would be expected for an extension activity (Figure 7).

4 Discussion and Conclusions

For the most part there was not much variability between the first and second lifts for the gap measurements, time to place box, kinetics and EMG. Additionally, it was discovered that for all of the placements there was never a case where all four corners landed at once, there was either one or two corners landing first followed by the other corners, or one or two corners touched more than once (skipping across table) before the final landing.

In conclusion, for the one subject participating in this study, it was shown that the highest side to side gap was with the 45-lb box in both restricted shelf heights, and the highest front to back gap was with the 25-lb box and 45-lb box in the restricted 30″ shelf. The weight of the box had some effect on the time to place the box, mostly in the un-restricted 60″ shelf.

Except for one case, placement takes more time in the 60″ shelf than in the 30″ shelf. In the 60″ shelf there were more cases where restricted space increased lifting time, but the opposite was true for the 30″ shelf. And there was never a case where all four corners landed at once.

The ES and LD had the highest MVC activity, and RO had the lowest muscle activity. The EMG activity across all muscles was influenced by box weight. The ES, EO, IO, and RO muscle activity was influenced by shelf height. And there is clear evidence that restricted space resulted in an increased muscle activity in the EO.

The changes described are reproducible and the method is non-invasive. It was notable that the temperature readings in the one patient who became asymptomatic changed significantly at his reassessment. Thermal imaging is considered a rapid and non-invasive technology to become a useful tool to study and assess the different lifting tasks.

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