SUSPENDED FREE BODY LIFTING DEVICES AND RIGID BODY SYSTEMS: A COMPARISON OF HAND FORCES DURING PUSHING ACTIVITIES

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CHAPTER 1

INTRODUCTION

1.1 Low back disorders and their cost to society

Low back pain is very prevalent in the general population as well as the working population. In fact, back pain is the second most common neurological ailment in the United States — only headache is more common[15]. Even more alarming than the frequency of lower back pain is the high cost of low back disorders (LBD) on society. Conservative cost estimates vary by source, but a reasonable figure is about $50 billion annually[19] in work-related costs— a figure representing approximately 1 percent of the GDP. The cost of back injuries is exasperated by their persistence. In a study by Mital and Kansal 24% of back injuries resulted in 21 or more work days being lost[14]. According to the Bureau of Labor Statisics, back injuries accounted for 43% of lost work days in 2003[2]. This study reported that 30% of all Workers' compensation lost time claims were due to lower back pain, with the low back claims accounting for a substantially larger portion of the costs. This is confirmed with data from Liberty Mutual that show that low back pain comprised 16% of the number of claims, but 33% of all costs, more than twice the amount of the average claim[22]. The cost of LBD to a company can be staggering as it costs the company far more than just medical expenses. The company looses money to absenteeism, reduced productivity and the cost to train replacement workers. Then there are additional costs for OSHA fines and penalties, legal expenses, workplace redesigns and ergonomic interventions. In order to combat these issues a large amount of ergonomic research is being done on lower back disorders.

1.2 Causes of Lower Back Disorders

Certain factors have been shown to have some relationship to the occurrence of low back disorders. Marras et al., reported an association between the risk of LBDs and five biomechanical variables including load moment, lift frequency, lateral trunk velocity, twisting velocity, and sagittal angle, suggesting that LBDs have a mechanical origin[12]. Studies have shown that repetitive exposure to back loading can lead to physical deformation of the tissues, which can impede the tissues' ability for self-repair. Repetitive exposure can also decrease tissues' load tolerance over time, thereby increasing the potential for injury. It has been recognized that by subjecting workers to high frequency, high weight lifting has a positive relationship with low back disorders. This has been confirmed by Videman et al., who found degenerative changes in the spinal units of cadaver spines whose donors were exposed to work that typically imposed large loads on the spine[23].

Manual material handling, especially heavy lifting, is known to be a risk factor for disorders in the lower back. In fact, manual material handling is the most expensive category of compensable loss[4]. To combat these losses, considerable ergonomic activity is expended in redesigning high-risk MMH jobs to fit a high percentage of the male and female industrial population. This situation has resulted in the implementation of many manual material handling interventions, such as carts, hoists, jibs and cranes, in an effort to minimize the load imposed on the worker. These are part of common redesign strategies that call for changing lifting, lowering and carrying tasks to pushing tasks.

1.3 Pushing tasks and LBDs

Manual handling devices such as carts, hoists and other lift systems are designed to lessen the amount of force directly supported by the worker. These MHDs reduce the magnitude of force that the worker is required to generate, and instead change the direction in which the force is now applied. These devices change the nature of a lift from gravity opposition to pushing and pulling tasks. Accordingly, these tasks change the force on the spine from a large compressive load to a shear force. While much research has been done on the body's ability to handle compressive loads in the spine, usually using compressed cadaver spines, the few studies involving shear forces have shown the spine to have much smaller tolerances to shear forces than compressive loads. Thus, even though pushing tasks remove dangerous lifting activities from the worker, they may still cause injury due to the body's low tolerance for shear forces in the spine. As pushing activities are becoming more and more common in industry, other risk factors are becoming apparent. National Institute of Occupational Safety and Health reported that 20% of overexertions occur during pushing activities. Another factor is the wide variety of devices being used. The most common devices for pushing tasks, carts, are often being replaced by overhead lifting systems. These new systems have not been thoroughly analyzed to see how they differ from carts during pushing activities.

CHAPTER 2

BACKGROUND

2.1 Pushing tasks

The high cost and frequency of injuries in MMH has led to the redesign of how material handling jobs are perrmed. Tasks that previously involved lifting have been replaced with the use of MMH aids, such as carts and wheeled cages, and have turned lifting tasks into pushing and pulling tasks. However, pushing and pulling tasks are not necessarily safer than lifting tasks and are frequently associated with musculoskeletal complaints in the lower back, shoulders and forearms. In fact, recent studies preformed at the Ohio State University Biodynamics Laboratory have shown that the risk in pushing and pulling is even greater than was previously thought[10]. The transformation from lifting to pushing tasks increasing the horizontal forces acting on the body, which act not only on the L5/S1 invertebral disc, but also may affect numerous discs throughout the lumbar and thoracic spine[21].

2.2 Industrial Operation

More and more industrial operations are incorporating overhead hanging interventions such as balancers that employ a pendulum style system for support. These devices can be seen in a plethora of industries including manufacturing, healthcare, warehousing and shipping. As these devices become more common, so do the number of injury claims due to pushing tasks. It is estimated that nearly 20% of all injury claims for LBP are related to pushing and pulling[9]. While not receiving the same focus as lifting tasks in research, pushing and pulling have been significantly related to the occurrence of low back pain[5]. Pushing and pulling tasks change the force from the vertical to the horizontal direction resulting in a greater application of shear force on the spine. In most research spinal compression has been the variable most often examined, but as the nature of jobs done in industry have changed and the amount of shear force that the spine is subjected to has increased, researchers have begun to associate shear force with LBDs.

2.3 Risk Assessment Snook Model

The most widely recognized guidelines pertaining to pushing and pulling are Snook's set of psychophysical tables[20]. Snook's study had subjects exert against a stationary handle while walking on a specially-designed treadmill. The horizontal force produced by the subjects was measured by a load cell with the goal to establish "realistic" dynamic exertions. Snook broke the forces into two categories: the initial force and the sustained force. Similar to friction where there is a static and dynamic element of friction, initial force is described as the force required to initiate movement and sustained force is the force required to maintain movement.

While the tables Snook developed from these studies are used in some places in industry, they have not been generally accepted in research. The Snook study fails to take into consideration several factors including friction, the difference between the treadmill and cart, the direction of the hand forces applied and precision movement. A study by Haslam et al. looked deeper into the friction element that the Snook study overlooked. The Snook study failed to look at the relationship between the subject's shoes and the floor surface. The Haslam study looked at the maximum acceptable loads for pushing on floor surfaces with good and reduced resistance to slipping. The Haslam study found that the maximum acceptable trolley loads were independent of the floor surfaces used, but the subject modified their posture and technique to compensate for poor footing[8]. The Haslam study also suggested that the subjects may have given little regard to slipping during the assessment. A slipping injury could be far more severe than that of pushing. In a similar study, Cirello et al. found a significant difference between maximum acceptable horizontal forces measured at the hands for a frequent, once per minute push over 7.6 meters, for high and low friction floors[4]. The Snook tables omit the application of force outside the horizontal direction underestimating the actual force applied. Accordingly, a study done by Cirello et al. compared the maximum acceptable initial and sustained forces on a magnetic particle brake treadmill (as used in Snook's study) and a high-inertia push cart. A similar psychophysical methodology was employed where the workers were asked to select a workload they could sustain for 8 hours without straining themselves or without becoming unusually tired, weakened, overheated, or out of breath. The results revealed that maximum acceptable initial and sustained forces of pushing on the high inertia cart were significantly higher (28 and 23%, respectively) than pushing forces on the magnetic particle brake treadmill[4].

2.4 Data Collection Method

In addition to the difference between the treadmill and a cart, there is also an underestimate of the forces used in Snook's study due to the way the data were collected. Snook's measurements were obtained using 2-dimensional load cells to measure horizontal force. The force that is applied to a handle during pushing or pulling exertions is actually the resultant vector of a 3-dimensional force[18]. As an increase in exerted hand forces is accompanied with an increase in mechanical stress on the musculoskeletal system, especially the shoulder and low back, it is plausible that the exerted forces are important contributors to the risk of musculoskeletal complaints. This would have yielded a higher amount of force being exerted by the subjects.

Another factor that both Snook and Cirello failed to consider is that of precision movements. Both studies had subjects push in a straight line, but it is common in industry for a worker to have to push loads around a corner. Pushing carts around corners creates twisting and asymmetrical loads on the worker, which are frequently linked to the incidence of low back pain[1,13]. A study by De Looze, et al. studied the direction of the force exertion and the force magnitude and their effect on musculoskeletal loading. In this study the forces at the hands were measured in the vertical and horizontal direction by a force transducer. It was found that as handle height and horizontal force level increased, the pushing force direction changed from 45° to near horizontal[6]. Thus, an accurate evaluation of musculoskeletal loads in pushing requires not only knowledge of the force magnitude, but the direction of force exertion with respect to the body as well.

2.5 Hand Forces

Hand forces have been identified in previous studies when analyzing the maximum push force. A 1999 study by Chaffin and colleagues measured the hand forces during pushing exertions at different handle heights on a stationary platform with instrumented handles[3]. They reported a maximum push of approximately 400N at 68cm handle height. They found that foot placement, handle height and posture were all important in determining maximum push capabilities. In a separate study Kumar et al. performed in both isokinetic and isometric modes with the lower torso secured reported maximum push forces of 520N occurred at a 100 cm handle height[11]. Experiments such as these helped to set guidelines often used in industry for pushing tasks. However, measuring hand forces in industry is very difficult for a variety of reasons. It may be too expensive, interfere with the job being preformed or the job itself lacks handles. As a result of this, there have been recent studies to simulate actual industrial work and the different pushing devices they use. A Donders et al. study of pushing four-wheeled cages ranging from 130-400kg found the maximum hand forces to be 217-315N[7]. A similar study by Van der Beek et al. found maximum hand forces to be 167-476N while pushing four-wheeled cages weighing 130-550kg[21]. Both of these studies found the maximum handle forces occured during the initial push. Resnick and Chaffin looked at three different manual material handling devices: an articulated arm, a hoist on an overhead rail and a fixed pivot hoist using loads of 10 and 30kg[16]. The maximum hand forces for the articulated arm and hoist on the overhead rail were 50-80N while the fixed pivot hoist was as high as 200N. In this study the hand forces were found to have significant vertical components, which suggested the need for multi-dimensional measurement devices. Finally, a study by Resnick and Chaffin looked at hand forces during twisting pushing of an articulated arm loaded with 68kg of weight[17]. Here the peak hand forces occurred during twisting with maximum hand forces ranging from 40-120N. These studies show the the influence of several factors on maximal hand forces (handle height, static friction, type of device, twisting), as well as the need to measure the hand forces in 3-dimensions.

2.6 Research Voids

Researchers have been able to understand how hand forces impact spinal load, which facilitates the study of pushing and pulling. However, in order to fully understand pushing and pulling, as seen in industry, it is necessary to investigate how the hand forces change when pushing and pulling loads that are applied to bodies that are free moving instead of rigid. The Ohio State University Biodynmaics Laboratory currently uses a rigid overhead rail system to study push-pull activities. While there is literature to support that pushing and pulling tasks may be dangerous, the conclusions of these studies need to be tempered by how the studies were performed. Almost all push-pull studies have been conducted while subjects pushed rigid body structures such as hand carts on treadmills or pushing on a stationary bar. The results of these previous studies using a rigid system may not be applicable to the type of pushing and pulling that is becoming more prevalent in industry: pushing a suspended device to form a pendulum system. These free hanging balancers create a pendulum-style interface between the worker and the hoist. As a force is applied to the body it will follow a pendulum path rather than a linear horizontal path as it would were the body rigid. Thus, the previous assessments made in literature may not apply to suspended systems.

2.7 Research Goals

The importance of studying pushing tasks as they are done in industry is well documented. This research is attempting to bridge a gap between the studies that have been done on rigid body systems and carts. This study is attempting to see if the results of previous studies done on carts is applicable to the free hanging balancers and overhead lifting systems now popular in industry or if there are significant differences between the two systems. This study will specifically look at the 3-dimensional hand forces and how they vary as a function of the type of device being pushed. This study will then focus on the maximal hand forces that occurred during a series of different types of exertions with both types of devices to see if there is a significant difference between the two systems.

CHAPTER 3

METHODS

3.1 Subjects

Twenty (20) subjects, 10 male and 10 female, were recruited from the University population to take part in this study. Subjects provided informed consent, Institutional Review Board (IRB) procedures and HIPPA regulations and were allowed to ask questions and stop at any time during the experiment. Basic anthropometric measurements of each subject were collected such as age, height and weight were also collected. The subject's statue was used to determine the handle heights being used during the study.

3.2 Experimental Apparatus

The subject was then moved into the room where the data would be collected. The overhead lifting system employed in the Biodynamics Laboratory is designed to replicate the free hanging balancers used in industry. The system consisted of a free horizontal bridge mounted perpendicular to two low friction linear track rails (IR Zimmerman, Rochester Hills, MI USA). The handles and transducers were mounted to a free vertical balancer and were weighted so that the handles would be parallel to the ground while at rest. The handle height could be adjusted by relieving air pressure in the overhead balancer. Loads were added to the overhead mechanism by its claming mechanism at the front of the balancer. The experimental setup for the overhead lifting device can be seen below in Figures 3.1 and 3.2.

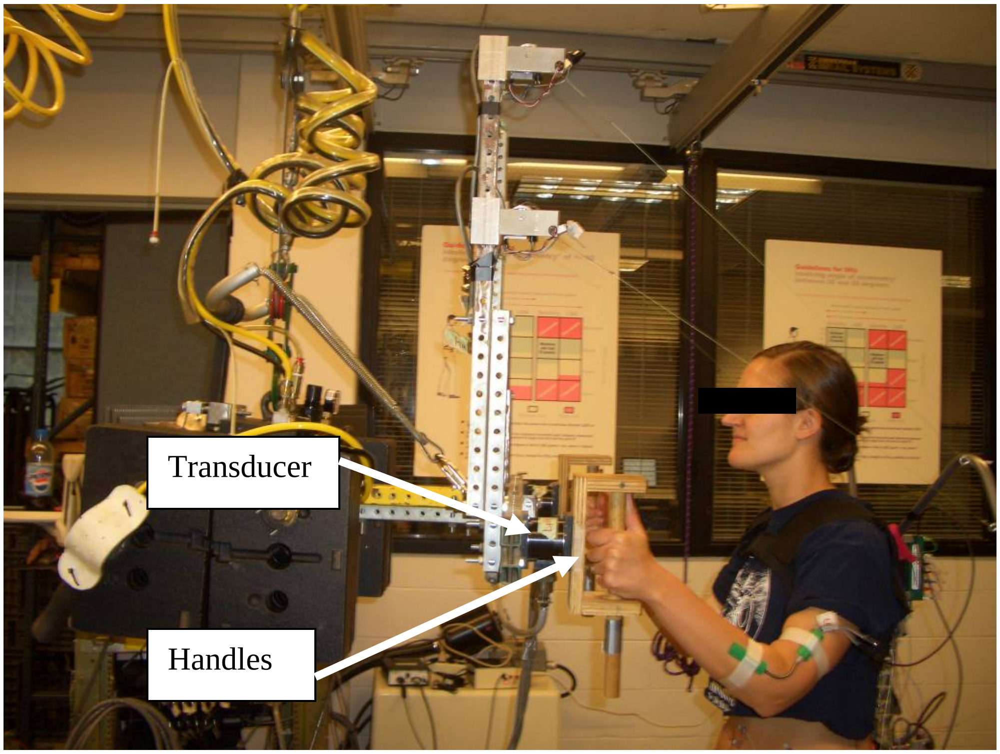

Figure 3.1: The overhead lift system, handles and transducers

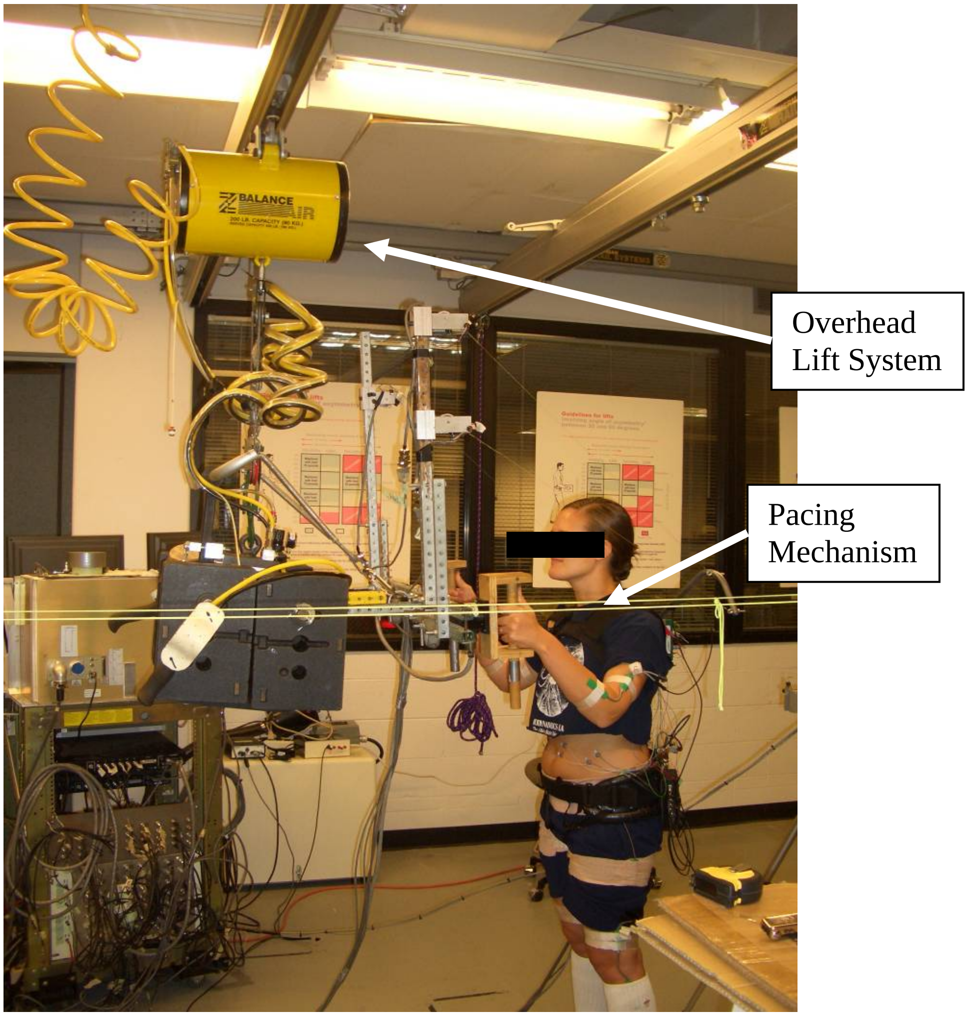

Figure 3.2: The overhead lift system with pacing mechanism in foreground

The cart utilized the same free vertical balancer with handles and transducers attached. In between trials where the subject was switching the type of device used, the balancer was taken off of the one system and affixed to the other. This kept consistency between the trials. The cart system can be seen in Figures 3.3-3.4.

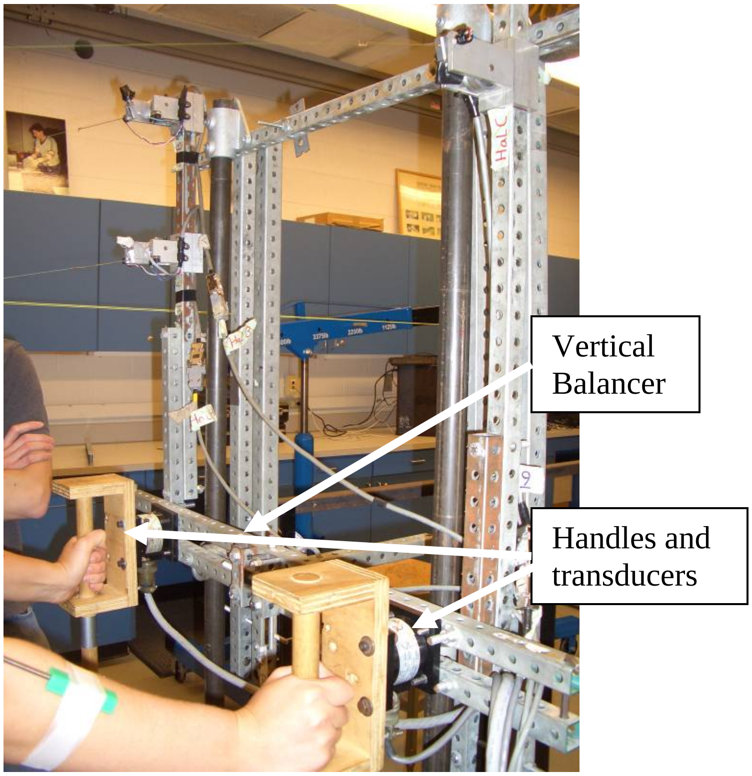

Figure 3.3: Cart system vertical balancer with attached handles and transducers.

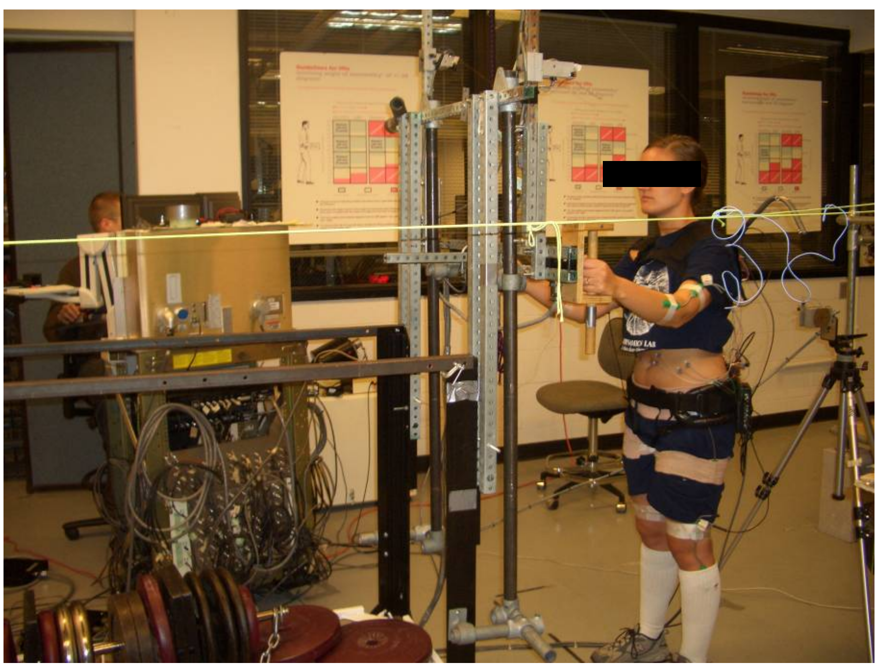

Figure 3.4: The cart system, with pacing mechanism in foreground.

3.3 Experimental Apparatus

Each subject was asked to perform 48 different tasks in randomized order. These tasks were comprised of two different lifting mechanisms (the cart and the overhead lifting device), they also consisted of three handle heights (50%, 65% and 80% of the subject's stature), two loads (370 pounds and 120 pounds), two speeds (slow and fast), and two movements (straight and precision). Each of these tasks was repeated twice for a total of 96 trials per subject. Subjects began each trial standing with their feet together facing the device and their hands at their sides. Subjects were then instructed to place their hands around the handles without touching them until instructed to begin the task. At the beginning of each trial the subject was asked to put their arms in a specific initial arm position to remain consistent with the initial conditions of the experiment. At the highest height subjects started with their arms parallel to the floor and their elbows at a 180 degree angle.. At the 65% and 50% heights subjects began with their elbows at a 90 degree angle. After the beginning the trial the subject was allowed to move their arms to any position they found comfortable to maneuver the load.

Subjects were given two speeds (fast and slow) and provided with a pacing mechanism for each trial. Subjects were asked to match the pacing mechanism as best they could during the trial, while still performing the task. Subjects were asked to perform two tasks: a straight push and a precision push. The straight push required the subject to push the cart or overhead device 10 feet and then stop it. The precision movement had the subject park the device between two makers slightly to the right of the subject's initial position. Subjects were allowed to rest one minute between trials and got a longer break when the devices were switched from the cart to overhead or overhead system to the cart.

3.4 Analysis

After collecting the data, the statistical significance of each independent measure was determined. The dependent measures were average maximum handle force and the angle at the peak resultant vector. The average maximum handle force is simply the composite of the maximum handle force in each trial. The peak resultant vector is the resultant vector in the XY and YZ plane. These planes are from the global coordinate system. Looking at the angle of this vector gives a better picture of which direction the subject is pushing the device. This study focuses on the impact of changing each of the independent variables as well as their interaction with the lifting device.

To test for significance we used the student's t-test equation which is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{s_{\overline{X}_1 - \overline{X}_2}} \text{ where } s_{\overline{X}_1 - \overline{X}_2} = \sqrt{s^2_{\overline{X}_1} + s^2_{\overline{X}_2}}.$$

Confidence level	**75%**	**80%**	**85%**	**90%**	**95%**	**97.50%**	**99%**
t-value	0.674	0.842	1.036	1.282	1.645	1.96	2.326

Table 3.1: One sided T-test Values and Confidence Level

This study will use the one-sided 85% confidence level to determine significance. If the t-value is greater than 1.036 then there is a significant difference between the two variables being measured.

CHAPTER 4

RESULTS

4.1 Maximum Hand Forces

The results of this research can be expressed in a variety of ways, because of the volume of data collected. One of the first issues to be resolved was the coordinate system of the hand force data that was collected. For this study it was decided to assess the hand forces in relation to the world rather than in relation to the device that was being pushed. This study focuses on the average maximal directional force exertion in the X, Y and Z axes. This is calculated by finding the maximal force vectors in each direction and then averaging these values over all the trials. To get a better picture of these loads in three-dimensional space, the average maximum resultant vector was also found, as well as the angle at the time that this maximum resultant vector occurred. The coordinate system is shown in Figure 4.1 with the relationship to the handles.

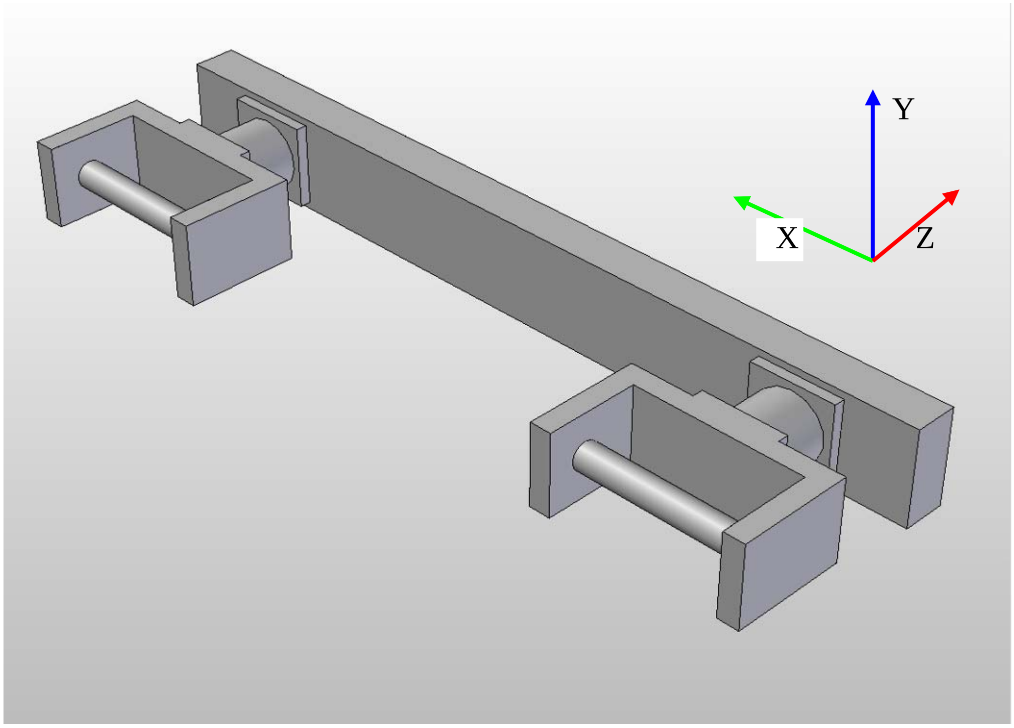

Figure 4.1: Hand Force Coordinate System[21]

This study focuses on the average maximal hand force in each direction for both handles during each observed trial. These values are: Handle_X, Handle_Y and Handle_Z. As stated in Section 3, there were 96 trials for each subject. A maximal hand force is the absolute max, whether in the positive or negative direction. This study looked at each independent variable that was used throughout the data collection. These variables were the system being used (overhead or cart), handle height, speed, gender, load, and activity (straight or precision). Each variable was then tested for significance using the student's t-test. The variables were also compared within carts and overhead lifting devices. For example the difference between light and heavy loads on carts was tested for significance as well as the heavy load on a cart against the heavy load on an overhead lifting system.

4.2 Load Findings

4.2.1 Effect of Lifting System

The first variable that was looked at was the handle system: the overhead lifting system versus the cart systems. The results of the handle forces can be seen below in figure 4.2. The error lines represent the standard deviation of the data.

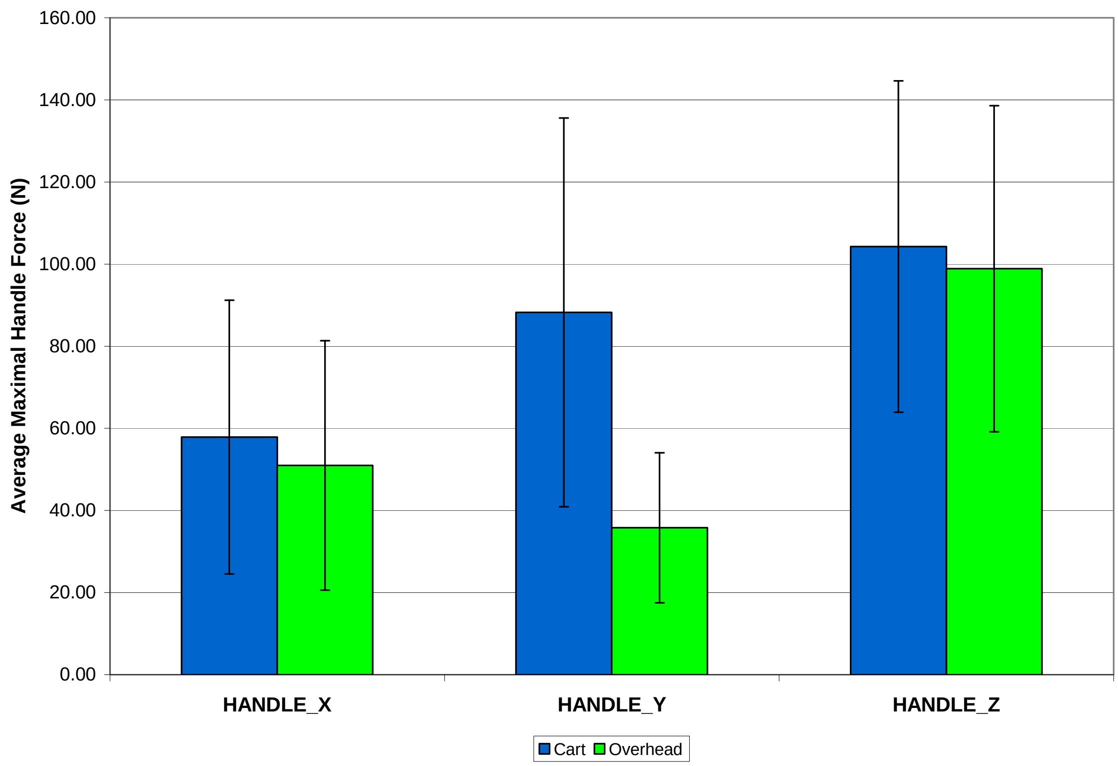

Figure 4.2: Average Maximal Handle Forces in Cart and Overhead Trials

The highest average maximal load was in the Z direction for both carts and overhead lifting systems. This was expected because that is the primary direction that the loads are being moved. What is surprising is the amount of force being exerted in the Y direction.

Direction	X	Y	Z
Cart vs Overhead	0.492	1.200	0.762

Table 4.1: T-test for Significant Values for Lifting System

(Highlighted values are significant

When looking at differences due to lifting system the differences between the Y values are significant at the 85% confidence level while the differences between the Z and X are not. This means that the subject is using significantly more force to push the cart in the Y direction.

To get a better picture of what is taking place when pushing the cart it is necessarty to look at the values in non-absolute terms. When we look at these values in non-absolute terms the Y- average for the cart is -43 N while the Y- average for the overhead lifting device is -9 N. These negative values mean that the subject is pushing down on the handles during the exertions. It is to be expected that the Y- average would be around zero so that the cart or overhead device is kept level. .

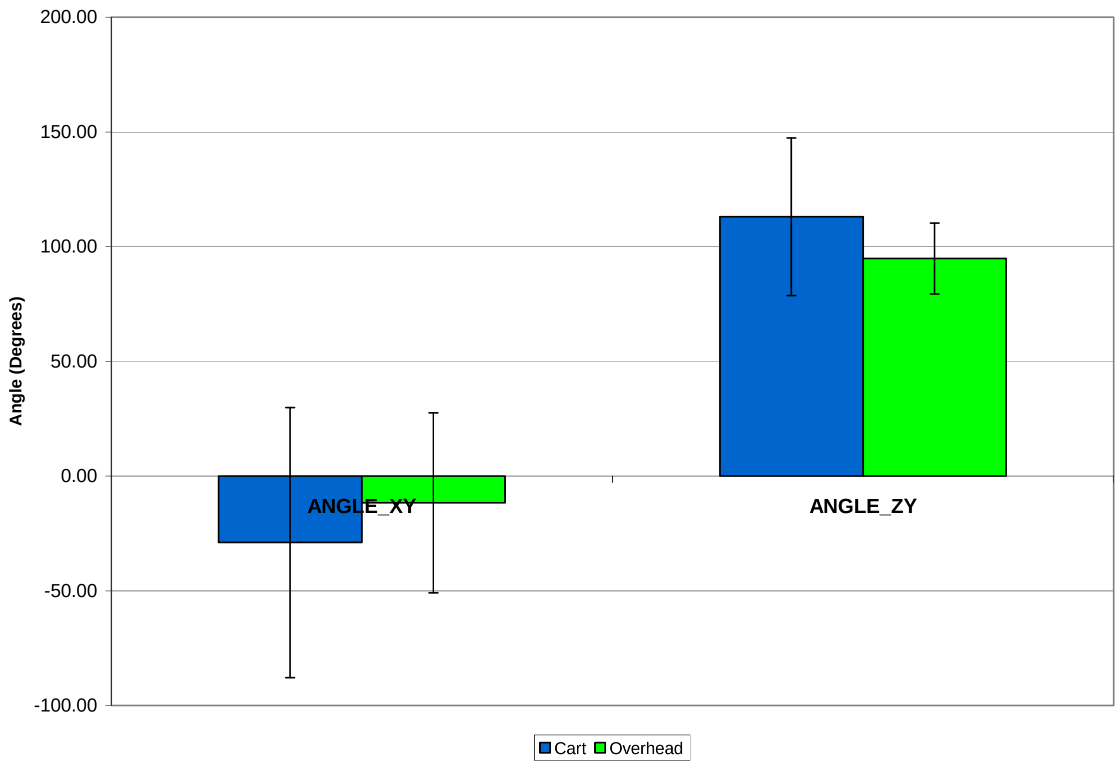

Figure 4.3: Average Angle During Maximal Resultant Pushes

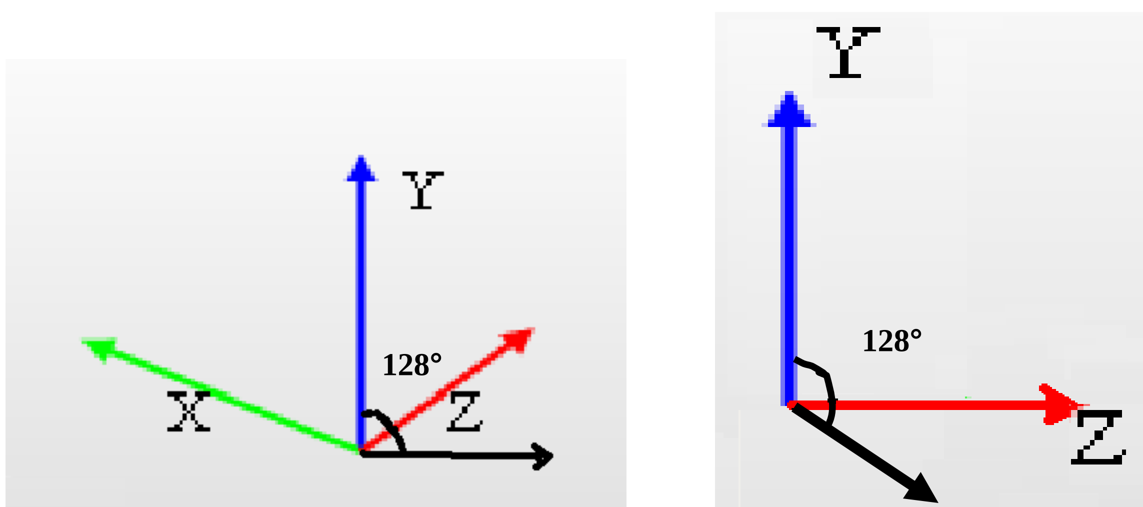

Figure 4.4: Direction of Resultant Angle in 3-Dimensions and 2-Dimensions

This can be seen very clearly when we look at the angle of the average maximal resultant vector in the YZ plane (see Figures 4.3 and 4.4). In an efficient push this would be around 90° (directly forward) so that there is no wasted motion pushing the cart up or down. The average angle of the maximal force resultant for the cart is 128° while the overhead lifting device is 99°. This really exemplifies to what degree subjects are pushing down when using the cart system.

4.2.2 Effect of Load

The next variable that was considered was the load of the cart. The average maximal handle forces can be seen below in Figure 4.4.

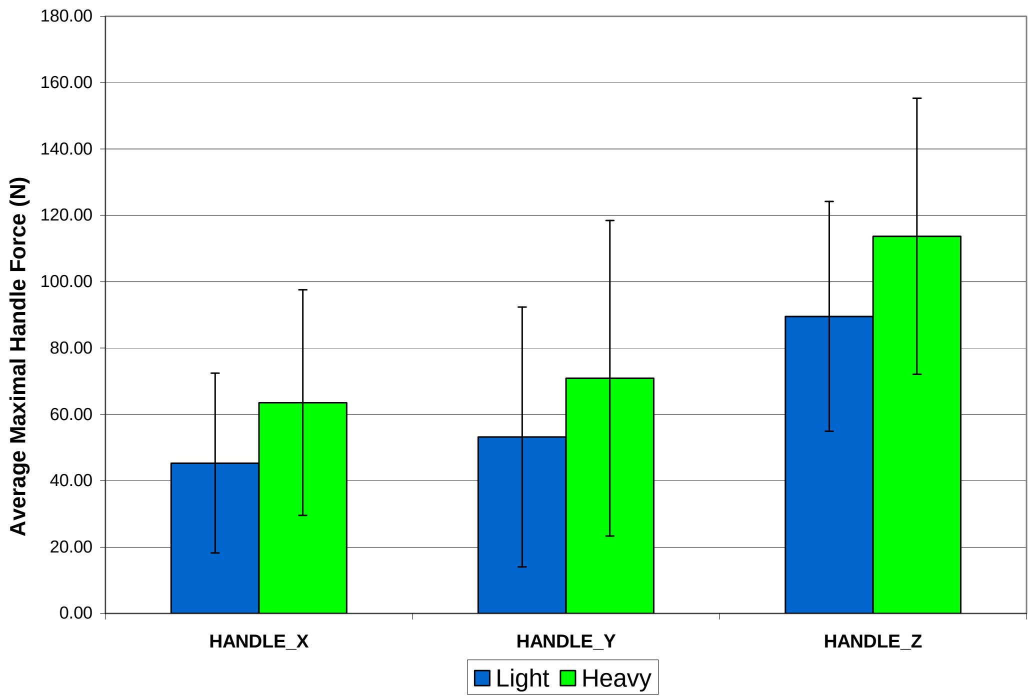

Figure 4.5: Average Maximal Handle Forces in Light and Heavy Trials.

Subjects were asked to push two loads: 370 pounds and 120 pounds. As expected there is more force exerted in all directions during pushes with the heavier load.

	X	Y	Z
Light vs. Heavy	0.887	0.659	1.042

Table 4.2: T-test for Significance Values for Lifting System

The only statistically significant difference occurs in the Z direction. This means that the effects of pushing up and down on the lifting system as well as side to side are not significantly related to the load of the system. The load also needs to be taken into consideration with other variables.

LOAD	X	Y	Z
Cart light	50.52	76.20	94.55
Cart heavy	65.40	100.32	114.11
OH light	40.17	30.08	84.57
OH heavy	62.02	41.57	113.28

Table 4.3: Average maximal hand forces for light and heavy trials (in N)

	X	Y	Z
Cart: light vs heavy	0.930	0.955	1.200
cart light vs OH light	0.485	1.168	0.467
OH: light vs heavy	0.857	0.904	0.981
cart heavy vs OH heavy	0.430	1.302	0.072

Table 4.4: T-values between lifting system and load

An interesting interaction takes place when we look at load in relation to lifting system. At the light load, there is more force being applied to the cart in all directions. At the heavy load there is little difference in the force in the X and Z direction between the two systems. There is a significant difference for the cart between the light and heavy loads. There is a significant difference at both loads in the Y direction. This is because there was a significant difference in the Y-values across all trials between the cart and overhead lifting system.

4.2.3 Effect of Direction

Another variable of interest was the direction. Subjects were asked to perform a straight push and a precision push where they had to place the cart between two poles which were offset 3 feet to the right from where the started their push. Results for the average maximal hand forces can be seen below in Figure 4.5.

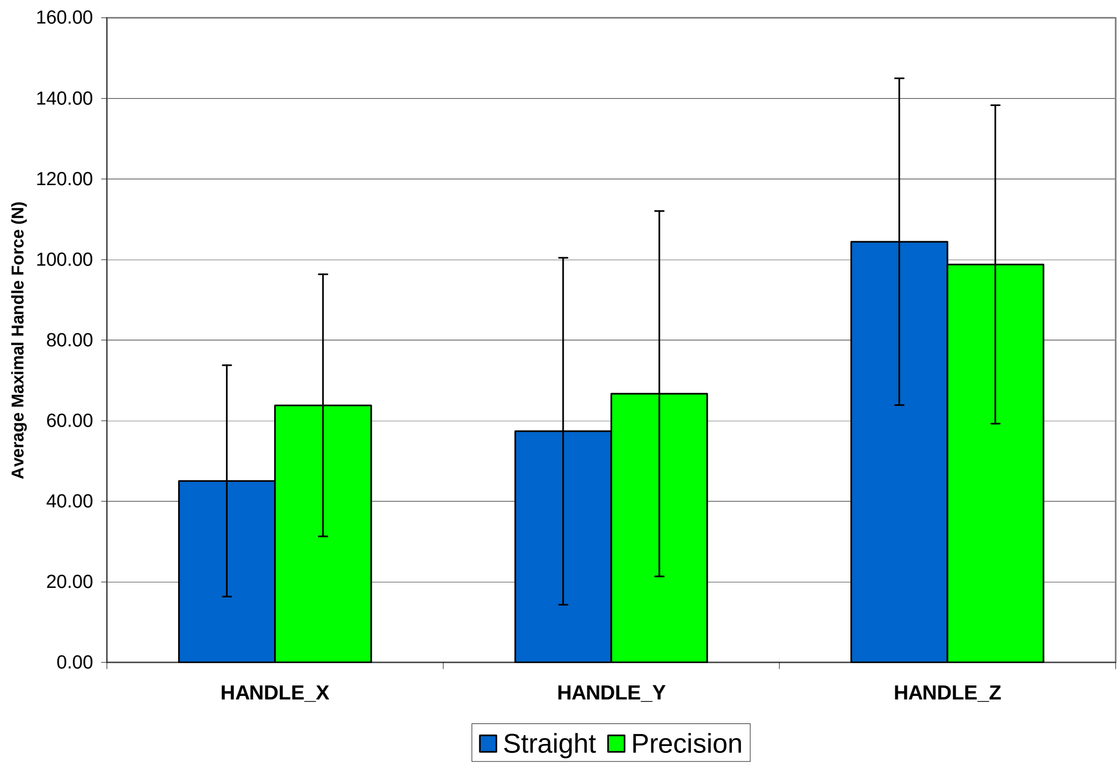

Figure 4.6: Average Maximal Hand Forces for Straight and Precision

	X	Y	Z
Straight vs Precision	0.124	0.662	0.611

Table 4.5: T-test for Significance Values for Direction

There is no significant difference between straight and precision tasks in any direction. However, when this data was compared to the forces of the overhead lifting device and the cart there were some significant differences that appeared (see Figure 4.6 and Table 4.7)

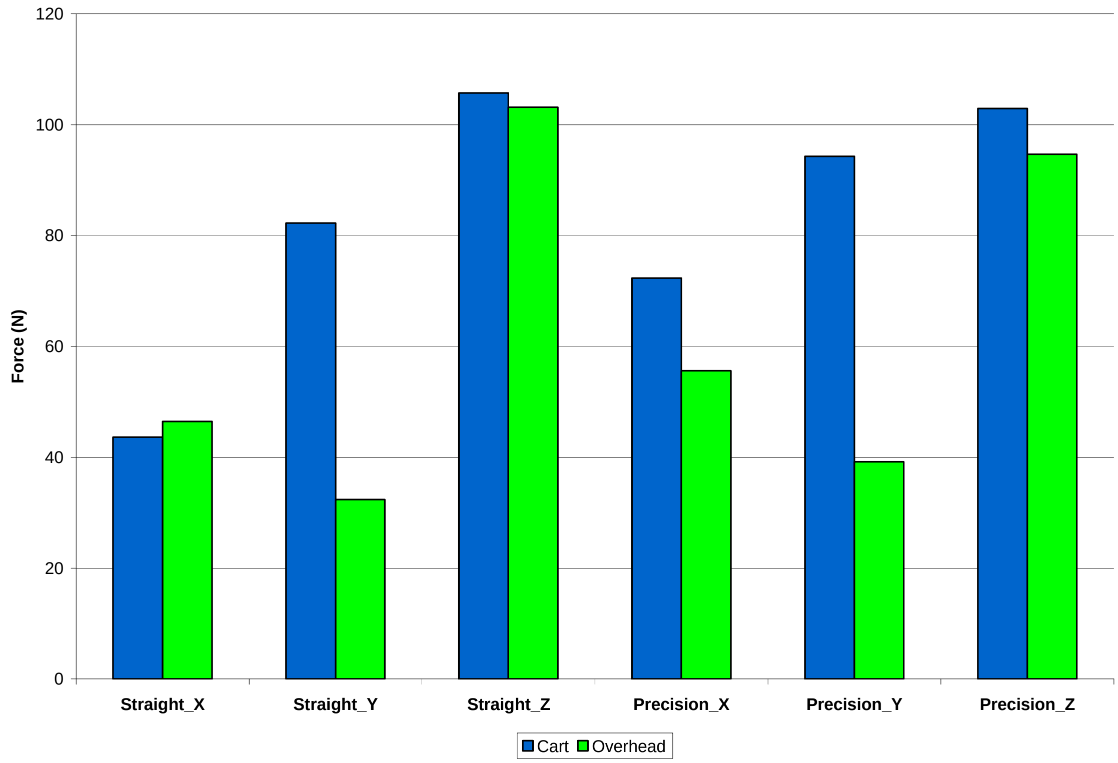

Figure 4.6: Average Maximal Hand forces with Direction and Lifting System

DIRECTION	X	Y	Z
Cart straight	43.64	82.23	105.70
Cart precision	72.32	94.27	102.92
OH straight	46.48	32.37	103.14
OH precision	55.60	39.21	94.66

Table 4.6: Average maximal hand forces for light and heavy trials (in N)

	X	Y	Z
Cart: Straight vs Precision	1.318	1.352	1.426
Cart straight vs. OH straight	0.164	1.107	0.423
OH: Straight vs Precision	0.758	0.471	0.591
Cart Precision vs OH Precision	0.935	1.320	0.629

Table 4.7: T-values between lifting system and direction

There is less force used in the overhead system than carts in all directions during precision tasks. However, the only significant difference occurs in the Y-direction. There is a significant difference in all directions between straight pushes and precision pushes with carts.

4.2.4 Effects of Gender

The next variable looked at was gender. The results (shown below in Figure 4.7) in this section were, as expected, very similar for both the male and females.

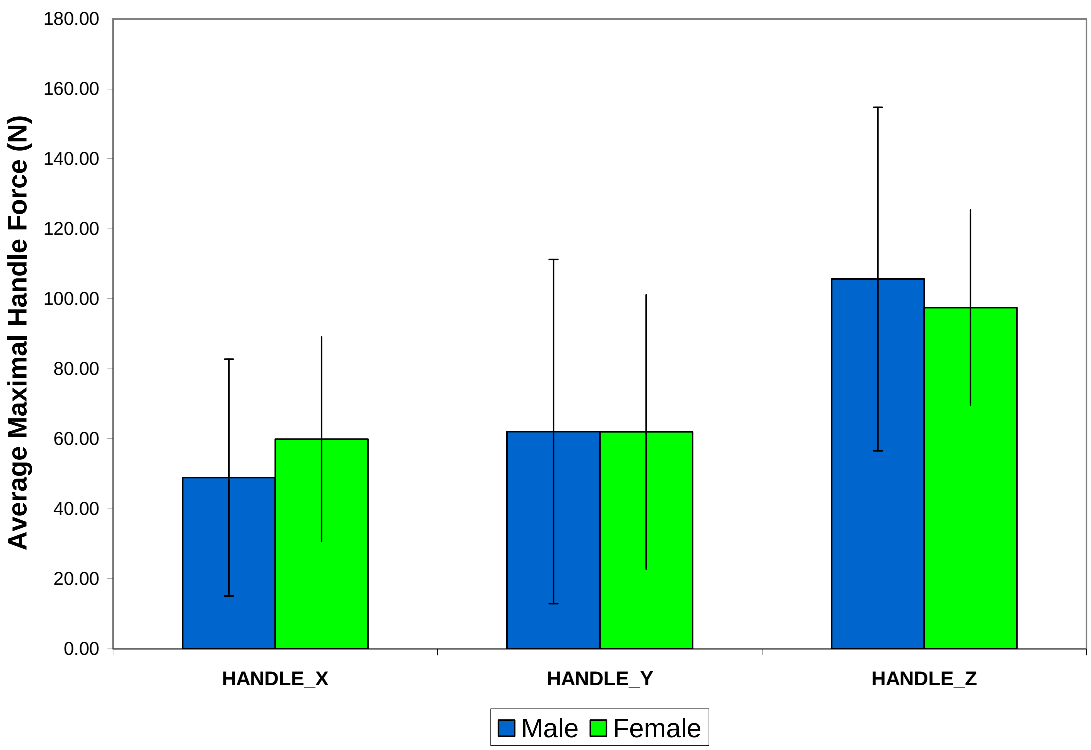

Figure 4.7: Average Maximal Hand Forces by Gender

	X	Y	Z
Male vs Female	0.657	0.003	0.202

Table 4.8: T-test for Significance Values for Gender

The males used a little more force in the Z direction while the females used more force in the X direction. These results suggest that it was easier for males to steer than females. However, none of these differences are statistically significant.

4.2.5 Speed

This study looked at the forces being applied to the handles when moving at two different speeds. When subjects were asked to move at a faster pace, the amount of force they applied was greater in all directions. There was significantly more force applied in the Z direction. This can be seen in Figure 4.8 shown below.

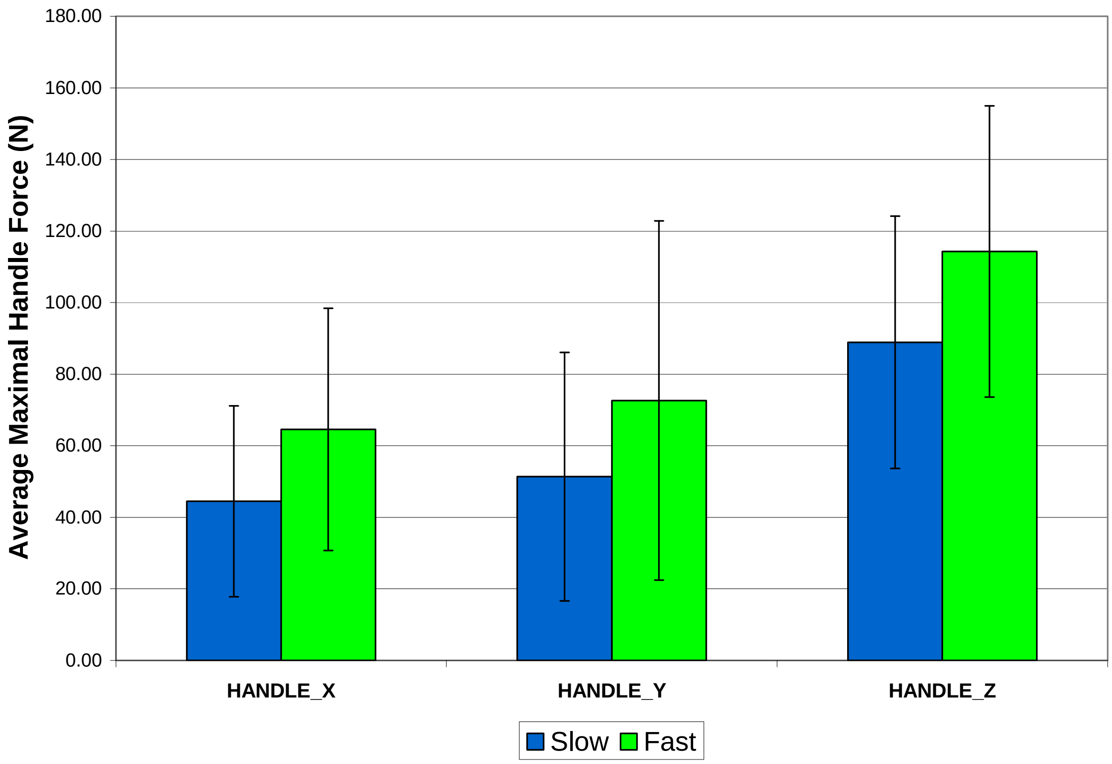

Figure 4.8: Average Maximal Handle Loads by Speed

	X	Y	Z
Fast vs Slow	0.963	0.587	1.253

Table 4.9: T-test for Significance Values for Gender

Both the cart and overhead lifting system were sensitive to changes in speed, and the difference in the Z direction was significantly more at fast speed. This confirms the logic that in order to reduce force, lower speeds should be used.

SPEED	X	Y	Z
Cart slow	47.93	71.06	91.67
Cart fast	68.01	105.48	117.01
OH slow	41.02	31.70	86.18
OH fast	61.13	39.92	111.60

Table 4.10: Average Maximal Hand Forces for Fast and Slow Trials (in N)

	X	Y	Z
Cart: Slow vs Fast	0.922	1.011	1.121
Cart Slow vs. OH Slow	0.551	1.187	0.814
OH: Slow vs. Fast	1.010	0.836	1.440
Cart Fast vs. OH Fast	0.449	1.410	0.437

Table 4.11: T-values Between Lifting System and Speed

When speed is compared to the lifting system we see that there is significantly more force used in the Z direction for both carts and overhead lifting systems at fast speeds. There is only significant difference between the cart and overhead lifting system in the Y-direction.

4.2.6 Handle Height

This study looked at the three different handle heights. Subjects pushed at 80%, 65% and 50% of their stature. As mentioned earlier the handle heights play a role in the amount of force being applied to the carts, with the low handle height having the greatest amount of force in the Y direction. In Figure 4.9, shown below, we can see that over the course of all the trials, handle height has little impact on the force being applied in each direction.

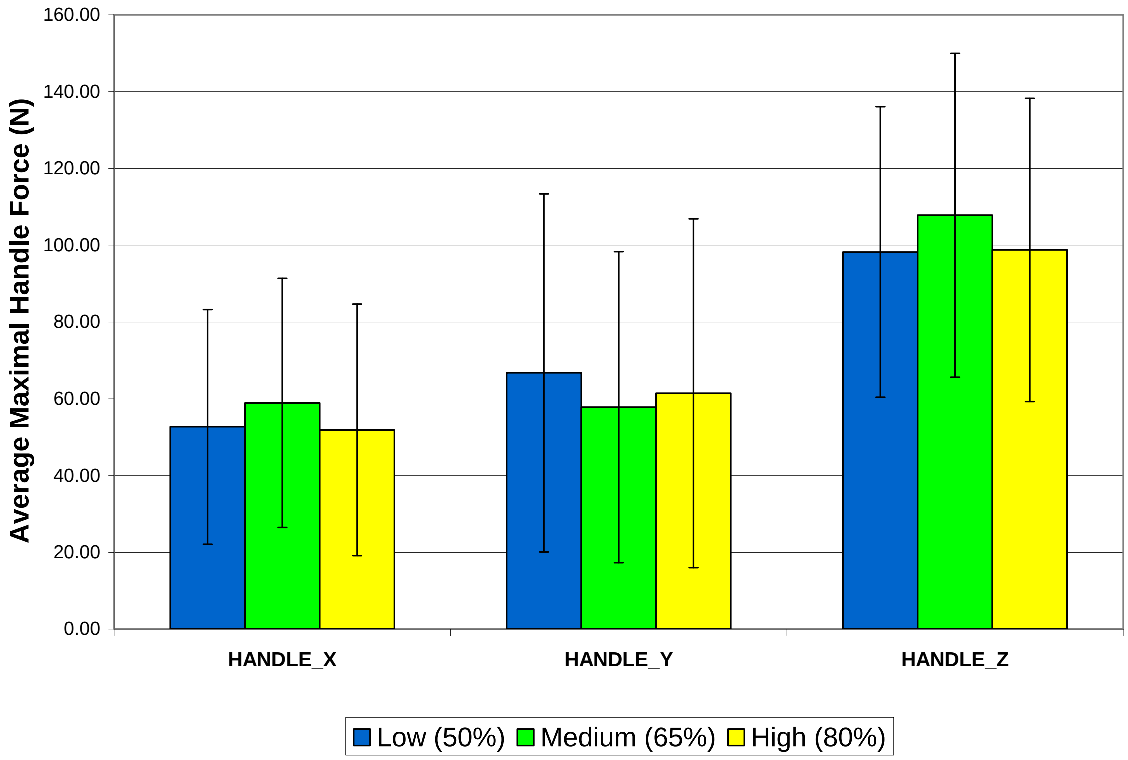

Figure 4.9: Maximal Handle Force by Handle Height

There are no significant differences between any levels of the handles. However, when we look at the handles in relation to the devices being used, a variety of statistically significant differences appear. This can be seen in Figure 4.10 below.

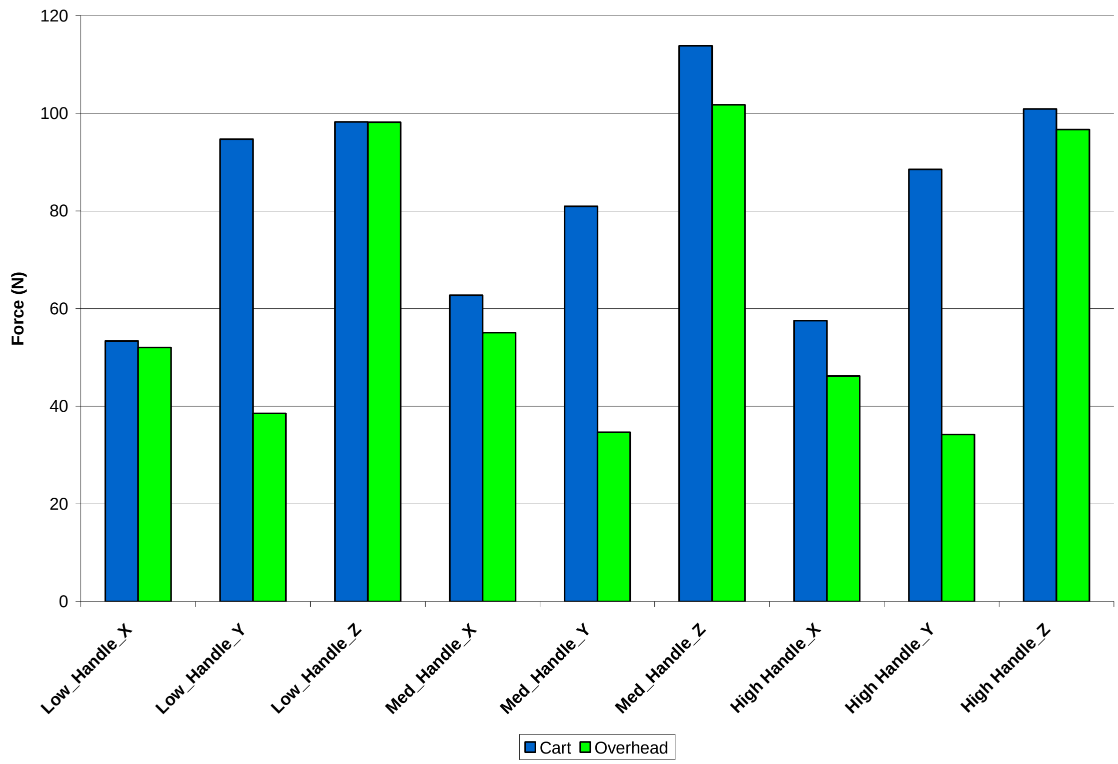

Figure 4.10: Handle Height in Relation to Lifting System

HANDLE HEIGHT	X	Y	Z
Cart low	53.45	94.92	98.31
Cart med	62.82	81.10	113.77
Cart high	57.60	88.65	100.92
OH low	51.97	38.51	98.14
OH med	55.04	34.68	101.85
OH high	46.18	34.24	96.63

Table 4.12: Average Maximal Hand Force for Handle Heights (in N)

	X	Y	Z
Cart: Low vs Med	0.505	0.589	0.589
Cart: Low vs. High	0.212	0.577	0.194
Cart: Med vs High	0.833	0.363	0.569
OH: Low vs Med	0.265	1.263	0.495
OH: Low vs. High	0.442	2.054	0.188
OH: Med vs High	1.468	0.196	0.475

Table 4.13: T-values Between Handle Heights in Each System

	X	Y	Z
Cart Low vs. OH Low	0.121	1.228	0.010
Cart Med vs. OH Med	0.429	1.179	0.549
Cart High vs. OH High	0.567	1.220	0.339

Table 4.14: T-values Between Lifting System and Handle Height

There is significantly more force being applied at the low handle height for the overhead lifting system in the Y direction. There is also significantly more force being applied in the X direction at the medium handle height.

There is also a significant difference between the cart and overhead lifting device in the Y-direction at all handle heights. To better understand this we need to look at there forces in non absolute terms to understand the direction of the push. The overall average in the Y-direction for the cart is -70N at the low handle height, -44N at the medium handle height and -14N at the high handle height. This shows that the lower the handle height on the cart the more force downward that subjects exert. These values are significantly higher than those of the overhead lifting system, whose overall maximum force in the Y-direction was -9N.

One possible explanation for this is that when pushing the overhead lifting system subjects were allowed to pull down or up on the handles after starting to push at what they felt was their optimal height. While the height of the load was still 80%, 65% and 50% of their stature at the initial push, the handles could be adjusted during the exertion to a height the subject could comfortably push. By allowing the subject's freedom to move the handles after their initial push, the overhead lifting system had lower average maximal hand force in the Y direction.

CHAPTER 5

CONCLUSION

This research was collected with the goal of better understanding the differences between the maximal handle forces being applied to overhead lifting devices and carts during pushing activities. This study showed that there are differences in the amount of force that is applied to carts versus overhead lifting devices and these differences are impacted by several other variables. When looking at these forces in relation to load, direction, gender, speed and handle height we can get a better picture of when an overhead lifting device is a more ideal pushing device than carts.

There is significantly less force being applied in the Y-direction to overhead lifting systems during all tasks. These differences are even greater when the non-absolute maxes are viewed at different handle heights. The rigid body of the cart does force subjects to maintain the same handle height throughout the exertion. This can be easily alleviated by implementing long vertical handles that allow the worker to grasp and push the cart at their desired height.

There are several other situations where overhead lifting devices performed better than carts, but the differences were not quite statistically significant. Overhead lifting systems used less force at light weight, during precision movements and at both speeds.

The results of this study show that there are significant difference in the maximal vertical hand force (Y) between carts and overhead lifting devices. This suggests that previous studies done on pushing activities using carts may provide results that may not applicable to overhead lifting systems. However, these results are only representative of the systems that were used in the OSU Biodynamics Laboratory. There are features on both the cart and overhead lifting system that if changed may change the results of this study. The size of the wheels on carts and the moment arm of the overhead lifting system are two large factors. The ceiling in the Biodynamics laboratory is considerably lower than those used in industry. The higher the ceiling the longer the arm between the handles and the overhead rails. As this moment arm increases there becomes a greater pendulum type effect, whereby the device will be pushed at the bottom before it begins to move along the rails. This effect could increase the Y-directional force and change the results of this study.

Future research should look into lengthening the moment arm of the overhead lifting system to see how this affects the maximal hand forces. Future studies could also look at hand forces in relation to the other muscles being used during the pushing activity to provide a more complete picture of the differences between carts and overhead lifting systems.

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