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Verbal estimation of peak dynamic hand forces in experienced and novice manual material handlers

Amber Phillips
University of Windsor

Verbal Estimation of Peak Dynamic Hand Forces in Experienced and Novice Manual Material Handlers

by

Amber Phillips

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Abstract

Verbal Estimation of Peak Dynamic Hand Forces in Experienced and Novice Manual Material Handlers

This study examined participants' verbally estimated peak dynamic hand forces compared to actual hand forces during various pushing and pulling tasks. Effects of manual material handling (MMH) experience and feedback training on hand force self-reporting were studied. Verbally estimated hand forces were similar across all four groups, despite different amounts of feedback training received and MMH experience. Participants were more accurate verbally estimating pushes than pulls for two-handed tasks, and at low force level for one and two-handed tasks (mean errors = 10.2 %MVC and 9.4 %MVC). Verbal estimation differences existed between high and medium forces for two-handed tasks, and medium and low forces for one and two-handed tasks. No differences were found between genders. Values generated by prediction equations demonstrated a strong relationship between actual and verbally estimated hand forces indicated by high R^2. Results indicate that a similar methodology could be performed in workplaces to attain force magnitudes.

Dedication

To my Mom and Dad.

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Glossary

CCOHS – Canadian Centre for Occupational Health and Safety is a federal agency that promotes the health and safety of Canadians in the workplace

MVC – Maximum Voluntary Contraction (MVC) is a measure of a maximal contraction that a given muscle can produce voluntarily. This is a measurement of force, and will be expressed in Newtons in this study.

MMH – Manual Material Handling involves pushing, pulling, lifting, lowering, carrying, and any other task that involves human effort to move an object.

WSIB – Workplace Safety and Insurance Board promotes workplace safety, and provides a worker's compensation system for Ontario workers and employers.

sEMG – Surface Electromyography is a technique for measuring a muscle's activity level that involves placing electrodes on the skin over an individual's desired muscle.

SI – The Strain Index is a method for assessing jobs to identify level of risk of obtaining an upper extremity (hand, wrist, and elbow) musculoskeletal disorder.

MAF – Maximum Acceptable Frequency is a subject selected rate of work that is deemed comfortable to maintain for an entire shift.

ANOVA – Analysis of Variance is a statistical model that is used to compare means.

Hand Force – The total force exerted at the hands as a result of the many muscles that help produce the desired movement.

Feedback – The inherent and concurrent visual, auditory, tactile, and kinematic information that the subject can derive from the task as they perform the training section of the study.

1.0 Introduction

Manual material handling (MMH) is still very common in industry today (Kumar, 1995; Hoozemans et al., 1998). Most of the MMH research has been conducted on the risks associated with lifting and carrying tasks (Chaffin and Anderson, 1991; de Looze et al., 2000). Push and pull tasks are gradually replacing lift and carry tasks in many industries. The relationship between push and pull tasks and their effect on the low back and shoulders has been studied by several researchers to determine their contribution to musculoskeletal disorders (Kumar, 1995; Hoozemans et al., 1998; de Looze et al., 2000; Schibye et al., 2001; Hoozemans et al., 2002). The effects of pushes and pulls on the body are diverse and need to be investigated as they are common elements of MMH today.

The increase in pushing and pulling tasks in industry has been attributed to the reduction in physical stress on the body when handling equal loads in comparison to lifting and carrying tasks (Schibye et al., 2001). The likelihood of injury associated with pushing and pulling increases when there are increases in frequency (Hoozemans et al., 2002) and amount of force needed to perform a movement (van Wendel de Joode et al., 1997). Hoozemans et al. (2002) found that with increased incidence of pushing and pulling, there was an increase in shoulder complaints, while low back pain complaints did not correlate as strongly. The types of injuries that may result from pushes and pulls are diverse, which makes it difficult to determine how common injuries due to pushing and pulling are in the workplace (CCOHS, 1997).

Biomechanical models are often used to quantify the physical stress on the body during MMH tasks. Many biomechanical models require hand forces as inputs for determining various joint moments and forces resulting from work (Delleman et al., 1992). Even though hand forces have been identified as important factors for calculating forces experienced at joints, they can be difficult to obtain in a workplace setting. Furthermore, technically analyzing jobs that have been identified as putting workers at risk using objective measures such as electromyography (Gagnon et al., 1987; Marras et al., 1999) and force gauges (Hoozemans et al., 2001) is time consuming and expensive (Hoozemans et al., 2001; Spielholz et al., 2001; Marshall et al., 2004; Bao and Silverstein, 2005; Koppelaar and Wells, 2005). Quantifying hand forces during work using direct techniques can also be intrusive and interfere with the work at hand or require mockups of actual tasks to be performed off-line.

Psychophysics is a less equipment dependent method that has the ability to realistically simulate industrial work, allowing workspace dimensions and task frequencies to be altered as needed for the study of workplace musculoskeletal risk factors (Snook, 1985). Psychophysical studies have been utilized to collect data to set guidelines for several MMH conditions. Previous psychophysical research has determined acceptable exposure limits for lifting, lowering, pushing, pulling, holding, and carrying (Snook, 1978; Snook and Ciriello, 1991), hand impacts during door trim installation (Potvin et al., 2000), hose insertions (Andrews et al., 2007), and grip force (McGorry et al., 2004). Previous upper limb studies found that psychophysics was a suitable method for determining acceptable exposure limits, and that limits were sensitive to changes in motion, frequency, duration, and hand grip type (Snook, 1991; Snook and Ciriello, 1995, Dahalan and Fernandez, 1993; Kim and Fernandez, 1993; Marley and Fernandez, 1995; Davis et al., 1998). Due to the subjective nature of this approach, other affects such as fatigue (Deeb, 1999), level of training (Wiktorin et al., 1996, Potvin et al., 2000, Marshall et al., 2004, Oliver, 2007), and level of experience/familiarity with the task (McGorry et al., 2004, Potvin et al., 2000, Kothiyal and Yuen, 2004), must be accounted for.

Previous work by Marshall et al. (2004) evaluated the potential for having workers verbalize their exerted hand forces as a percent of their maximal effort following training in various one-handed MMH work simulation tasks. Oliver (2007) extended this work to include two-handed pushing and pulling tasks that involved gross trunk and upper extremity movements that were more representative of those characteristic of manual material handling (MMH) tasks. These studies found that a minimal training protocol was just as effective at ensuring accuracy (as a %MVC) of verbal estimations of peak dynamic hand forces in novice manual material handlers as a more extensive protocol. The current study will advance this research by comparing the performance of experienced and novice manual material handlers to determine whether the training effect is the same in both populations. Previous research has found differences between novice and experienced manual material handlers in lifting and carrying tasks (Parakkat et al., 2007; Marras et al., 2006; Gagnon, 2005). By including participants of a range of experience in this study, the findings will be applicable to a larger population. Also, a greater range of pushing and pulling tasks will be employed to increase the generalizability of the results.

1.1 Purposes

Therefore, the purposes of this study are:

1. To compare actual and verbally estimated peak dynamic hand forces from a variety of MMH tasks requiring pushing and pulling in different directions and positions in experienced and novice manual materials handling populations.
2. To create regression equations that can be used to predict actual peak dynamic hand forces from verbally estimated peak dynamic hand forces.
3. To determine the effect of feedback training on verbally estimated peak dynamic hand forces.
4. To increase the applicability of existing regression equations by incorporating one and two-handed tasks.
5. To compare the accuracy of verbally estimated peak dynamic hand forces in males and females.

1.2 Research Questions

1. How does level of manual material handling experience affect ability to verbally estimate peak dynamic hand forces required for pushing and pulling tasks after training?
2. What is the relationship between participants' verbally estimated peak dynamic hand forces and actual hand forces?
3. What is the effect of feedback training on verbally estimated peak dynamic hand forces?

4. What is the difference in verbal estimation of peak dynamic hand forces for one-handed compared to two-handed pushing and pulling tasks?
5. Is there a difference between males' and females' verbally estimated peak dynamic hand forces?

2.0 Review of Literature

2.1 Pushes and Pulls in Relation to Musculoskeletal Disorders

Manual material handling (MMH) is still very common in industry today (Kumar, 1995; Hoozemans et al., 1998). The majority of MMH research has focused on quantifying and determining risks associated with lifting and carrying (Chaffin and Anderson, 1991; de Looze at al., 2000). The collection of data on pushing and pulling activities has been sparse (Hoozemans et al., 1998; Laursen and Schibye, 2002), even though they make up almost half of all MMH tasks (Kumar, 1995).

Hoozemans et al. (1998) reviewed the literature on pushes and pulls from four perspectives: epidemiology, psychophysics, physiology, and biomechanics, to determine musculoskeletal effects on the lower back and shoulders caused by the physical demands of these actions. Conditions including symmetry, type of exertion, gender, height of target, frequency of exertion, and participants' body weight were all found to effect force exertion capabilities during pushing and pulling (Hoozemans et al., 1998). The effects of pushes and pulls need to be investigated as they are common elements of manual material handling today.

The relationship between pushing/pulling tasks and their effect on the low back and shoulders has been studied by several researchers (Kumar, 1995; Hoozemans et al., 1998; de Looze et al., 2000, Schibye et al., 2001; Hoozemans et al., 2002). The types of injuries that may result from pushes and pulls are diverse, making it difficult to determine a formal and inclusive statistic reflecting how common injuries due to pushing and pulling tasks are in the workplace (CCOHS, 1997). Overexertion injuries, such as muscle strains, are most commonly sustained when pushing and pulling. Acute injuries that occur as a result of slips and falls may also be associated with pushing and pulling tasks. Other acute injuries such as lacerations to the fingers, hands, and lower limbs may occur from bumping objects against each other (CCOHS, 1997).

2.1.1 Epidemiology and Survey Data for Pushes and Pulls

The link between push and pull tasks and shoulder and low back complaints was examined by Hoozemans et al. (2002). It was found that with increased incidence of pushing/pulling, there was an increase in shoulder complaints, but low back pain complaints did not correlate as strongly. This latter finding was contrary to earlier work using epidemiological data by the same author (Hoozemans et al., 1998). These results suggest that pushing and pulling may put both the shoulder and lower back at risk of sustaining an injury.

Laursen and Schibye (2002) looked at pushing and pulling of a two wheeled cart on three different flat surfaces. The surfaces varied in smoothness, but were consistent within each trial. Within all conditions, shear and compression forces on the lower back were found to be below 1000 Newtons and 3400 Newtons, respectively (Laursen and Schibye, 2002). However, these findings should be accepted with caution, since the experimental conditions may not accurately represent true working conditions. On an actual construction site, surfaces may change, and push/pull tasks may require direction changes. These differences in conditions will most likely expose workers to greater low back shear and compression forces than seen in this study.

The majority of ship maintenance work, as examined by van Wendel de Joode et al. (1997), was found to consist of pushes and pulls. A large proportion of the ship maintenance workers reported by survey to have experienced back pain (80%) and shoulder pain (60%) in the past year. Different tasks associated with ship maintenance were examined and the average push/pull force for grit blasting was 400 Newtons. Grit blasting was performed for between thirty minutes and five hours per day, and push/pull tasks in general made up two thirds of the work. It can be concluded that ship maintenance workers in this study were at a high risk for injuring the lower back and shoulders.

2.1.2 Identifying Musculoskeletal Loads Produced by Pushing and Pulling

Historically, the majority of manual material handling tasks were lifts and carries. Push and pull tasks are gradually replacing lift and carry tasks in many industries. The reasoning for this is that when handling equivalent loads, pushing and pulling put less physical stress on the body. Schibye et al. (2001) measured the mechanics of pushing and pulling in comparison to lifting and carrying loads with the same magnitude. They found that compression forces at the low back (L4/L5) were relatively low (400 N - 1600 N) during pushes and pulls, while compression forces on the lower back during lifting reached up to 4195 N, exceeding the NIOSH limit of 3400 N. In general, pushing and pulling tasks are easier on the body than lifting and carrying of identical loads, but increases in frequency (Hoozemans et al., 2002) and amount of force needed to perform a movement (van Wendel de Joode et al., 1997) may increase the likelihood of injury.

Increasingly, in order to reduce the risk of musculoskeletal injuries in the workplace, manual handling of objects is being replaced by assistive devices such as hoists. When introducing equipment to increase efficiency of industrial tasks, pushing and pulling of the hoist is often still required. Mechanical assists should be thoroughly investigated before they are chosen to ensure physical risks are being reduced. de Looze et al. (2001) identified a physically stressful construction site job that was associated with a lot of worker injuries. The bricklayer's assistant would transport brick and mortar in a wheelbarrow across the uneven terrain of a construction site, requiring high push forces. This task was substituted with a crane system that greatly reduced the level of stress on the workers (de Looze et al., 2001). The researchers in this study identified a job with a high risk of injury, and replaced it with a mechanical system. Often, these types of fixes can be implemented relatively easily, and cost less than an injury.

In another study by de Looze et al. (2000), torques at the shoulder and L5/S1 joints were calculated as participants walked on a treadmill while pushing or pulling at three different handle heights. It was determined that the magnitude and direction of the applied force relative to body positioning were both important to consider for the most accurate shoulder and low back torques (de Looze et al., 2000). By allowing individuals to adjust the height of their workstation components, they will be able to optimize their body positioning, thus reducing the likelihood of shoulder and lower back injuries.

2.1.3 One-Handed Pushing and Pulling

Research on pull exertions has assessed two main scenarios: requiring participants to walk backwards while pulling with two hands (Kumar, 1995; Lett and McGill, 2006), and walking forwards while pulling the object with one hand behind the body (Laursen and Schibye, 2002; Schibye et al., 2001).

In addition to traditional two-handed push/pull tasks, one-handed tasks are also prevalent in the workplace and their effect on the body should therefore be determined to ensure safe working conditions. MacKinnon and Vaughan (2005) studied one-handed pulls in the frontal plane while varying reach distances as a percent of stature. It was found that at close proximity to the handle, shoulder muscles contributed the majority of work. As the distance to the handle increased, more muscle activation was seen from the erector spinae and external obliques. These findings suggest that a moderate distance from the handle (25% of stature) will allow both trunk and shoulder muscles to contribute, thus decreasing the overall risk for shoulder and low back injury. Interestingly, unbalanced muscle contributions between left and right sides were not observed during one-handed pulling (MacKinnon and Vaughan, 2005).

Gielo-Perczak (2004) looked at the relationship between one-handed pull forces and shoulder geometry. It was proposed that knowledge of individuals' glenohumeral joint characteristics will help predict strength and injury susceptibility. The complex structure of the shoulder joint and its large range of mobility put it at increased risk of sustaining injury compared to other joints (Gielo-Perczak, 2004).

2.2 Psychophysics

Psychophysics is the branch of psychology dealing with the relationships between stimuli and resultant sensations (Ayoub and Dempsey, 1999). It is a subjective form of quantifying environmental conditions that relies upon self-reports from participants. An advantage of the psychophysical approach is its ability to allow the simulation of jobs more realistically than other approaches (Snook, 1985). Psychophysical studies have been utilized to collect data to set guidelines for several MMH conditions. Psychophysical data exists for lifting, lowering, pushing, pulling, holding, and carrying tasks (Snook, 1978; Snook and Ciriello, 1991). Previous upper limb studies found that psychophysics was a suitable method for determining acceptable exposure limits, and that limits were sensitive to changes in motion, frequency, duration, and hand grip type (Snook, 1991; Snook and Ciriello, 1995, Dahalan and Fernandez, 1993; Kim and Fernandez, 1993; Marley and Fernandez, 1995; Davis et al., 1998). This sensitivity makes it important to conduct studies on the appropriate populations using the psychophysical approach. Due to the subjective nature of this approach, other affects such as fatigue (Deeb, 1999), level of training (Wiktorin et al., 1996, Potvin et al., 2000, Marshall et al., 2004, Oliver, 2007), and level of experience/familiarity with the task (McGorry et al., 2004, Potvin et al., 2000, Kothiyal and Yuen, 2004), must be accounted for.

The sensitivity and flexibility of the psychophysical approach are perhaps some of the reasons why this method has not been replaced by other more objective means. The lack of extensive equipment required to use this method and the lower cost as a result, makes the psychophysical approach a desirable choice when performing workplace studies. Using a psychophysical approach, workplace tasks can be performed as they would be normally, without extensive equipment interfering or altering the performance of the task. Results from psychophysical studies have been found to be reproducible (Snook, 1985). Psychophysics has the ability to realistically simulate industrial work, allowing workspace dimensions and task frequencies to be altered as needed (Snook, 1985). Also, combinations of tasks can be performed to find cumulative effects (Snook, 1991).

Kim and Fernandez (1993) tried to determine participants' maximum acceptable frequency for a simulated sheet metal drilling task. Levels of force and wrist flexion angles were varied during the task. Participants were required to select the maximum frequency they could tolerate for an eight hour shift at each experimental condition. Physiological responses (heart rate, muscle EMG, blood pressure) increased with RPE as task demands escalated. Increases in force application and wrist flexion angle led to decreases in self-selected maximum acceptable frequencies. Kim and Fernandez (1993) concluded that, in the absence of objective physiological and biomechanical measures, the psychophysical approach is a suitable tool for determining acceptable limits for wrist and hand work.

Similar to Kim and Fernandez (1993), Dahalan and Fernandez (1993) studied maximum acceptable frequency of a gripping task at four grip force levels and durations. When grip force and duration increased, participants' self-selected maximum acceptable frequency decreased. Physiological measures (heart rate, blood pressure, muscle EMG) increased along with participants' RPE. From both studies, it is evident that people are able to self-select a comfortable frequency they can safely work at.

The psychophysical approach was used by Potvin et al. (2000) to determine acceptable peak force and impulse for a hand impact task to install door panels. Both skilled and unskilled manual material handlers participated in this study. Two studies were conducted: the first examined the effects of gender, skill, and impact location, the second study examined effects of gender and impact frequency. Significant differences were found between skill levels on the resistance setting chosen by participants in the first study; unskilled participants selected higher impulse values than skilled participants.

In the second study, impact frequency had a significant effect on peak force, load rate, and impulse. In both studies, significant effects were found between males and females, with males selecting higher resistance settings and producing higher impulse values.

Andrews et al. (2007) studied participants' ability to self-select maximum acceptable force during a hose insertion task that is commonly seen in the automotive industry. The task conditions were varied by three frequencies and five postures. Participants were asked to exert the maximum acceptable force they could endure for an eight hour shift without causing fatigue and undue stress to themselves for each condition. At a frequency of one exertion per minute, the average force accepted was 63% of the participants' maximum voluntary contraction. As the frequency increased, the self-selected acceptable force decreased.

Support for using the psychophysical approach was strengthened by Kothiyal and Yuen (2004) from their work with experienced nurses. Nurses' perception of forces placed on their body during a patient transfer task with and without a transfer aid was analyzed. Participants were asked to rate their perceived exertion (RPE) experienced at the shoulder and low back during manual and sling assisted patient transfer tasks. Both EMG activity (trapezius and erector spinae) and nurses' RPE were higher for transfers using the transfer aid. These findings demonstrate that the use of RPE scale supported findings seen in the EMG activity.

2.2.1 Psychophysical Training

In order for the psychophysical approach to be effective, participants must first be trained to achieve accurate estimations of their exertions (Deeb, 1999; Potvin et al., 2000;

Marshall et al., 2004; Andrews et al., 2007; Oliver, 2007). When testing participants with varying levels of expertise and experience, training has been utilized in an attempt to equalize the groups' familiarity with the experimental tasks (Potvin et al., 2000). In a study by Potvin et al. (2000), the unskilled group received 8 hours of training over two days, and the skilled group received 4 hours of training on one day in an attempt to ensure they were familiar with the repetitive hand impact tasks performed. Significant differences in force variables (peak force, time to first peak, rate of loading, and impulse) were not found between the skilled and unskilled groups following training, suggesting the training protocols were adequate for the unskilled workers to establish their acceptable limits (Potvin et al., 2000).

McGorry et al. (2004) conducted multiple psychophysical experiments on grip force estimation in experienced and novice meat cutters. This study examined the effects of the nature of the task, experience and learning, and measurement system on grip force estimate accuracy. The first experiment required participants to perform a variety of gripping tasks, and replicate the force used immediately after performing the task on a dynamometer or instrumented test handle that were provided randomly. The second experiment consisted of novice meat cutters performing a simulated meat cutting task (clay was used). Following the cutting task, participants were asked to replicate the grip force exerted on the knife handle during the task on a dynamometer or instrumented knife handle. Lastly, experiment three was conducted in a meat packing plant with experienced meat cutters as the participants. Real meat cutting tasks were performed, after which participants were asked to replicate gripping forces using the instrumented knife handle. In the first experiment, grip force estimations showed large variability between participants, although as grip forces increased, there was increased error estimation accuracy. The lack of a training effect in the second experiment was explained by the complexity of the meat cutting task. Perhaps a longer training period is required for novice meat cutters to be able to show a learning effect for grip force estimation accuracy (McGorry et al., 2004). The variability of conditions between experiments 2 and 3 differed too much to provide meaningful comparison between experienced and novice meat cutters.

Marshall et al. (2004) reported both an increase in accuracy (as a % MVC) and precision (standard deviation) with training. Even in the group that received the least training, significant increases in force estimation accuracy were found upon testing. Oliver (2007) also looked at different levels of psychophysical feedback training for verbal estimation of peak dynamic hand forces. Participants were divided into groups and presented with different amounts of force feedback training on a variety of pushing and pulling tasks. Similar to Marshall et al. (2004), it was found by Oliver (2007) that the group receiving the least amount of training was also just as accurate at verbally estimating peak dynamic hand forces as the more extensively trained group. These findings are favourable for implementing a psychophysical training approach in the workplace to identify hand force requirements.

2.3 Quantification of Hand Forces

Many sources have agreed that hand forces are a risk factor for musculoskeletal disorders (Silverstein et al., 1986; Spengler et al., 1986; Moore and Garg, 1995; Koppelaar and Wells, 1995). It is important to be able to obtain accurate hand force measures so that biomechanical model outputs can better predict forces experienced by the lower back and shoulders. Identifying hand force magnitudes is very important for ergonomists in order to determine the level of risk associated with a given task. Many biomechanical models require hand forces as inputs to calculate forces at various joints (Delleman et al., 1992). Many different methods have attempted to acquire acceptable hand forces while minimizing the cost of performing technical analyses of manual material handling tasks (Marshall et al., 2004; Spielholz et al., 2006; Koppelaar and Wells, 2005; Wiktorin et al., 1996; Bao and Silverstein, 2005; Oliver, 2007). Results from Oliver (2007) are promising for the potential to apply force feedback training in the workplace to acquire hand forces with little or no equipment while the tasks are being performed.

Often, the cost required to obtain accurate hand force measurements is high. Although knowing accurate hand force measurements is important for calculating forces experienced at joints, they can be quite difficult to obtain. Furthermore, technically analyzing jobs that have been identified as putting workers at risk is time consuming and expensive (Hoozemans et al., 2001; Spielholz et al., 2001; Marshall et al., 2004; Bao and Silverstein, 2005; Koppelaar and Wells, 2005). Two types of objective measures that have been used to measure hand forces are electromyography (Gagnon et al., 1987, Marras et al., 1999) and force gauges (Hoozemans et al., 2001). Both these direct measurement techniques may interfere with the worker as they perform the task; therefore, offline mockups of jobs may be required, which are both costly and time consuming (Spielholz et al., 2001; Marshall et al., 2004; Koppelaar and Wells, 2005).

Other less equipment-dependent methods have been utilized in the past to try and reduce the costs and time required to perform biomechanical assessments in the workplace. Self-report (Marshall et al., 2004; Spielholz et al., 2006), observation (Koppelaar and Wells, 2005), and force matching (Wiktorin et al., 1996; Bao and Silverstein, 2005) methods have all been tried with varying degrees of success.

Verbally estimated hand loads are relatively easy to obtain and have been found to be a fairly accurate way for ergonomists or researchers to gather individuals' dynamic hand forces (Marshall et al., 2004). Oliver (2007) looked at the accuracy of verbal estimates of peak dynamic hand forces in participants given different levels of feedback training. Following force feedback training, a testing session was conducted, requiring participants to verbally estimate their peak dynamic hand force (expressed as % MVC) immediately after each exertion. They found that a less extensive training protocol produced similar mean absolute errors for peak dynamic hand force reporting as the more extensive and time consuming protocols (Oliver, 2007).

Observational methods are performed at the workplace or video recorded and analyzed afterwards using checklists or more detailed task recording. Spielholz et al. (2001) noted that results from video-based observations may be more reproducible than workplace observation due to the ability to repeatedly view the same trials. The same study also found that video-based observational methods with measured hand forces matched direct measurement measures more closely than self-reports. Koppelaar and Wells (2005) also found that observational methods based on video, or researchers observing and recording workers' actions were more accurate when force and moment data were provided to the observers during the assessment.

Force matching is a form of force measurement that requires an individual to perform a manual task, then immediately replicate the perceived force requirement on a force measuring device (Bao and Silverstein, 2005). The force matching method has been used to identify hand grip forces (Bao and Silverstein, 2005), as well as push/pull magnitudes and dynamic lifting forces (Wiktorin et al., 1996). Bao and Silverstein (2005) found hand grip force matching to be accurate and consistent at a group level. They noted that instructions given to participants were a very important factor in ensuring good pinch and power grip estimations. Participants' ability to reproduce force requirements for familiar push/pull and lifting tasks were good, however, ability to quantify force requirements in Newtons was not as accurate (Wiktorin et al., 1996).

There have been many different interpretations of the term hand force in the literature (Koppelaar and Wells, 1995). Hand forces, for the purpose of this study will be defined as the total force exerted at the hands as a result of several muscles being activated to create an intended action.

2.3.1 Self-reports Used to Acquire Hand Forces

Wiktorin et al. (1996) examined the ability of participants with manual work experience to reproduce simulated, familiar manual work forces and to quantify these forces in absolute terms (kilograms or Newtons) by self-reports. It was found that participants were able to reproduce forces physically, but were not as proficient at verbally quantifying forces in Newtons. This can possibly be attributed to the fact that Newtons are not familiar units of measure to most people. Also, training was shown to improve accuracy, and participants were better at estimating forces in relative terms rather than absolute. Underestimation of forces was seen for familiar lifting, high force pushing, and pulling tasks. Overestimation of forces was seen for tasks requiring low forces to be exerted. Sufficient participant training and practice time are needed to scale manual forces into objective units when perceiving and immediately estimating force during or directly after an exertion (Wiktorin et al., 1996).

Andrews et al. (2007) used psychophysical methods to determine participants' acceptable peak forces and impulses for automotive assembly hose insertion tasks. Female participants underwent extensive training in several hose insertion task conditions, followed by testing. It was concluded that trained individuals consistently chose to apply less force as frequency increased (Andrews et al., 2007). Interestingly, maximum allowable force exertions were found to be steady across all conditions when expressed in relative terms (% MVC).

Marshall et al. (2004) exposed groups to a varying number of benchmarks expressed in relative terms as a % MVC. Even with a modest training protocol consisting of one physical benchmark (100% MVC), the magnitude of verbal force estimation error was significantly reduced from that of the control group (Marshall et al., 2004). The addition of two more benchmarks (25% and 75% MVC) reduced estimation errors to a slight underestimation (-3% MVC) overall, from the slight overestimation (4% MVC) of the one physical benchmark group.

2.3.2 Combination of Methods to Acquire Hand Forces

A limitation of the self-report method for obtaining hand forces is its subjective nature. Often, more objective measures are considered to be superior when trying to measure musculoskeletal risk factors. Several studies have compared psychophysical data to various objectively measured criteria such as electromyography and force gauge measurements (Kim and Fernandez, 1993, Dahalan and Fernandez, 1993, Kothiyal and Yuen, 2004, Wiktorin et al., 1993, Morose et al., 2004). In Kothiyal and Yuen (2004), a nursing transfer aid (sling) was tested using RPE and EMG on the lower back and shoulders. It was found that EMG matched the RPE scores for the lower back, but not the shoulders. Wiktorin et al. (1993) distributed a questionnaire to various working populations ranging from furniture movers to secretarial work. Questions on work posture and manual material handling were validated by an observing ergonomist. The agreement between worker verbally estimated exposures and direct measurements (pedometer, posimeter, and inclinometer) made by an ergonomist was stronger for more extreme postures and load amplitudes than for smaller exposures. Wiktorin et al. (1993) concluded that worker self-reports of working postures and manual material handling tasks were an acceptable means of determining if exposure was present or absent, but they were poor at determining more detailed levels of exposure.

Morose et al. (2004) compared rate of perceived exertion and muscle activation of the forearm and hand (EMG) during gripping tasks. Participants performed identical pinch, hold, and grasp tasks twice, although the second trial was conducted on a modified pinch/grip dynamometer. A linear relationship between task RPE and task reproduction of perceived effort on the dynamometer was found. The EMG readings showed differences in muscle activation within tasks, while RPE remained constant. The suggested explanation for this was that RPE is a holistic view of all proprioception, so it may not change when one level of muscle activation increases and another decreases because the overall force produced may remain constant (Morose et al., 2004).

2.3.3 Limitations of Biomechanical and Psychophysical Methods

Biomechanical models of the lower back and shoulders are predominantly used to assess whether the musculoskeletal system is overloaded (Dempsy, 1998). The data used to validate biomechanical models were originally based on maximum intervertebral disc compression values found through research conducted on spinal failure of cadavers (Dempsy, 1998). This cadaver data may not be valid for determining tissue tolerance levels in living participants; it is unknown whether in-vitro spines respond similarly to force application as in-vivo spines do. Other limitations associated with biomechanical modeling include the oversimplification of the model itself, and erroneous kinematic data (Dempsy, 1998). This study aimed to address the inability to accurately measure external forces an individual is exposed to in the field.

The most significant limitation of the psychophysical method is that it is based on the assumption that workers are able to identify a safe level to work at for an eight hour shift that while remaining below their injury threshold (Ayoub and Dempsy, 1999). The subjective nature of psychophysics is another limitation of this method. When working at higher task frequencies (greater than 6 lifts/min), using the psychophysical approach may exceed limits recommended by the physiological approach. This can be due to the fact that when collecting psychophysical data, safe limits for an 8 hour shift are often set after 20-25 minutes. Workers may select faster acceptable frequencies earlier in the shift if they are not able to project the fatigue they will experience towards the end of a shift

(Ayoub and Dempsy, 1999). More recent studies by Potvin et al. (2000) and Andrews et al. (2007) have included more extensive training protocols that have lasted several hours. The above mentioned limitation may be less of a consideration when participants are required to perform tasks for longer times closer to what would be experienced at work.

2.4 Experienced and Novice Manual Material Handlers

Previous research looking at verbal estimations of peak hand loads used novice manual material handlers as participants (Marshall et al., 2004; Oliver, 2007). It is important to ensure applicability to more experienced groups if the technique is to be implemented in the workplace. By including participants with a range of experience in this study, the findings will be applicable to a larger population.

Gagnon (2005) found that experienced MMH workers performed lift and carry tasks differently than novices performing the same task. Experienced MMH workers (those with at least 10 years of MMH experience) oriented their pelvis, supporting foot and load toward the deposit location and avoided large knee flexion. They also took several small steps, rather than fewer large steps, as seen in novice participants. In contrast, the novices faced the location of pick up, took larger steps, and bent their knees to a greater extent. The strategies were compared in this study to determine if the experienced manual material handlers performed tasks significantly safer than the novices. Upon finding significant differences between novices and experienced MMH workers, the aim is to incorporate safe experienced MMH worker handling strategies in training programs for novice workers.

Gagnon (2003) also examined whether the experienced worker strategies made tasks safer. It was found that mechanical work was reduced, and a decrease in back extension moments were noted when novices adopted techniques employed by the experienced workers and were allowed time to practice.

Padula et al. (2008) evaluated trunk movements of novice and experienced load carriers. They found that both groups had a tendency to flex or extend the spine during the carry phase of a transfer task depending on whether the deposit location was high or low. For high deposit locations, back extension was noted, and for low deposit heights, forward flexion was observed. It should be noted that the amount of MMH experience required in order to be classified into the experienced MMH group was only six months in this study. This may explain why differences were not found between the novice and experienced groups.

Spine loading differences between experienced workers and novices were studied by Marras et al. (2006). Experienced workers experienced higher spinal loads when they performed slower lifting tasks (2, 4, 6 lifts per minute), while novices displayed the reverse effect, eliciting higher spinal loading while lifting at higher frequencies (8, 10, 12 lifts per minute). An explanation given for this may be that lower spinal loading is experienced during familiar tasks. When tasks are familiar, muscle activation may shift from simultaneous to sequential (reducing the force generated by co-contraction) (Marras et al., 2006).

Due to the difficulty in getting physiological and biomechanical measurements in a workplace setting, discomfort ratings are often utilized to assess risk in the workplace. Parakkat et al. (2007) compared experienced workers and novices' ratings of discomfort during a lifting task. The task was varied by frequency and moment on the low back. Experienced workers were found to report the same low level of discomfort under all conditions. Novices were much more sensitive to increased duration, moment, and frequency. These findings demonstrate the variability in how tasks are perceived by participants with varying level of work experience.

Paris and Kothiyal (2005) studied heart rate and subjective perceptions of fatigue in trained and untrained MMH workers. Participants performed a lift and lower task for 15 minutes at a rate of 12 lifts per minute. Participants in the trained group had at least two years of MMH experience, while those in the untrained group included sedentary administrative workers who had not participated in weight lifting, conditioning exercises, or gym training for the past two years. Statistically significant differences were found between groups for both measures; the untrained group obtained a 25% increase in heart rate and 65% increase in subjective perception of fatigue at the completion of the trial compared to the trained group. These results further emphasize the impact that level of MMH experience can have on how physical tasks are experienced and perceived.

2.5 Summary

Pushing and pulling tasks are replacing lifting and carrying tasks in the workplace (Schibye et al., 2001). Links between pushing and pulling tasks and MSDs of the lower back and shoulders have been found in epidemiological research. When pushing and pulling tasks are work requirements, it should be ensured that they are not performed at high frequencies or with excessive loads to minimize the amount of risk to the worker.

Accurate measurement of hand forces is very important as they are inputs to biomechanical models and have been shown to be biomechanical risk factors for lower back pain and potential injury (Silverstein et al., 1986; Spengler et al., 1986; Delleman et al., 1992; Moore and Garg, 1995; Koppelaar and Wells, 2005). Due to the difficulty of using direct measurement techniques to acquire hand forces on the job, the psychophysical method is often employed. When utilizing the psychophysical method to acquire verbally estimated efforts, data can be collected as work is being performed, allowing for a more realistic job simulation (Snook, 1985).

Psychophysical methods have been used to determine acceptable work forces (Potvin et al., 2000; Andrews et al., 2007), frequencies (Dahalan and Fernandez, 1993; Kim and Fernandez, 1993), to discover how fatigue influences the perception of weight (Deeb, 1999), and to estimate actual peak dynamic hand forces from verbal estimations (Marshall et al., 2004; Oliver, 2007). When using the psychophysical method, it is important that participants receive feedback training, which has been shown to improve accuracy of verbally estimated forces (Deeb, 1999; Andrews et al, 2007; Potvin et al, 2000; Marshall et al, 2004; Oliver, 2007).

Differences have been found between novice and experienced manual material handlers' working strategies (Gagnon, 2005; Padula et al., 2008). Other differences identified between novice and experienced workers include discomfort ratings (Parakkat et al., 2007) and the effect of lift frequency on spinal loading (Marras et al., 2006). When applying experimental findings to working populations, it is important that research participants are of a comparable level of work experience to the target population.

3.0 Methodology

3.1 Participants

Thirty two participants were recruited for this study. Sixteen (8 males, 8 females) were experienced manual material handlers (average of 6.4 years experience, SD=4.6) and sixteen (8 males, 8 females) were novice manual material handlers (Table 1). The novice group was recruited from the student population at the University of Windsor, as well as the surrounding community. The experienced group was also recruited from the community by means of posters in local Goodlife Fitness Clubs and word of mouth. To be eligible to participate in this study, individuals must have been free of injury and pain in the upper extremities, shoulders, and back at the time of data collection. This was explained to participants prior to data collection, as well as outlined in a consent form which was signed by participants. The study procedures were sent to the University of Windsor's Research Ethics Board for approval prior to data collection.

Table 1. Participant age, years of experience manual material handling, height, body mass, and occupation.

Subject Code	Group	Age	Yrs Exp	Height (cm)	Body Mass (kg)	Occupation
S04	1	20	0	178	64	No job
S05	1	21	0	173	68	Student
S13	1	25	0	160	63.5	Clerical
S17	1	31	0	173	70	Journalist
S20	1	39	0	185	103	Manager
S25	1	20	0	178	70	Insurance Adjuster
S29	1	23	0	168	60	Teacher
S30	1	24	0	171	62	Student
S01	2	18	2	168	63.5	Barn hand (clean stalls, handle horses)
S02	2	18	4	189	86	Mold maker-move steel, use wrenches, pliers, etc
S08	2	34	2	158	57	RMT, yoga teacher
S10	2	24	5	185	75	Mechanic
S11	2	27	5	180	77	Landscaping, brick laying
S12	2	42	20	158	68	Paramedic
S14	2	22	6	180	88	Factory-working heavy machinery, presses
S21	2	37	11	170	60	Pharmaceutical factory-run soft gel capsule machine
S06	3	30	0	166	78	Office (IT)
S09	3	27	0	175	86	Student
S15	3	26	0	175	68	Health Promotion Specialist (office)
S16	3	31	0	168	67	Office
S18	3	31	0	173	84	Office-Mechanical Engineer
S22	3	45	0	155	67	Office-Customs Rater
S24	3	31	0	180	88	Office-Customs Officer
S31	3	18	0	180	64	Student
S03	4	24	7	178	70	Labourer-operate backhoe and yard jobs
S19	4	28	4	183	93	Personal trainer
S23	4	26	6	168	79	Factory- packing, lifting
S26	4	29	2	170	59	Lifting patients, computer work
S27	4	29	10	173	77	Factory-process technician
S28	4	21	6	163	61	Picking up packages, pulling heavy equipment
S32	4	26	3	164	75	Personal support worker
S35	4	29	10	168	95	Truck driver, landscaping

To reduce any learning effects, tasks (see description below) were randomized for each group. All of the study participants were unfamiliar with the test apparatus. The experienced manual material handling group, it was hypothesized, would be more familiar with the tasks due to their experience in manual material handling. Also, it was hypothesized, they would be more comfortable performing manual work, and thus, more comfortable with moving their bodies during the tasks. The proposed feedback training was aimed at improving the ease and accuracy of on the job ergonomic analyses, so it was important to test the training protocol on an experienced manual material handling workforce. This ensured that the recommended use of the proposed protocol is warranted. The novice group was used to provide a comparison to previous work (Oliver, 2007).

3.2 Equipment and Data Collection

Both one and two-handed pushes and pulls were examined in the proposed study. Push and pull forces were applied to either a two-handed straight bar handle, or a one-handed handle mounted at the axis point in the centre of the two-handed straight bar (Figure 1). These handles were mounted to an apparatus consisting of a force gauge (MLP-500-CO, Transducer Techniques, Temecula, CA) in line with a pneumatic cylinder (6.35 cm in diameter with a 10.16 cm stroke – 20060823-27, Chelic Pneumatic Equipments, Taiwan). Air pressure within the cylinder is regulated by a solenoid which controls the flow of air between the two sides of the cylinder. Air flows freely between the sides when the solenoid is open, which allows both push or pull movements of the handles. When the solenoid is closed, pushing or pulling on the handles does not elicit any movement. The pressure in the cylinder was controlled by the experimenter via a nearby computer. The hand force apparatus was mounted on a vertical sliding frame, so the height of the tasks could be adjusted (Figure 2). The set up of the handles in line with the force gauge allowed the exertion levels to be measured and transmitted to the computer (Figure 1).

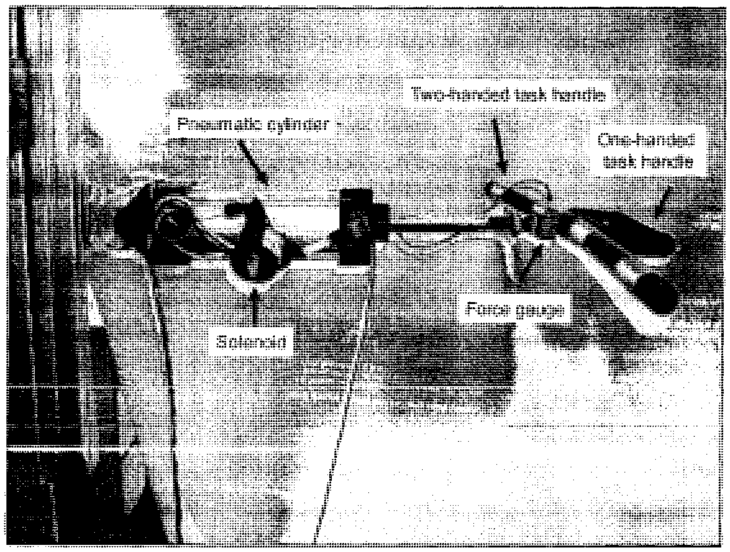

Figure 1. Apparatus that was used to test dynamic hand force estimations.

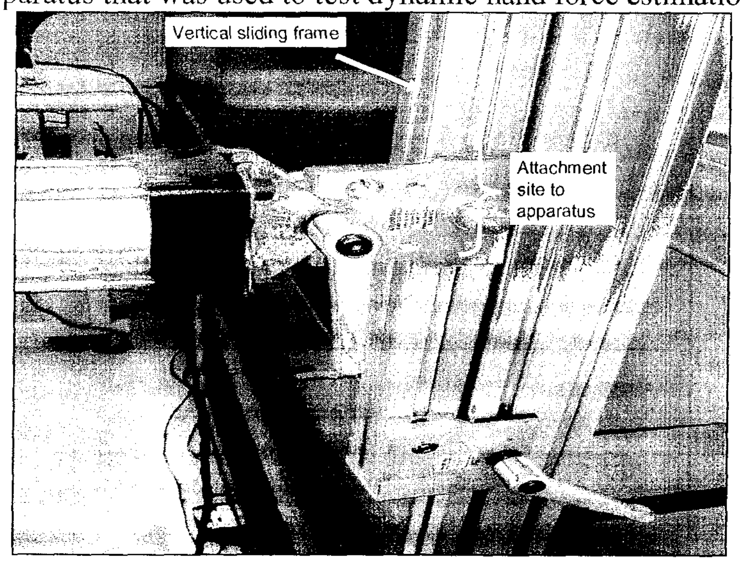

Figure 2. Close up view between the attachment between the vertical sliding frame and the apparatus.

During training, participants had access to visual feedback of their applied forces via the computer screen as tasks were being performed. The feedback indicated to them what level of force (as a % MVC) they were exerting. Exposure time was controlled and standardized across all participants by having them trace a line in real time on the computer screen (Figure 3). A custom software program created in LabView (Version 8.2, National Instruments, Austin, TX, USA) allowed the experimenter to control the visual feedback to the participants, resistance levels, and the magnitude and exposure time of the training sessions.

During testing, participants tried to match their exertion forces to the indicated force level on the computer screen. The % MVC being exerted was not displayed on the computer screen during testing. Once participants reached the desired force level, the solenoid opened, allowing the handle to move. At this point, the subject verbally estimated what % MVC they were exerting at the point of movement.

Signals from the force gauge were amplified with a maximum output of 2224 N or 10 VDC (S7DC, R.D.P Electronics, Wolverhampton, UK). Once the signal was amplified, it was A/D converted using a 12 bit card (NI-DAQ version 6.9.3f3, National Instruments, Austin, TX, USA) and then recorded onto a personal computer at a sampling rate of 100 Hz. The peak force exerted by the participant and the force level set by the investigator was saved as a text file, which was analyzed later in Excel.

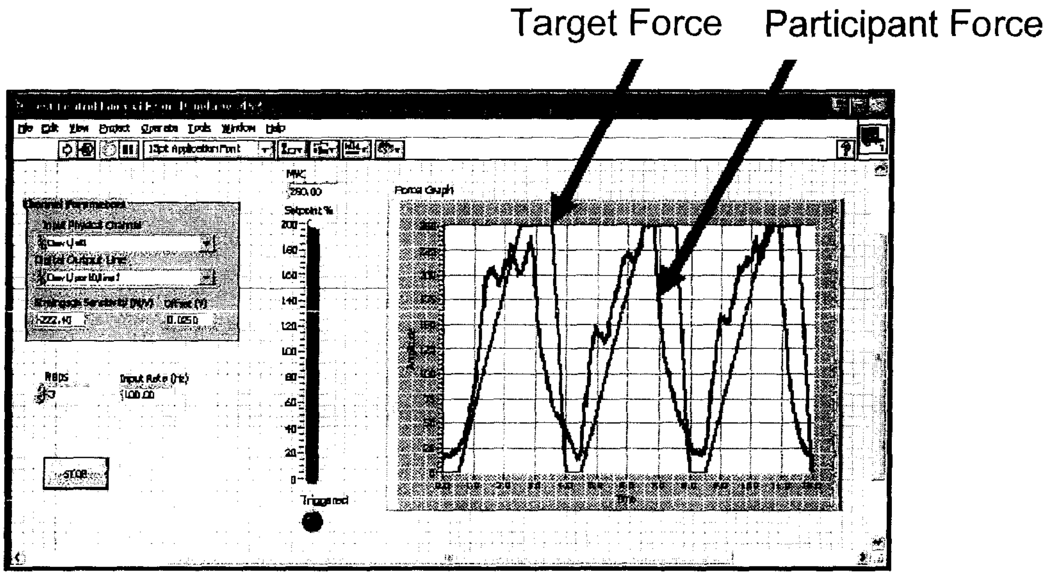

Figure 3. Computer screen displayed during training. The arrows indicate which line represents the target force to be traced and the actual force exerted by the participant.

3.3 Experimental Procedures

3.3.1 Push and Pull Tasks

All participants performed one-handed, two-handed, symmetrical, asymmetrical, pushing, and pulling tasks. Tasks were also performed at three handle heights: knee (low), waist (medium), and forehead (high) height (Figure 4). All one-handed tasks were performed with the right (dominant) hand.

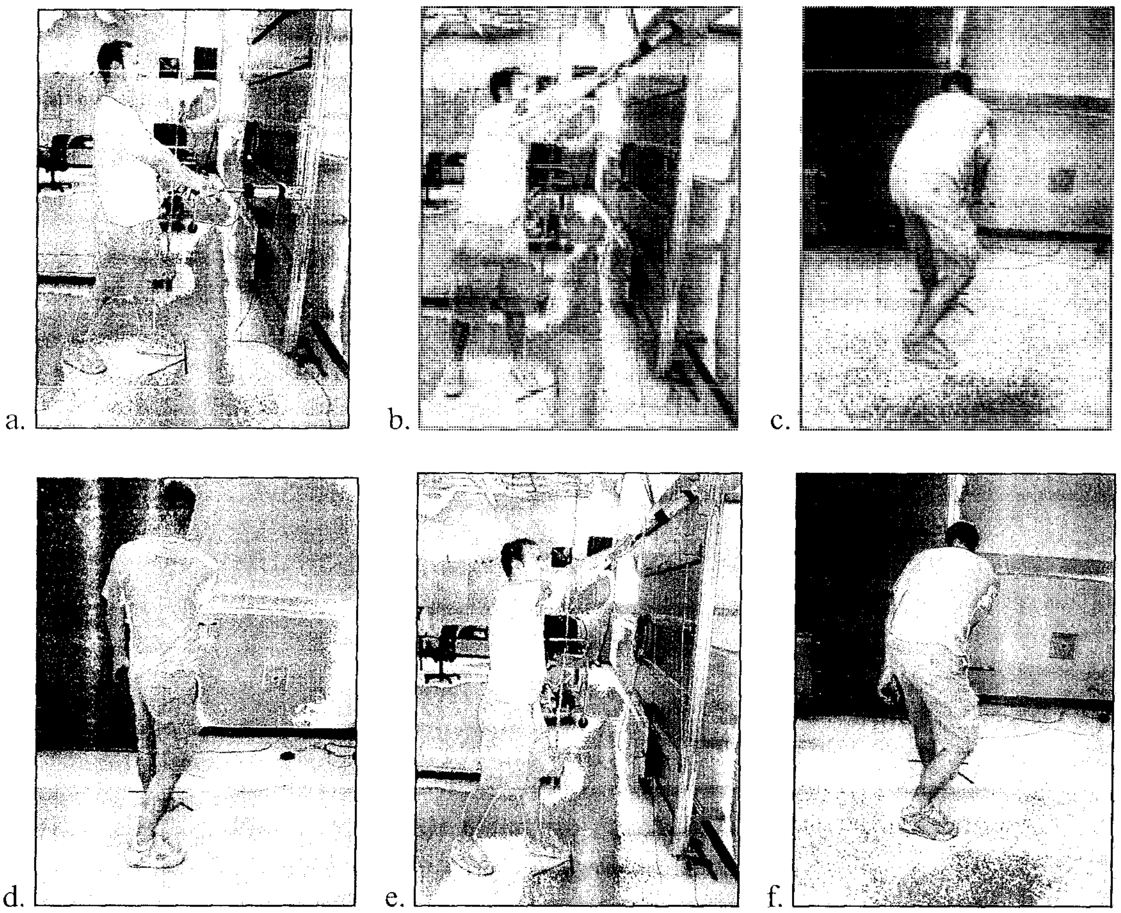

Figure 4. Photographs of the positions in which tasks were performed. a) Symmetrical two-handed at medium height. b) Asymmetrical two-handed at high height. c) Asymmetrical two-handed at low height. d) Asymmetrical one-handed at medium height. e) Symmetrical two-handed at high height. f) Asymmetrical one-handed at low height.

The location of the participant in relation to the apparatus was determined by the participant's extended arm length. Participants faced the apparatus, and extended their arms straight in front of them until the tips of their fingers touched the vertical frame (Figure 5). Once in place, the experimenter put tape on the floor to mark the placement of the participants' feet. Floor markings were placed so that all asymmetrical tasks were performed from a 45 degree angle to the right of the apparatus, making it necessary that participants turn to their left to perform asymmetrical tasks. For one-handed asymmetrical tasks, this required the participants' right arms to reach across the front of their bodies to apply the required push or pull force. It was assumed that participants would be more familiar with performing tasks with their dominant hand. Tape marks were placed on the handles to standardize hand placement. Participants were informed prior to performing the tasks that they may use the body positions they find most comfortable to execute each task within the imposed spatial restrictions (their position relative to the apparatus for upper body and feet).

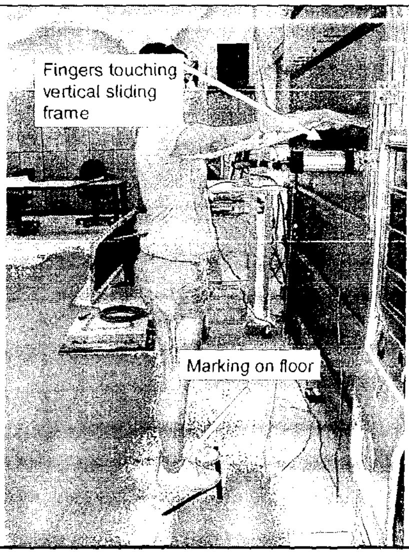

Figure 5. Horizontal distance from the vertical sliding frame and location of the participant's feet to normalize exertion positions between participants.

3.3.2 Tasks

A previous study by Oliver (2007) looked at verbal estimation of peak hand forces in two-handed push and pull tasks. In contrast, Marshall et al. (2004) only looked at one-handed tasks. In order to compare the effects in both types of tasks, this study analyzed one-handed and two-handed tasks. In fields such as automotive assembly and nursing it is common that tasks require both hands. It is also common for workers to only have one hand free to perform pushing or pulling tasks.

Symmetrical and asymmetrical one-handed and two-handed tasks were included in this study to provide a larger variety of inputs for the regression analysis, and were not used as factors in the Analyses of Variance (ANOVAs) (see Section 3.5 below). A larger variety of tasks allowed the generated equations to be more generalizeable. Two separate ANOVAs were performed, one for one-handed tasks, and another for the two-handed tasks. Some combinations of task variables were excluded from data collection to keep the data collection time to a reasonable length. It is reasoned that tasks performed at the medium height are most common in the workplace so all task variations were included at this height. The three heights were adjusted for each participant so that the handles were placed at knee height (low), waist height (medium), and forehead height (high).

The sixteen tasks that were studied are described as follows:

Task 1 – Symmetrical two-handed pull at the medium height

Task 2 – Symmetrical two-handed pull at the high height

Task 3 – Symmetrical two-handed push at the medium height

Task 4 – Symmetrical two-handed push at the high height

Task 5 – Trunk symmetrical one-handed pull at the medium height

Task 6 – Trunk symmetrical one-handed pull at the high height

Task 7 – Trunk symmetrical one-handed push at the medium height

Task 8 – Trunk symmetrical one-handed push at the high height

Task 9 – Asymmetrical two-handed pull at the medium height

Task 10 – Asymmetrical two-handed pull at the low height

Task 11 – Asymmetrical two-handed push at the medium height

Task 12 – Asymmetrical two-handed push at the low height

Task 13 – Trunk asymmetrical one-handed pull at the medium height

Task 14 – Trunk asymmetrical one-handed pull at the low height

Task 15 – Trunk asymmetrical one-handed push at the medium height

Task 16 – Trunk asymmetrical one-handed push at the low height

3.3.3 Maximum Voluntary Contractions (MVC)

Force levels required during the training and testing periods were scaled to the participant's maximum voluntary contraction (MVC). In order to obtain the MVC, three attempts were sampled for each task. Participants were advised to increase their effort over 1 or 2 seconds, hold for 3 seconds, and then decrease until rest. This method attempted to reduce or eliminate jerky force production which can lead to spikes in the applied forces. The highest value of the three trials was selected to be used in scaling participants' forces during training and testing.

3.3.4 Training and Testing Protocols

Four experimental groups were included in this study. Groups 1 and 2 were exposed to the same amount of training. These were the control groups: group 1 consisting of novice manual material handlers, and group 2 consisting of experienced manual material handlers. Both of these groups received 2 repetitions of visual feedback training at 50% and 100% of their MVC for all tasks. Group 3 (novice) and group 4 (experienced) participants received the same feedback training as groups 1 and 2, but only for 4 of the total number of tasks (chosen to be as representative as possible of the full number of tasks). Tasks 1, 6, 12 and 15 were utilized. The order of tasks during training was randomized to minimize any learning effects. The training that was provided to groups 3 and 4 was the same as conducted in Oliver (2007) for their group 4. This level of feedback training was utilized in this study due to the fact that it was the simplest approach, and yielded similar results to those in the more extensive training protocols.

Visual feedback was provided to the participants via a computer screen as push and pull exertions were executed during training. Exposure time was controlled during all training and testing trials by having the participants trace, in real time, a line on the computer screen. It should be noted that % MVC values were only visible on the computer screen during training trials. During test trials no visual force feedback was provided to participants; force was applied until movement of the handle occurred.

Once all training trials were complete, participants were tested on the same tasks they were trained on. Each test trial was performed by either pushing or pulling one of the handles until movement was initiated. Participants ramped up his/her effort until the handle moved (without visual force feedback). Once the handle moved, the participant was required to verbally estimate the % MVC they thought they were exerting at the instant movement occurred. For each task, three trials were performed during testing. Three different force levels were utilized for each of the three repetitions; low (10-30% MVC), medium (40-60% MVC), and high (70-90% MVC). One trial was executed at each force level for each task. The computer software allowed the experimenter to adjust force requirements as specifically as 1% MVC. Participants were allowed to redo trials if they jerked the device, resulting in a force spike.

In this study, error was quantified as the difference between the actual force output (% MVC from the transducer) and verbally estimated force output (% MVC from the participant). This provided a measure of accuracy of verbal estimation of peak dynamic hand forces.

3.3.5 Timeline and Repetitions

An outline of the time requirements and number of repetitions for each group of participants is included here. The same information is shown graphically in Figure 6.

Group 1 = [16 tasks x 2 repetitions x 2 levels of training] + [16 tasks x 1 repetition x 3 levels of force for testing]

=112 repetitions

Group 2 = [16 tasks x 2 repetitions x 2 levels of training] + [16 tasks x 1 repetition x 3 levels of force for testing]

=112 repetitions

The time requirement for participants in groups 1 and 2 was approximately 1 hour.

Group 3= [4 tasks x 2 repetitions x 2 levels of training] + [16 tasks x 1 repetition x 3 levels of force for testing]

=64 repetitions

Group 4= [4 tasks x 2 repetitions x 2 levels of training] + [16 tasks x 1 repetition x 3 levels of force for testing]

=64 repetitions

The time requirement for participants in groups 3 and 4 was approximately 30 minutes.

		Training		Testing			Total # of Reps
Group 1	Fit apparatus to the subject	**Feedback** **Tasks 1-16** - 2 reps at 100%MVC - 2 reps at 50%MVC	→	**No Feedback** **Task 1** - 1 rep low force level - 1 rep med force level - 1 rep high force level	Verbally estimate peak force exerted after each force level	Tasks 2-16 follow the same pattern	112
Group 2	Fit apparatus to the subject	**Feedback** **Tasks 1-16** - 2 reps at 100%MVC - 2 reps at 50%MVC	→	**No Feedback** **Task 1** - 1 rep low force level - 1 rep med force level - 1 rep high force level	Verbally estimate peak force exerted after each force level	Tasks 2-16 follow the same pattern	112
Group 3	Fit apparatus to the subject	**Feedback** **Tasks 1, 6, 12, 15** - 2 reps at 100%MVC -2 reps at 50%MVC	→	**No Feedback** **Task 1** - 1 rep low force level - 1 rep med force level - 1 rep high force level	Verbally estimate peak force exerted after each force level	Tasks 2-16 follow the same pattern	64
Group 4	Fit apparatus to the subject	**Feedback** **Tasks 1, 6, 12, 15** - 2 reps at 100%MVC - 2 reps at 50%MVC	→	**No Feedback** **Task 1** - 1 rep low force level - 1 rep med force level - 1 rep high force level	Verbally estimate peak force exerted after each force level	Tasks 2-16 follow the same pattern	64

Figure 6. Training and testing conditions for each group of participants. Prior to training, participants exerted three MVCs for each task.

3.4 Experimental Design

The independent variables in this study were: Training Group (Group 1 to 4), Exertion Type (push or pull), Handedness (one-handed or two-handed), Gender (male or female), and Force Level (low, medium, or high). The dependent variable investigated was: verbally estimated peak dynamic hand force. The absolute differences between actual exertion forces and the participants' verbal estimation of peak dynamic hand force were determined and statistically analyzed.

This study consisted of a mixed design, with Exertion Type and Force Level as the within-subject factors and Training Group and Gender as between-subject factors (Figure 7). Two levels of training were presented to the groups. Groups 1 and 3 consisted of novice manual material handlers, groups 2 and 4 were made up of experienced manual material handlers. Each group had an equal number of males and females (4 males and 4 females). This was done to determine whether the amount of feedback training, level of participant's experience, or gender had an effect on their ability to verbally estimate peak dynamic hand forces. Three levels of force were studied: low (10-30% MVC), medium (40-60% MVC), and high (70-90% MVC). During the testing phase of data collection, 1 repetition was performed at each force level for each of the 16 tasks (Figure 6).

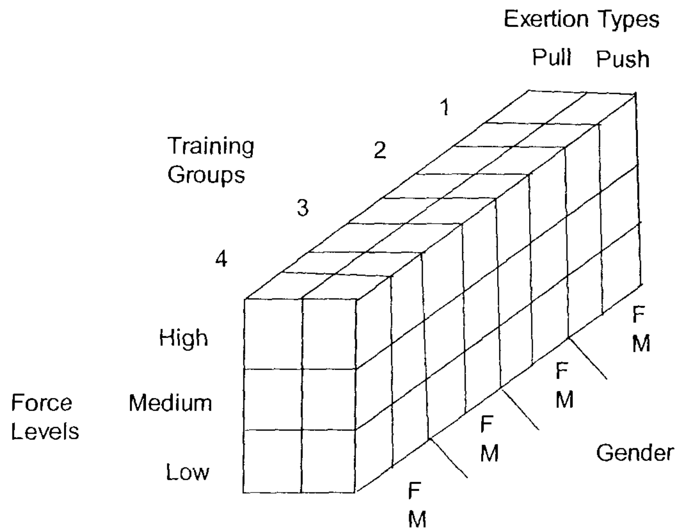

Figure 7. Study design cube demonstrating the independent variables in this study. One-handed and two-handed tasks were analyzed separately.

3.5 Statistics

Three analyses were performed to attend to the purposes of the study.

Analysis 1a – A 4 x 3 x 2 x 2 mixed Analysis of Variance (ANOVA) was performed for two-handed pushing and pulling tasks. The repeated measures were Force Level and Exertion Type, and the between-subject factors were Training Group and Gender. An alpha level of 0.05 was used for all comparisons. Tukey's HSD post hoc test was completed on significant interactions and main effects.

Analysis 1b – The same analysis as in Analysis 1a was performed for one-handed pushing and pulling tasks.

Analysis 2 – As a function of the independent variables, scatter plots were created for actual peak hand forces in relation to verbally estimated peak dynamic hand forces. A variety of tasks were included in this study to increase the generalizability of the equations.

Several steps were taken before the regression analyses in order to treat the raw data scores, including the following:

1. Each possible combination of independent variables (i.e. Exertion Types, Training Groups, Gender, Level of Experience, Level of Training) and the participants' verbally estimated peak dynamic hand force were manually run to determine the best possible combination of variables that generated the largest adjusted R^2 and smallest standard error of the estimate (SEE) values.
2. Data were entered into SPSS via the "enter" process with the constant maintained in the equation in all circumstances.
3. Based on the findings of step three, various equations were generated. The aim was to keep the number of equations to a minimum, making for easier use in industry. Oliver (2007) found that four models (male pull, male push, female pull, female push) produced the best adjusted R^2 and SEE values. Gender and exertion type are both easy variables to identify upon observation, thus making these models user-friendly in the workplace.
4. Investigative curve estimations of different orders (eg. Linear, quadratic, cubic) were conducted in SPSS to discover the relationships that produced the largest adjusted R^2 for the generated equations.
5. To determine whether there were any outliers in the data, z scores were calculated. No z-scores were outside of the +/- 2.5 range, so all data was included in the analyses.

4.0 Results

4.1 Analysis 1a (two-handed tasks)

There was a significant main effect of absolute error in peak dynamic hand forces for exertion [$F(1, 24) = 5.484$, $p \leq 0.05$], and force [$F(2, 23) = 17.401$, $p \leq 0.05$]. Significant differences were not found between the genders or the four training groups, even though two of the groups received more extensive feedback training, and two of the groups consisted of participants with at least one year MMH experience. There were also no significant interactions found between any of the independent variables.

4.1.1 Main Effect – Exertion Type

The mean absolute error for pushes was significantly smaller than for pulls ($p \leq 0.05$), with values of 12.5% MVC and 14.7% MVC, respectively (Figure 8).

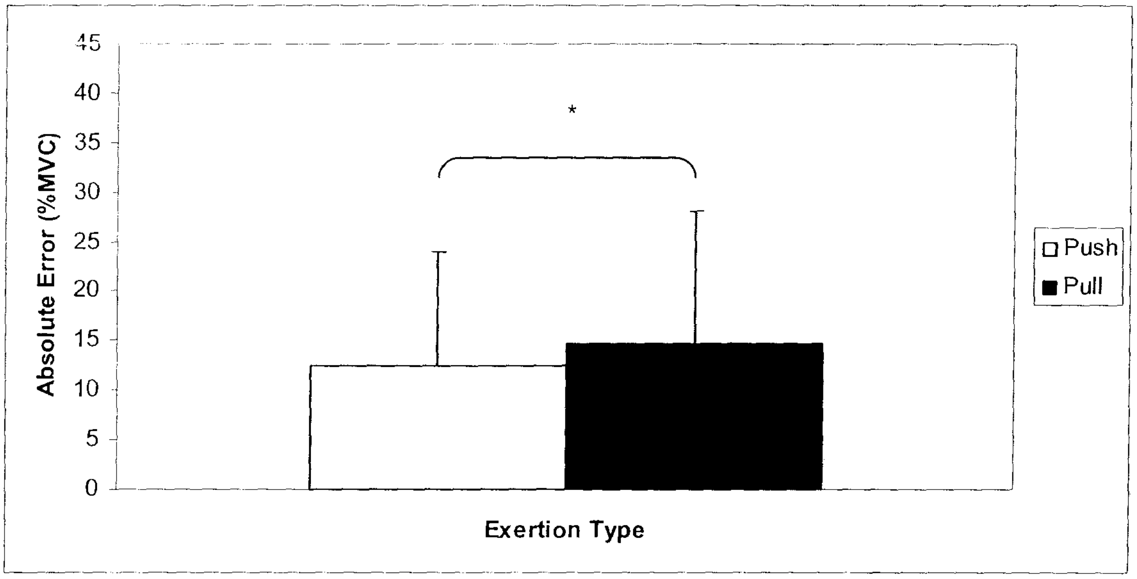

Figure 8. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces for two-handed pushes and pulls ($p<0.05$).

4.1.2 Main Effect – Force Levels

There was a main effect for force for two-handed tasks, with significant differences between the high and medium forces ($p \leq 0.05$), and the medium and low forces ($p \leq 0.05$) (Figure 9). The mean absolute error for exertions at the medium force level was 18.9% and 16.2% for pulls and pushes, respectively. These errors are much greater than those elicited at the low force level, which were 9.4% and 9.5% for pulls and pushes. A greater difference in mean absolute error was seen between medium and high force levels for the pushing tasks, with 11.8% mean absolute error for pushes at the high force level, compared to 16.2% for pushes at the medium level.

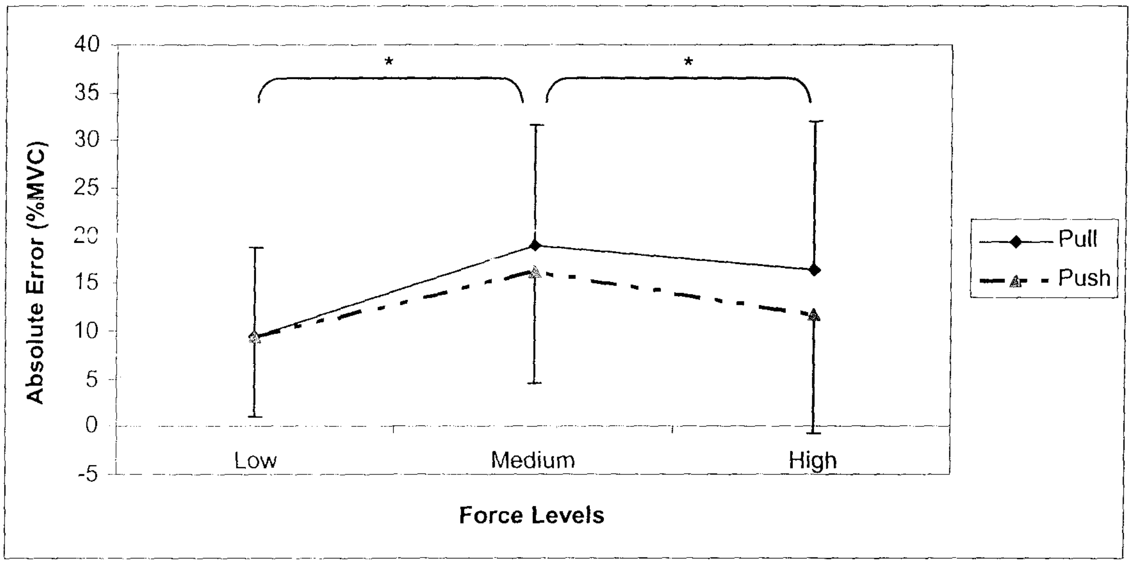

Figure 9. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces for each force level and exertion type during the two-handed tasks. Significant differences were noted between high and medium force levels, and medium and low force levels .

4.1.3 Group

There were no significant differences in error between the four training groups for two-handed tasks (Figure 10). These results are encouraging, as participants in Group 3 and 4 were given much less feedback training and still performed as well as the more extensively trained groups (Groups 1 and 2).

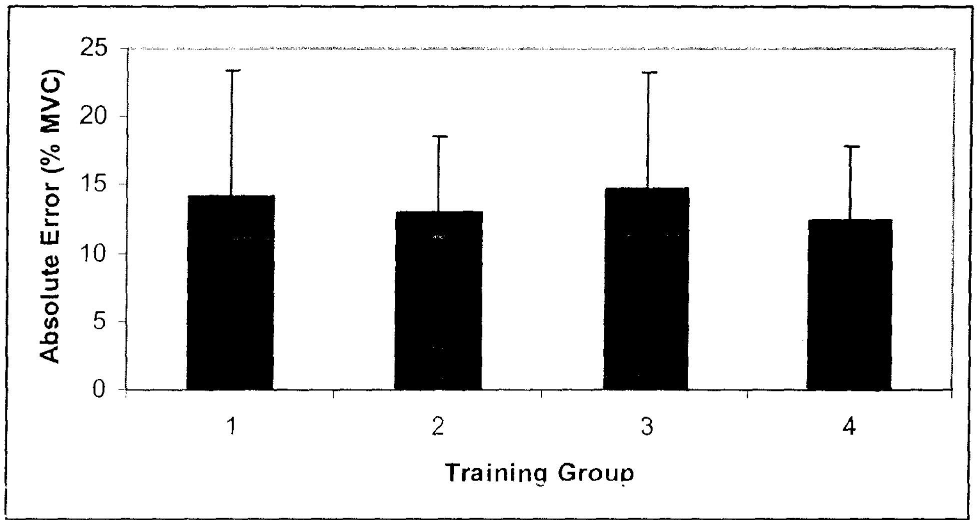

Figure 10. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces during two-handed tasks for each Training Group.

4.1.4 Gender

There were no significant differences in absolute error between men and women for two-handed tasks (Figure 11). The mean absolute error value for females was less than 1% greater than for males (13.9% MVC vs. 13.2%).

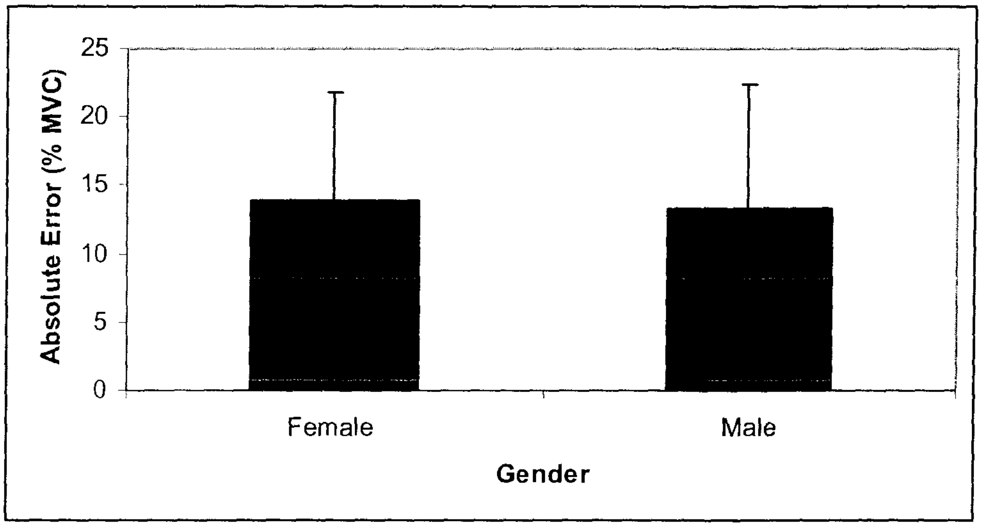

Figure 11. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces during two-handed tasks for each Gender.

4.2 Analysis 1b (one-handed tasks)

Force Levels was the only variable for the one-handed tasks where a significant main effect was present [F (2, 23) = 6.007, p≤0.05]. Similar to the analysis of two-handed tasks, no significant interactions were found between any of the independent variables.

4.2.1 Main Effect – Force Levels

The mean absolute error was significantly different between medium and low force levels for one-handed tasks (p≤0.05) (Figure 12). Mean errors at the medium force level were 15.2% and 16.5% for pulls and pushes, respectively, compared to 10.2% and 10.4% at the low force level.

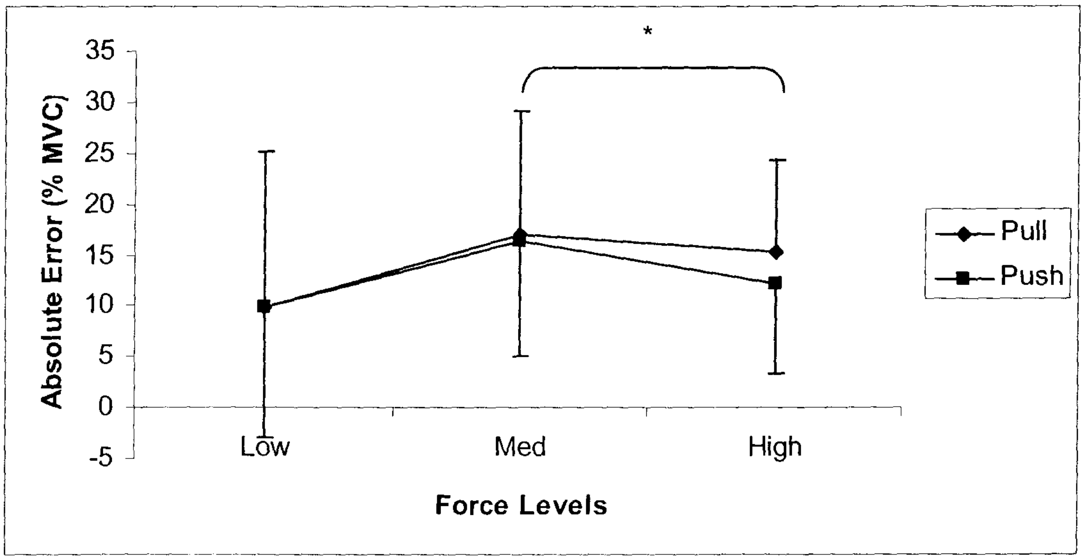

Figure 12. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces for each force level and exertion type during the one-handed tasks. Significant differences were noted between medium and low force levels (p=0.019).

4.2.2 Training Group

There were no significant differences in error between the four training groups for one-handed tasks (Figure 13). These results are encouraging, as participants in Group 3 and 4 were given much less feedback training and still performed as well as the more extensively trained groups (Groups 1 and 2).

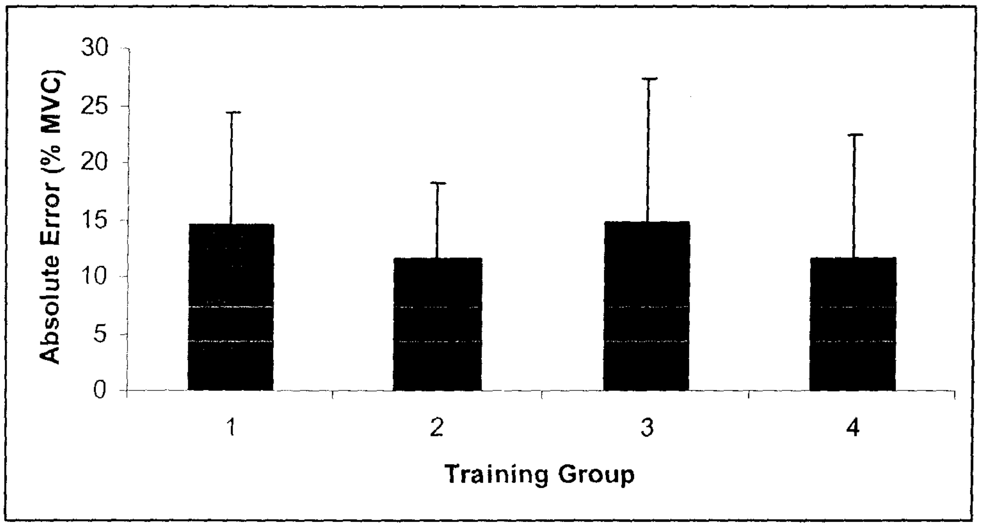

Figure 13. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces during one-handed tasks for each Training Group.

4.2.3 Gender

There were no significant differences in absolute error between men and women for one-handed tasks (Figure 14). The mean absolute error value for females was 3% greater than for males (14.6% MVC vs. 11.6% MVC).

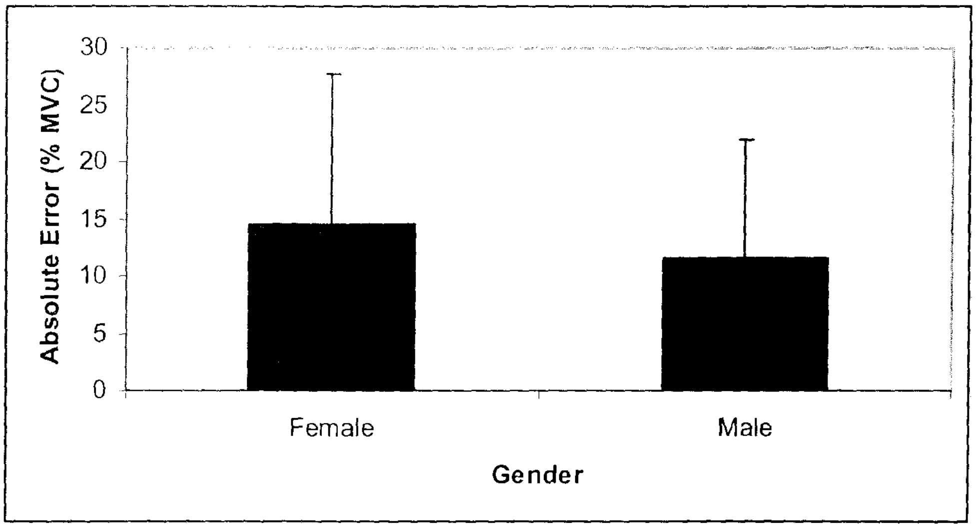

Figure 14. Mean (SD) absolute errors between actual and verbally estimated peak dynamic hand forces during one-handed tasks for each Gender.

4.3 Estimation Bias

On average, participants underestimated their hand forces between two and three times as often as they overestimated (Table 1). When taking all responses into consideration, participants underestimated their hand forces by 13% on average. For each training group there were 384 responses given (inclusive of one and two-handed tasks). Percent (%) errors (overestimations and underestimations) were calculated by dividing the number (#) of overestimations and underestimations by the total number of responses (384). A similar trend was observed for both males and females (Table 3).

Table 2. The total number (#) and percent (%) of overestimation errors, underestimation errors, and responses without error, given by participants in each training group.

Group	*Underestimations*		*Overestimations*		*No Errors*	
	#	%	#	%	#	%
1	226	58.9%	146	38.0%	12	3.1%
2	282	73.4%	93	24.2%	9	2.3%
3	262	68.2%	109	28.4%	13	3.4%
4	285	74.2%	92	24.0%	7	1.8%

Table 3. The total number (#) and percent (%) of overestimation errors, underestimation errors, and responses without error, given by participants in each gender.

Gender	*Underestimations*		*Overestimations*		*No Errors*	
	#	%	#	%	#	%
Males	566	74%	186	24%	16	2%
Females	490	64%	255	33%	23	3%

4.4 Maximum Voluntary Contraction Forces

Male and female participants demonstrated similar trends in the maximal force produced for two-handed exertions, on average, with greater forces for pushes than pulls. The exception to this was the low height for females (Table 2). For one-handed maximum voluntary exertions, male and female participants produced greater forces for pulls than pushes. The exception to this was male exertions at the high height (Table 2).

Table 4. Mean (SD) maximum voluntary forces (N) exerted during two-handed and one-handed push and pull tasks by females (N=16) and males (N=16) at different heights.

	High Height		*Medium Height*		*Low Height*	
	Push	Pull	Push	Pull	Push	Pull
Two-handed						
Female	271 (76)	254 (75)	225 (61)	212 (66)	266 (47)	295 (106)
Male	528 (242)	385 (114)	355 (139)	289 (99)	390 (120)	371 (115)
One-handed						
Female	165 (52)	201 (46)	154 (32)	187 (51)	227 (39)	259 (83)
Male	317 (120)	309 (88)	261 (109)	268 (86)	307 (98)	343 (132)

4.5 Regression Analysis

To determine the strengths of the relationships between verbally estimated peak dynamic hand forces and the actual forces exerted when movement was initiated, exploratory simple regression analyses were performed. Data were grouped in various ways to establish the predictive equations that produced the highest adjusted R^2 and lowest SEEs. Prior to performing the analyses, the data were screened for outliers by converting participant mean responses to z-scores. Results of this assessment revealed that no outliers existed within the data. All z-scores were found to be between -1.56 and 1.74. The majority of z-scores fell between -2 and -1.5 standard deviations (approximately 50% of all values), while all categories between -1.5 and 2.0 standard deviations consisted of 10% or less of the data. As all data points fell within 2.5 standard deviations of the mean, no data were removed from the data set (Kirk, 1995). Other factors taken into consideration when selecting the best predictive equations included the applicability and ease of use in the workplace. For example, linear predictive equations would reduce the number of terms to be entered into the equations when using this method in the field. Also, the gender of the worker and whether workers are pushing or pulling in a particular task are other factors that are usually fairly easy to determine visually in the field.

The data collected were separated by several factors to determine the strongest relationship. Upon running the analyses with the data split up by force levels, the strength of the relationships greatly diminished. The r^2 values ranged from 0.0011 to 0.183 when the data were split up by force level. When data were collapsed by gender, the resulting r^2 values ranged between 0.6184 and 0.6747. In an attempt to determine the strongest relationships, data were divided to a greater extent. It was found that eight regression models (female two-handed push, female two-handed pull, male two-handed push, male two-handed pull, female one-handed push, female one-handed pull, male one-handed push, and male one-handed pull) provided the most applicability while maintaining good adjusted R^2 and SEE values. Table 3 and 4, and Figures 13-20 show the relationship strengths, the scatter plots and the regression equations that were fit to the data for all eight models. The linear, quadratic, and cubic regression equations that were fit to the data were all significant ($p<0.001$) and produced very similar adjusted R^2 and SEE values. The male one-handed pull model produced the highest adjusted R^2 and lowest SEE values (0.79 and 11% MVC) (Table 4), while the female two-handed pull equation produced the weakest adjusted R^2 and highest SEE values of 0.56 and 17% MVC, respectively (Table 3).

Table 5. Regression equations for two-handed pushing and pulling tasks describing the relationship between actual force (Y) and verbally estimated force (X). X = participants' verbally estimated peak dynamic hand force. Y= actual peak dynamic hand force.

	Cubic	*Quadratic*	*Linear*
Female two-handed Pull			
Equation	$Y=1.512+2.373(X)-0.039(X)^2+0.0003(X)^3$	$Y=16.334+0.8688(X)-0.002(X)^2$	$Y=19.511+0.676(X)$
Adj. R^2	0.56	0.55	0.55
(+/-) SEE (%)	17	17	17
F	$F(3, 188) = 81.377$	$F(2, 189) = 115.584$	$F(1, 190) = 230.301$
P	<0.001	<0.001	<0.001
Female two-handed Push			
Equation	$Y=7.6481+2.025(X)-0.0245(X)^2+0.0002(X)^3$	$Y=16.271+0.8905(X)-0.0018(X)^2$	$Y=18.898+0.7185(X)$
Adj. R^2	0.66	0.65	0.65
(+/-) SEE (%)	15	15	15
F	$F(3, 188) = 120.518$	$F(2, 189) = 177.127$	$F(1, 190) = 353.435$
P	<0.001	<0.001	<0.001
Male two-handed Pull			
Equation	$Y=13.363+1.3007(X)-0.0071(X)^2+1E\text{-}05(X)^3$	$Y=14.089+1.2223(X)-0.497(X)^2$	$Y=21.003+0.7585(X)$
Adj. R^2	0.64	0.64	0.63
(+/-) SEE (%)	15	15	15
F	$F(3, 188) = 111.687$	$F(2, 189) = 168.394$	$F(1, 190) = 321.088$
P	<0.001	<0.001	<0.001
Male two-handed Push			
Equation	$Y=9.3376+1.2728(X)-0.0056(X)^2+7E\text{-}06(X)^3$	$Y=9.7057+1.2341(X)+0.0046(X)^2$	$Y=16.544+0.8014(X)$
Adj. R^2	0.748	0.75	0.74
(+/-) SEE (%)	12	12	12
F	$F(3, 188) = 190.415$	$F(2, 189) = 287.124$	$F(1, 190) = 543.183$
P	<0.001	<0.001	<0.001

Table 6. Regression equations for one-handed pushing and pulling tasks describing the relationship between actual force and verbally estimated force (X). X = participants' verbally estimated peak dynamic hand force. Y= actual peak dynamic hand force.

	Cubic	*Quadratic*	*Linear*
Female one-handed Pull			
Equation	$Y=4.3435+2.4069(X)-0.0434(X)^2+0.0003(X)^3$	$Y=20.212+0.717(X)-0.0005(X)^2$	$Y=20.940+0.6691(X)$
Adj. R^2	0.58	0.56	0.56
(+/-) SEE (%)	16	17	17
F	$F(3, 188) = 87.163$	$F(2, 189) = 121.101$	$F(1, 190) = 243.356$
P	<0.001	<0.001	<0.001
Female one-handed Push			
Equation	$Y=4.2727+2.2(X)-0.0357(X)^2+0.0002(X)^3$	$Y=17.39+0.8182(X)-0.0015(X)^2$	$Y=19.593+0.6771(X)$
Adj. R^2	0.60	0.59	0.59
(+/-) SEE (%)	16	16	16
F	$F(3, 188) = 93.998$	$F(2, 189) = 134.507$	$F(1, 190) = 269.102$
P	<0.001	<0.001	<0.001
Male one-handed Pull			
Equation	$Y=7.9112+1.3831(X)-0.0073(X)^2+2E-05(X)^3$	$Y=8.7372+1.2965(X)-0.0051(X)^2$	$Y=16.171+0.8218(X)$
Adj. R^2	0.79	0.79	0.78
(+/-) SEE (%)	11	11	12
F	$F(3, 188) = 237.718$	$F(2, 189) = 358.366$	$F(1, 190) = 667.107$
P	<0.001	<0.001	<0.001
Male one-handed Push			
Equation	$Y=8.363+1.3454(X)-0.0063(X)^2+1E-05(X)^3$	$Y=8.8906+1.2887(X)-0.0049(X)^2$	$Y=15.671+0.8375(X)$
Adj. R^2	0.79	0.79	0.78
(+/-) SEE (%)	12	12	12
F	$F(3, 188) = 236.932$	$F(2, 189) = 357.245$	$F(1, 190) = 671.325$
P	<0.001	<0.001	<0.001

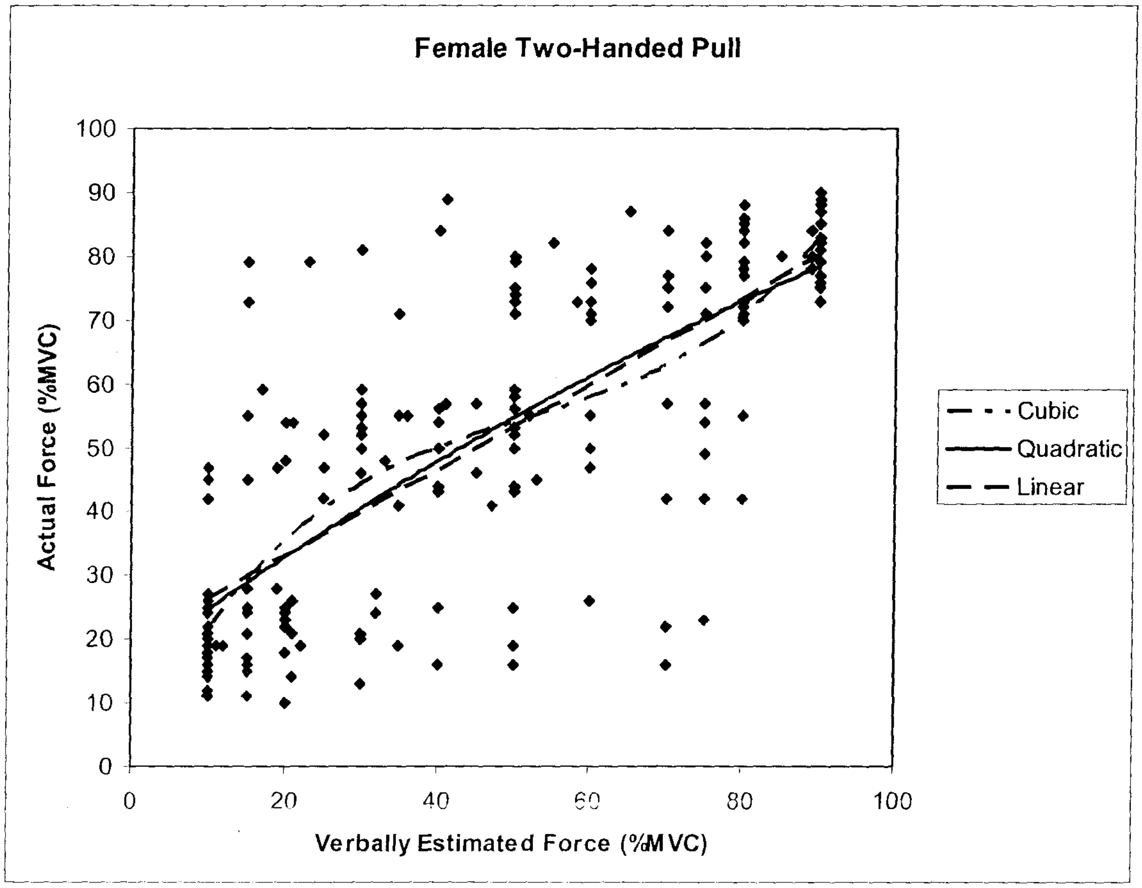

Figure 16. Scatter plot (Female Two-Handed Pull) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

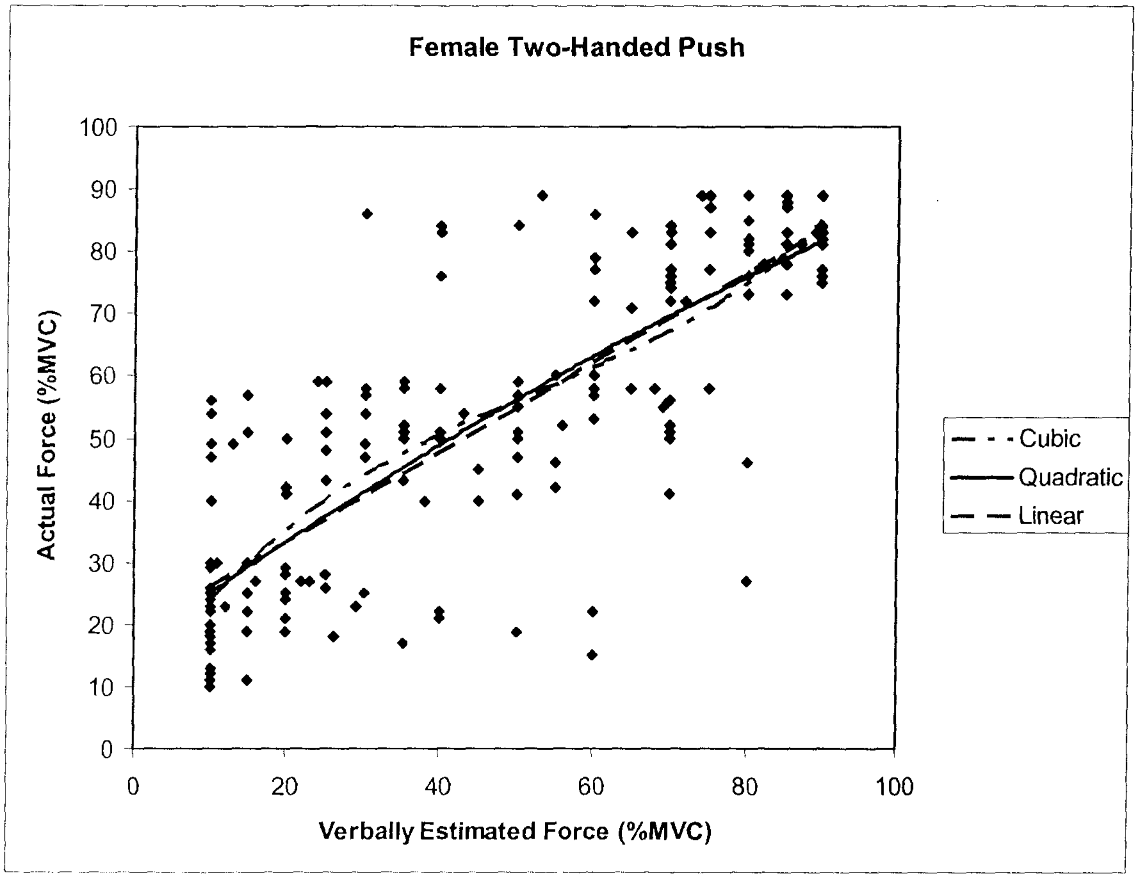

Figure 17. Scatter plot (Female Two-Handed Push) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

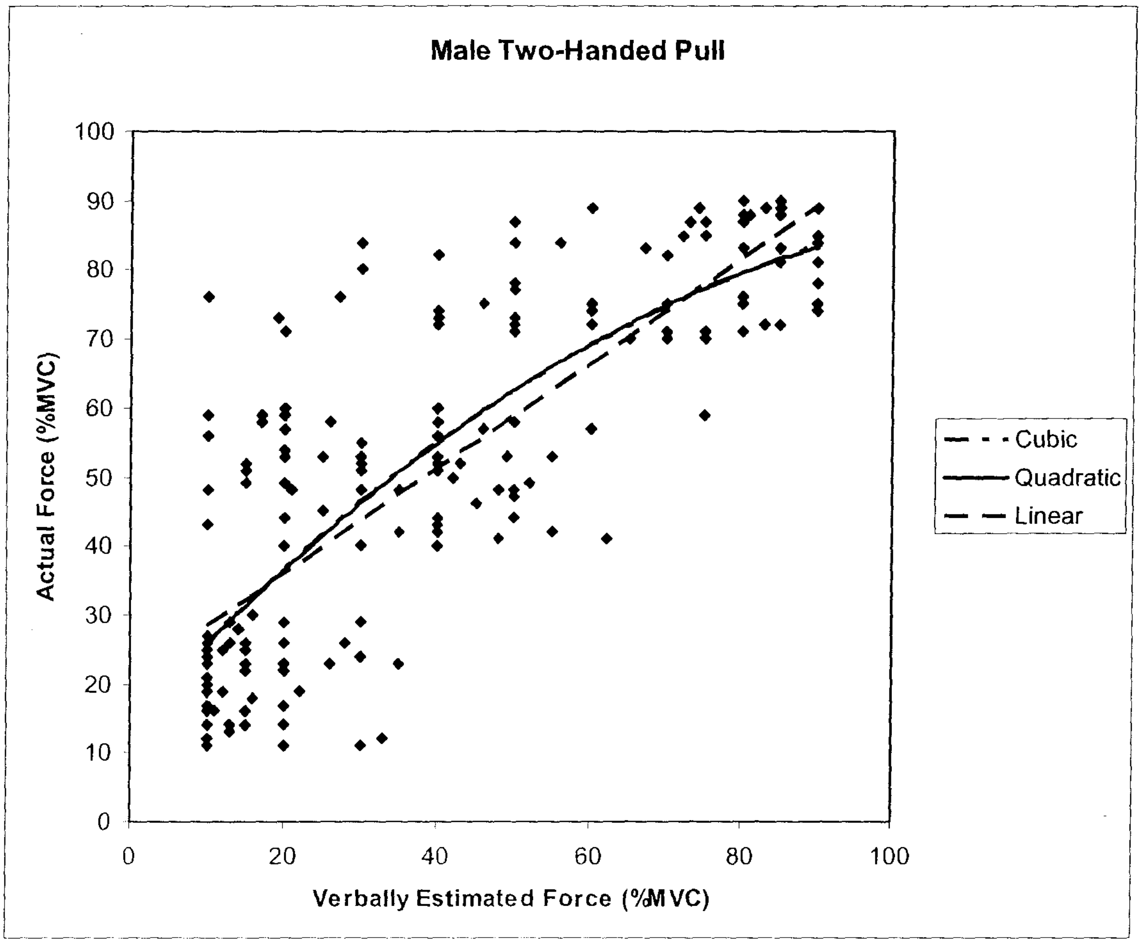

Figure 18. Scatter plot (Male Two-Handed Pull) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

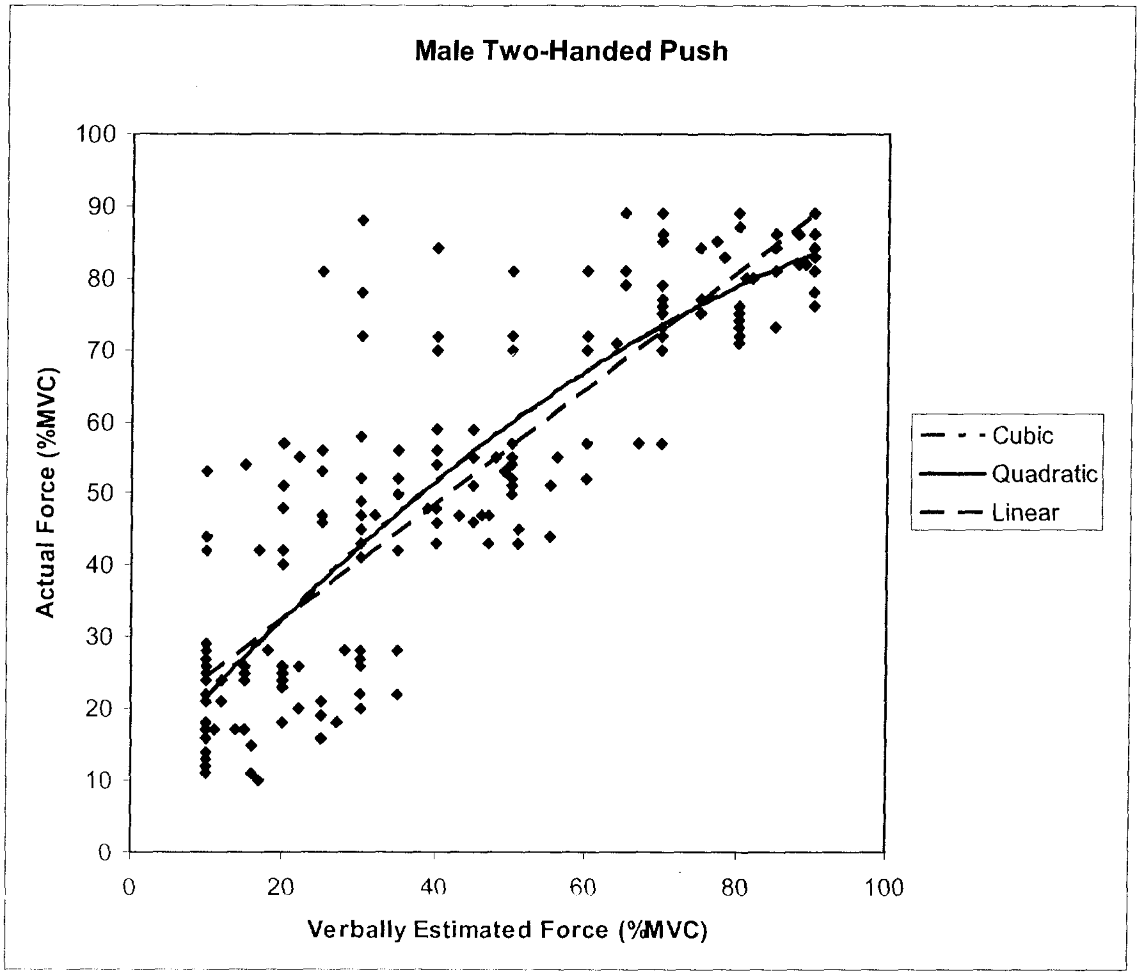

Figure 19. Scatter plot (Male Two-Handed Push) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

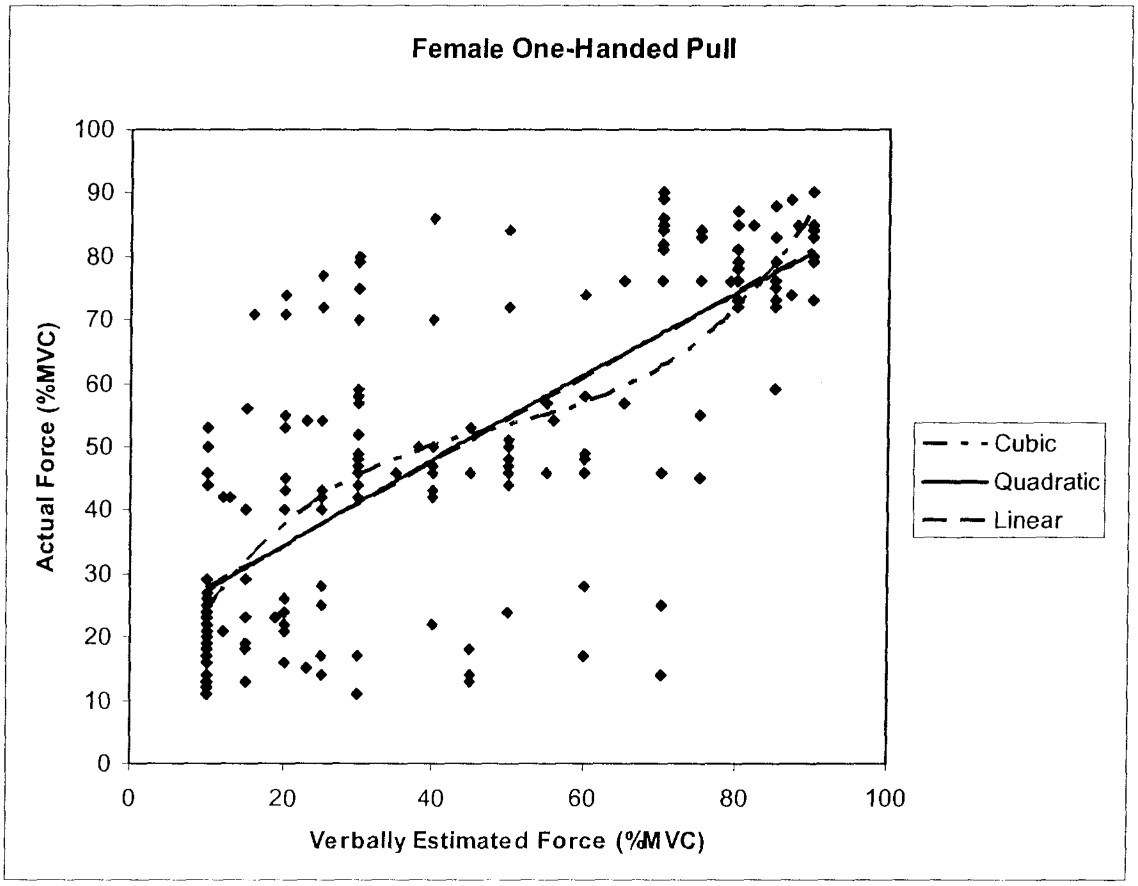

Figure 20. Scatter plot (Female One-Handed Pull) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

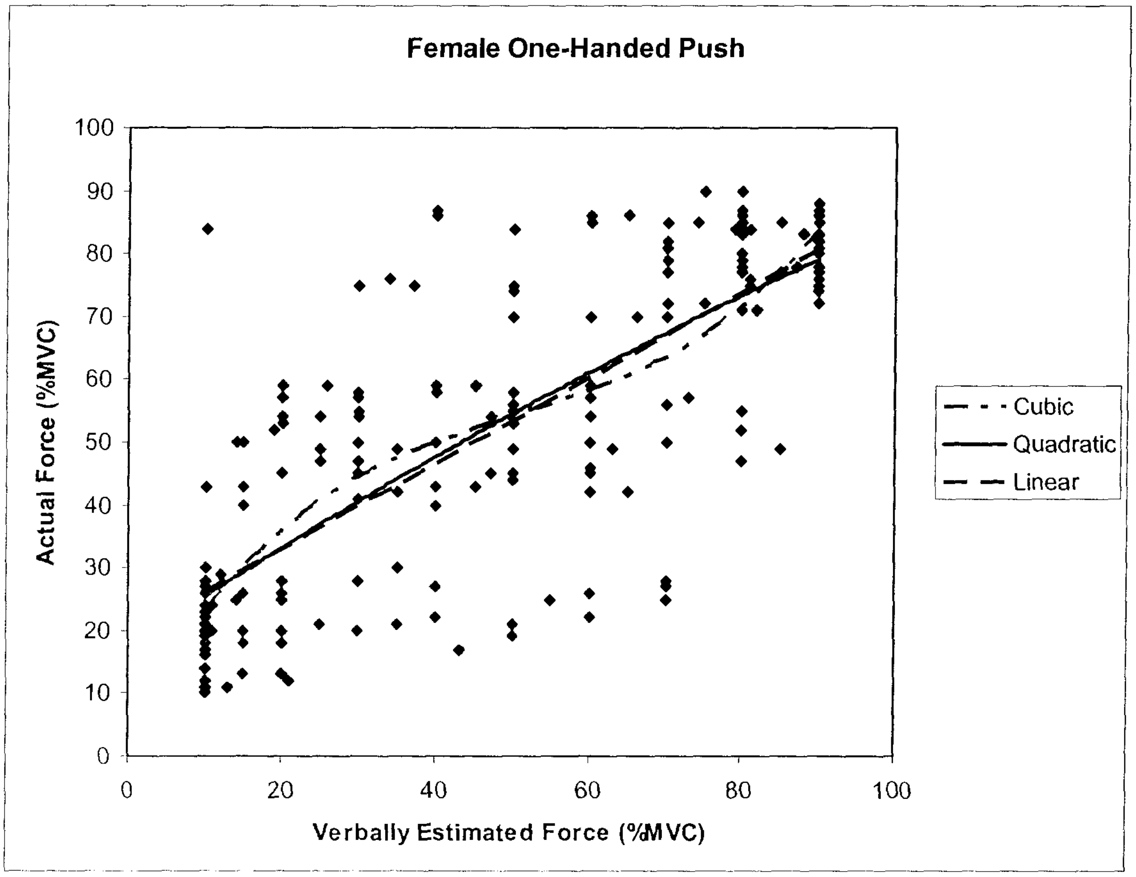

Figure 21. Scatter plot (Female One-Handed Push) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

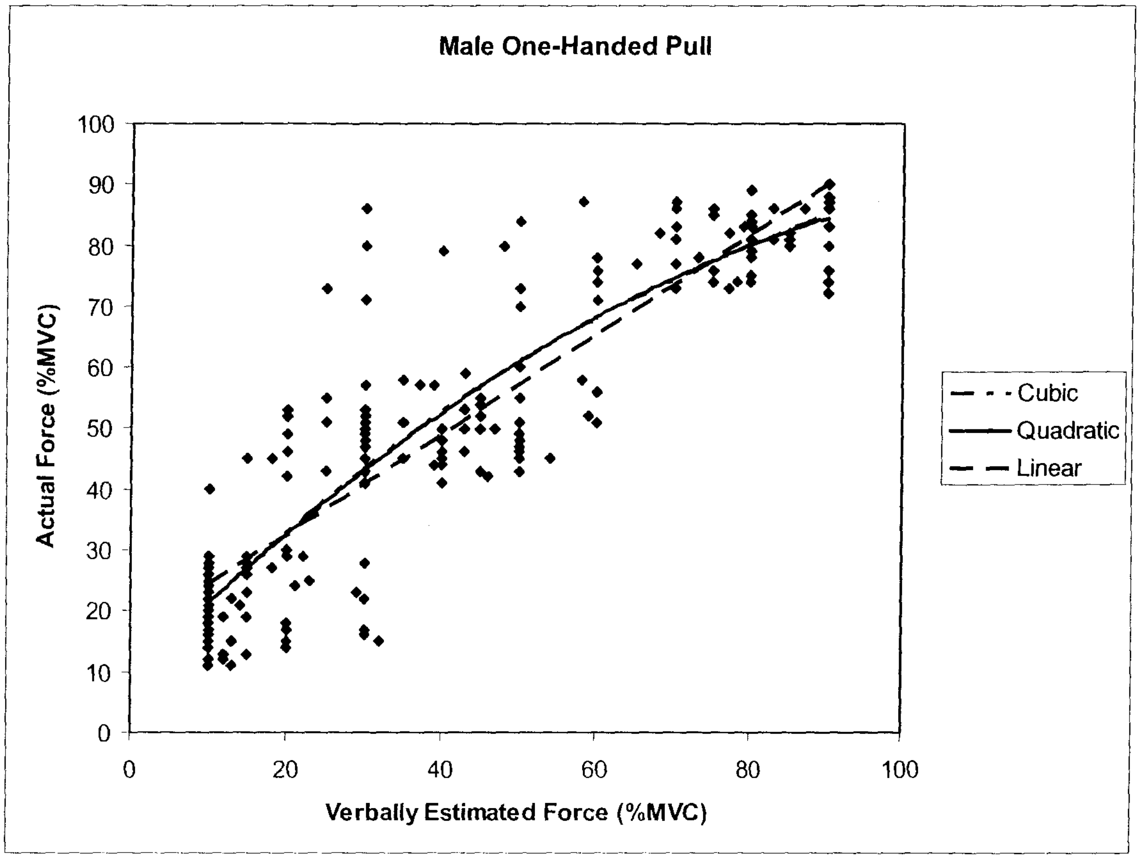

Figure 22. Scatter plot (Male One-Handed Pull) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

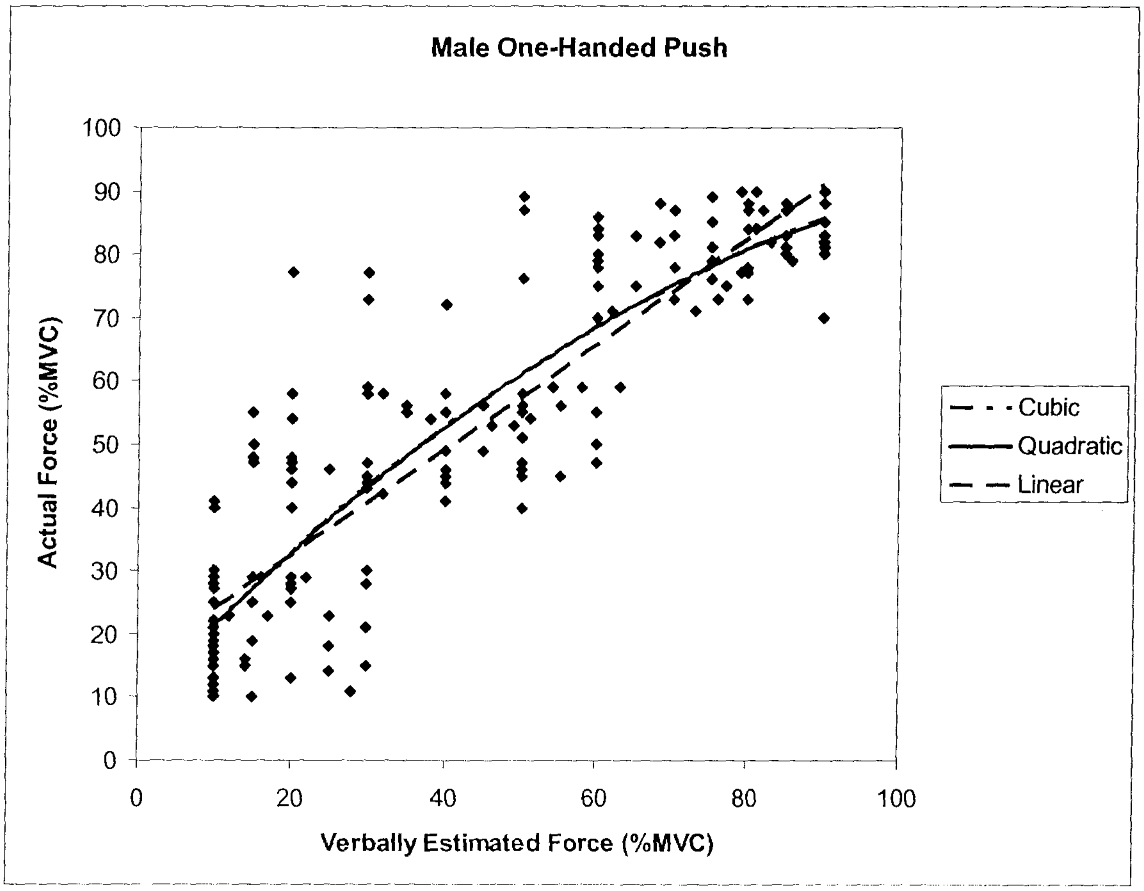

Figure 23. Scatter plot (Male One-Handed Push) of participants' verbally estimated peak dynamic hand forces (% MVC) versus the actual peak dynamic hand forces set by the researcher.

5.0 Discussion

5.1 Summary

This study examined how participants' verbally estimated peak dynamic hand forces compared to actual hand forces during simulated pushing and pulling tasks in a variety of positions. The effects of MMH experience and feedback training on hand force self-reporting were also studied. Verbally estimated hand forces were similar across all four groups, even though two groups received more extensive feedback training and two groups consisted of participants with at least one year of MMH experience. Participants were significantly more accurate at self-reporting pushes than pulls for two-handed tasks, but there was no difference for one-handed exertions. Participants were most accurate when self-reporting hand forces at the low force level for one-handed and two-handed tasks (errors of 10.2 %MVC and 9.4 %MVC, respectively). Significant differences in hand force self-reports were found between high and medium forces, and medium and low forces for two-handed tasks, and between medium and low forces for one-handed tasks. Participants tended to underestimate their level of exertion in general by 7.7% on average, across all conditions. Eight regression equations were developed to predict actual peak dynamic hand forces from verbally estimated hand forces during one and two-handed push and pull tasks. Separate equations were generated for men and women, however no significant differences were found in absolute error between genders. A strong relationship between actual and verbally estimated hand forces was indicated by the fairly high adjusted R^2 values (range from 0.55 to 0.78).

5.2 Training

The literature that exists on psychophysical training is highly variable in terms of the amount of training participants receive and task complexity. In order for the psychophysical approach to be effective, participants must first be trained to achieve accurate estimations of their exertions (Deeb, 1999; Potvin et al., 2000; Marshall et al., 2004; Andrews et al., 2007; Oliver, 2007). In the current study, the amount of feedback training participants received was not found to significantly influence their ability to self-report peak dynamic hand forces. Participants in groups 1 and 2 received feedback training on all tasks, compared to groups 3 and 4 which were trained on only 4 of the 16 tasks (chosen to be as representative of all tasks as possible). This is a favourable finding, since a shorter training protocol would make this method easier to employ in the workplace.

The training protocol that groups 3 and 4 received was comparable to that given to "group 4" in the study by Oliver (2007). Oliver (2007) also found no difference between the less involved and more extensive training protocols. Marshall et al. (2004) found that when participants were exposed to physical exertion benchmarks (e.g. 25%, 75%, and 100% MVC), their force estimation errors decreased from 14% MVC (control) to 4% MVC with one benchmark, and -3% MVC after three benchmark training. In comparison, the current study only trained participants at two force levels (50% and 100% MVC) and did not have a control group that received no training, so direct comparison to the findings of Marshall et al. (2004) is not possible. Differences in error rates could be attributed to the varying levels of feedback between studies, as well as the level of complexity of the tasks. Tasks in this study and in Oliver (2007) were whole body pushes and pulls, whereas Marshall et al. (2004) used tasks that were mainly hand-intensive. Participants may be more accurate at perceiving exerted forces that involve fewer muscle groups. This supports previous research that suggested perceived force estimation was dependent on the size of the muscles being utilized to complete the movement (Banister, 1979; Deeb, 1999).

Differences found in training effects may be due to training protocol rather than the training itself. Training protocols differed greatly between this study and the study by Potvin et al. (2000). They examined participants' ability to set their maximal workload for one task (hose insertion) during an eight hour shift after receiving four to eight hours of training (dependent on experience level). Training improved participants' ability to set acceptable workloads. Participants were exposed to between 1000 and 2000 repetitions on separate days from when testing commenced. This training protocol differs greatly from those employed in this study and Oliver (2007). Participants endured only 12 to 48 repetitions on the same day as testing in Oliver (2007), and 16 to 64 repetitions in the current study. The wide variation in training protocols found between these studies may explain the differences in training effects that were found.

The current study's findings support those reported by McGorry et al. (2004) who found that training did not have an effect on error rates in participants' verbal estimation of peak dynamic hand grip forces. A difference between this study and that by McGorry et al. (2004) is that different types of forces were exerted; hand forces and grip forces, respectively.

5.3 Exertion Type and Force Levels

Overall, participants were significantly more accurate at reporting their peak dynamic hand forces for pushing exertions than pulling. The mean absolute error for two-handed pushes was 12.5% MVC and 13.1% MVC for one-handed pushes, compared to 14.7% MVC and 13.2% MVC for two and one-handed pulls, respectively. The difference was only statistically significant for two-handed exertions. This finding supports that of Oliver (2007). However, Wiktorin et al. (1996) and Marshall et al. (2004), by contrast, found no differences in how participants reported push and pull forces.

Between studies, there is a large variation in tasks. Wiktorin et al. (1996) conducted three experiments which included lifting, pushing/pulling, and performing the four most common work tasks for each participant (that fit into certain categories). Marshall et al. (2004) utilized tasks that were one-handed and primarily hand intensive in nature. Oliver (2007) employed two-handed pushing and pulling tasks and the current study included one-handed and two-handed pushes and pulls. The different findings may be due to the variety of tasks utilized across the four studies. The tasks included in this study and Oliver (2007) were similar, employing larger movements than those performed in Marshall et al. (2004). Tasks utilized in Wiktorin et al. (1996) varied widely between participants, also making it difficult to compare results.

The current study included a wide variety of tasks: one-handed and two-handed, symmetrical and asymmetrical, pushes and pulls, at three different heights. Tasks performed at low and high heights were described by several participants as being awkward and uncomfortable. During asymmetrical tasks, participants were required to stand at a 45° angle to the handle. For one-handed asymmetrical tasks the right hand was employed, requiring participants to reach across the front of their bodies. Many participants stated that if given the choice, they would utilize their left hand since it was closer to the handle and felt less awkward. This feeling of discomfort may have altered participants' perception of their effort, making it feel more difficult than it really was. In a work environment, people experience awkward postures, so it is important to include tasks with awkward postures so that perceptions in these realistic positions can be quantified. The inclusion of a variety of tasks in this study was done to be representative of workplace demands. Another benefit of including a large variety of tasks in this study was to allow for the creation of regression equations that were more applicable in a workplace setting.

Participants in this study were most accurate at self-reporting peak dynamic hand forces at the low force level (10.3% MVC, 9.5% MVC), followed by the high force level (13.4% MVC, 14.1% MVC), and were the least accurate at the medium force level (15.9% MVC, 17.6% MVC) for both one-handed and two-handed tasks, respectively. These findings were similar to those of Oliver (2007), Cooper (1979), and the control group of Marshall et al. (2004). After participants in Marshall et al. (2004) were exposed to training, no differences were noted between low, medium, and high force level errors. A possible explanation for the lower errors at the low and high force levels could be that they are close to the ends of the % MVC range, limiting the estimation possibilities at either end of the scale. Participants were advised that no forces would be generated below 10% MVC or above 90% MVC. When using this protocol in the future, more training may be needed in the medium force range so participants are able to verbally estimate their forces more accurately across all levels of force. Also, the importance of getting accurate estimates at the medium and high force levels is important when applying this method to ergonomic evaluations in the workplace to ensure high risk jobs are identified.

5.4 Estimation Bias

In this study, participants tended to underestimate the forces they were applying by 13 %, on average. Greater accuracy was seen at estimating peak dynamic hand forces for pushes than pulls, and at the lowest force level (9.4% MVC and 10.2% MVC for two and one-handed exertions, respectively). The greatest error was found at the medium force level for both one-handed and two-handed tasks.

Previous studies have produced mixed results in this regard. Marshall et al. (2004) studied a variety of one-handed tasks, and found that participants tended to overestimate the forces they exerted. Cooper et al. (1979) reported that participants overestimated (in % MVC) the effort required to match a chosen force level to be generated by the quadriceps. In contrast, Oliver (2007) studied two-handed pushing and pulling tasks and found on average, that participants underestimated their peak dynamic hand forces by approximately 14%. During pushing and pulling tasks, Wiktorin et al. (1996) found that participants exerted higher forces when low forces (10N, 50N, 100N) were requested, and lower forces when high force (300N) was requested. When requested to exert a mid-range force (150N), participants did not show under or overexertion trends. The different findings may be due to the complexity of the tasks. In Marshall et al. (2004) and Cooper et al. (1979) tasks required more detailed movements (hand-intensive and knee extension tasks, respectively). Tasks in this study, Oliver (2007), and Wiktorin et al. (1996) utilized both larger and more muscles. To improve participants' perception across all force levels, more training may be needed at the medium force level for tasks comparable to the ones in this study.

5.5 Gender

This study examined whether gender differences existed in self-reporting of peak-dynamic hand forces. No significant differences in absolute error between men and women were observed. These findings agree with findings by Jackson and Dishman (2000) for a chest press task scaled to individuals' MVCs and by Marshall et al. (2004) for one-handed manual tasks. Pincivero et al. (2003) had participants express their exertion level on the Borg CR-10 scale and also reported no gender differences. In contrast, Oliver (2007) found males to be more accurate at self-reporting peak-dynamic hand forces than females. Deeb (1999) also reported gender differences in a weight holding and comparison task. It should be noted that in Deeb (1999), the weight was 500g for all participants (representing 10 on an RPE scale). This may represent varying levels of exertion for individuals depending on their strength. Overall, the findings on whether gender differences exist in how peak dynamic forces are perceived are mixed even though similar methodologies and rating scales have been utilized.

5.6 Experienced and Novice Manual Material Handlers

Differences in verbally estimated hand forces between novice and experienced participants were not significant in this study. Previous studies have differed in their classification of experienced workers with ranges between six months and ten years. The average level of experience in the current study was six years (SD=4.6). All participants in the inexperienced group held sedentary jobs including clerical, office, and managerial positions. The experienced group consisted of a variety of professions including paramedic, factory worker, landscaping, and personal support worker. The variety of MMH professions was included to make the findings of this study more generalizable to a variety of workplaces.

Prior research on experience level of manual material handlers focused on worker mechanics and strategies (Gagnon, 2005; Padula et al., 2008), whether the strategies of the experienced workers was safer than strategies employed by novices (Gagnon, 2003), as well as spine mechanics during lifting (Marras et al., 2006). These studies did not take into consideration how workers perceived the forces they were being exposed to. Also, these studies did not use worker expertise to try and quantify forces. The lack of significant differences between experienced and novice participants in the current study helped clarify that this type of research done in the lab can be applied to a working population.

Discomfort ratings have been utilized to assess risk as an alternative to obtaining physiological and biomechanical measurements. Parakkat et al. (2007) found novices to be much more sensitive to increased duration, moment, and frequency of a lifting task. In comparison, experienced manual material handlers reported the same low level of discomfort across all conditions. Paris and Kothiyal (2005) also found differences in how trained and untrained manual material handlers perceived and responded to a lifting task. Untrained participants yielded heart rates that were 25% greater than trained participants, and reported subjective fatigue ratings that were 65% greater. These findings demonstrate the variability in how tasks are perceived by participants with different levels of work experience.

5.7 Regression Analysis

Scatter plots were generated of actual and verbally estimated peak dynamic hand forces as a function of each independent variable. Data were organized in a variety of ways, including by task symmetry (asymmetrical/symmetrical), level of experience, group membership, level of training, as well as collapsing across gender and exertion type. The number of variables included was also assessed. These combinations of independent variables were analyzed systematically to determine the best fitting regression equations. The fit of the equations to the data was determined by means of the adjusted R^2 and SEE values. Equations that were developed with force levels divided produced much lower r^2 values than when all date were included. Equations generated from data with genders collapsed produced slightly lower r^2 values, compared to those with genders separated. Many of the developed equations had values that were comparable in magnitude, so equations were also assessed based on which ones would be easiest to apply in a workplace. Eight equations were ultimately selected as being the best based on fit to the data and usability in the field. These equations represented female and male one-handed and two-handed pushes and pulls. All the factors included in these equations are generally easy to determine visually while the task is being executed, which will help with how applicable the approach will be in the workplace.

The order of the equations was also considered. In most cases, the linear, quadratic and cubic models all produced very similar R^2 and SEE values. The cubic and quadratic models were slightly more accurate in general, but the simplicity (fewer terms) of the linear model makes it an attractive choice for use in the field. These findings are similar to those of Oliver (2007) who suggested using the linear model due to it being the least complex (fewest terms).

The R^2 values generated for the prediction equations in this study ranged from 0.55 to 0.78 (linear), to between 0.56 and 0.79 (cubic). The same values in Oliver (2007) were 0.61 to 0.74 and 0.64 to 0.75 for the linear and cubic R^2 values, respectively. These findings are also similar to the study by Marshall et al. (2004) with R^2 values ranging between 0.67 – 0.81 for linear curves of the control group and three benchmark group, respectively. Although variation existed in terms of which mathematical model best fit the relationship between actual and verbally estimated forces, Marshall et al. (2004) found the linear model to fit the data best. Considering that these R^2 values are based on only one variable, and are able to account for 55 to 78% of variance, this demonstrates a strong relationship.

During data collection, force levels were divided into three ranges, 10% to 30% MVC, 40% to 60% MVC, and 70% to 90% MVC. This resulted in data that were not continuous on the regression plots. It should be noted that for force levels between 0% to 9% MVC, 31% to 39% MVC, 61% to 69% MVC, and 91% to 100% MVC there were no data points recorded. This limitation was also present in Oliver (2007). Whether or not there would be any effects resulting from this discontinuity could not be checked post hoc in this study. Future work would need to present participants with non-overlapping force values in order to determine the impact of the current and previous (Oliver, 2007) study designs.

Other studies have reported different findings with respect to determining the best fitting mathematical relationship between verbally estimated and actual force exertion. Pincivero et al. (2000) and Oliver (2007) both found quadratic curves fit their data best. However, Oliver (2007) found the cubic and linear models to fit almost equally well, and justified that the linear models would be the easiest to apply in practice given the reduced number of factors. Marshall et al. (2004) and Cooper (1979) also found the differences between curves to be small. Jackson and Dishman (1999) and McGorry et al. (2004) both reported the linear model to best fit their data, while the power curve had the strongest relationship for Stevens and Mack (1959), Ljungberg et al. (1982), and Gamberale et al. (1987). The discrepancies between these studies may be due to disparities that existed in the methods used and what type of force participants perceived. For example, participants in Jackson and Dishman (2000) were asked to produce chest press forces at various % MVC levels without any training. On the contrary, participants in Oliver (2007), Marshall et al. (2004) and this study were required to report in % MVC the forces they thought they had exerted after training was administered.

Previous studies have required participants to verbally estimate forces in both absolute and relative terms. It has been hypothesized that reporting in relative terms (e.g. %MVC) may provide greater accuracy because participants are able to provide estimates based on their inherent understanding of their overall strength capacities (Marshall et al., 2004). When using absolute force references, researchers must train participants to remember what the absolute force values feel like. McDowell et al. (2006) had participants memorize hand push forces between 15N and 75N; they were then required to recreate the forces on an instrumented handle. When the memorization of forces is required, it tends to result in the participants forgetting shortly thereafter (Marshall et al., 2004). Research by Wiktorin et al. (1996) supports this, showing that without prior training, intellectualizing absolute forces (Newton) and quantifying them is very difficult. This finding may also be due to the fact that Newtons are not a very commonly used unit in activities of daily living. Verbal estimates made in relative terms, such as in % MVC, may be more accurate due to them being linked to an individual's strength capacity (Marshall et al., 2004). Overall, these studies have identified that the relationship between how a person perceives the force they are exerting and their verbal estimation is promising. The favourable relationship between these factors and the relatively low error rates indicates that this type of method can be used by researchers and ergonomists in work environments (Marshall et al., 2004).

5.8 Research Questions Revisited

1. .How does level of manual material handling experience affect ability to verbally estimate peak dynamic hand forces required for pushing and pulling tasks after training?
    a. Participants in Groups 2 and 4 had an average of 6 years of MMH experience, while participants in Groups 1 and 3 did not have any MMH experience. It was found that the differences in the mean absolute errors between any of the four groups were not statistically significant. Therefore, data are collected on inexperienced manual material handlers may be suitable for application in the workplace.
2. What is the relationship between participants' verbally estimated peak dynamic hand forces and actual hand forces?
    a. Participants had a tendency to underestimate their verbally estimated peak dynamic hand forces. Group 1 had the fewest underestimates compared to overestimates (58.9% vs. 38.0%), while Groups 2, 3, and 4 had approximately three times as many underestimates to overestimates.
    b. Eight regression equations were produced to predict peak dynamic hand forces for one-handed and two-handed push and pull exertions for males and females. Adjusted R^2 values for the equations ranged between 0.55 to 0.78, demonstrating there was a strong relationship between actual and verbally estimated hand forces for tasks that were tested.
    c. Standard error of the estimates ranged from 12-17% across all eight regression equations.

3. What is the effect of feedback training on verbally estimated peak dynamic hand forces?
    a. Groups 1 and 2 were given visual feedback training for all 16 tasks, and Groups 3 and 4 received feedback training on only 4 of the tasks. Statistically significant differences in the mean absolute errors were not found between any of the groups. This indicates that a less involved feedback training protocol may be just as effective as a more extensive one.
4. What is the difference in verbal estimation of peak dynamic hand forces for one-handed compared to two-handed pushing and pulling tasks?
    a. The mean absolute errors in verbally estimated hand forces were comparable between one-handed and two-handed tasks. Differences were observed for high force pulls, with the mean error being greater for two-handed exertions (16.3% MVC) than one-handed exertions (14.2% MVC). Errors for two-handed pulling tasks were also greater at the medium force level (18.9% MVC and 15.2% MVC for two-handed and one-handed tasks, respectively).
    b. There were higher adjusted R^2 and lower SEE values for the one-handed regression equations than the two-handed equations.
5. Is there a difference between males' and females' verbally estimated peak dynamic hand forces?
    a. Gender differences were not found for verbally estimated peak dynamic hand forces. All force levels were normalized to the individual

participant's MVC, which may have minimized discrepancies between genders.

5.9 Limitations

The main limitations of this study were:

1. Training and testing were only performed on hand forces between 10-90% MVC as the computer program didn't allow the investigator to select hand forces outside of this range. Participants were informed of the range and advised not to report forces outside of the possible range. When self-reporting their forces, participants tended to use 90% MVC as their anchor for maximum, and 10% MVC as an anchor for their minimal exertion level. When considering the applicability of forces at either ends of the force range, low forces would not pose an ergonomic risk for the types of tasks tested, and tasks above 90% MVC would most likely be deemed ergonomically unacceptable. The working range in this study was appropriate for application in the workplace.
2. During data collection, force levels were divided into three ranges, 10% to 30% MVC, 40% to 60% MVC, and 70% to 90% MVC. This resulted in data that were not continuous on the regression plots. In other words, no data points were recorded between 0% to 9% MVC, 31% to 39% MVC, 61% to 69% MVC, and 91% to 100% MVC.
3. Muscle fatigue was not quantified during the training and testing phases. Fatigue may alter an individual's ability to perceive force. Participants were advised they could take breaks as they were needed, and a water fountain was also nearby.

Only one of the participants needed to take a water break. Some of the participants were sweating, but in comparison to workloads experienced in the field, the data collection for this study lasted between thirty minutes to one hour, fatigue experienced over an eight hour (or greater) shift would be greater.

4. The temperature conditions in the lab were not controlled during the study. Some participants were tested in the evening and some on the weekends when the temperature was lower than during the day. Although variable, these conditions may be similar to those experienced in a workplace during various times of the day or year.
5. The duration of force application may not have been long enough in the current study to simulate actual working conditions. All forces were maintained for approximately three seconds in length, which did not include the one to two seconds for participants to ramp up their force to produce movement of the handle. Pushing and pulling efforts in the field may be carried out over varied periods of time (e.g. pushing a hospital bed versus a paramedic lifting a patient). Three seconds has been previously used in the literature for force self-reporting, future work could consider the effect length of exertion has on self-reporting peak-dynamic hand forces.
6. Many of the participants in the novice group were healthy, active individuals. These participants may have just as much body awareness as the average MMH worker due to their lifestyle activities (e.g. exercise, sports). Perhaps individuals in more sedentary occupations (such as office work) who are not regular exercisers may be worse at providing verbally estimated hand forces than

participants in this study. This study's findings have shown that active, healthy inexperienced manual material handlers were just as proficient at self-reporting their peak-dynamic hand forces as participants with experience in manual material handling.

5.10 Future Directions and Method Application

This study could be improved in the future by requiring all experienced manual material handlers to have a greater baseline amount of experience, by recruiting novice participants from a sedentary population and screening their lifestyle activities to ensure they are inactive, and by exposing participants to force applications over varying amounts of time. In addition, the applicability of the approach could have been improved if it had been conducted in a workplace environment.

Future work in this area should attempt to include a wider range of forces during testing. Overlapping ranges of actual hand forces could be presented to participants so that no discontinuities would exist in the resultant scatter plots. This would make the findings more representative of true working conditions.

The findings of this study are encouraging in terms of being able to apply the proposed method in the field. The use of verbal estimations of peak dynamic hand forces would be especially useful in situations or environments where it is difficult or not possible to obtain objective measurements (e.g. no access to a force gauge, exertion in a curvilinear direction, the transfer of a patient). Another encouraging finding of this study is the similar level of accuracy found between groups receiving varying levels of training. This supports the use of a shorter training protocol when applying this method in the field. A shorter training period makes this approach more appealing to researchers and practitioners that wish to use it in the workplace and to the workers being assessed, as their involvement can be significantly reduced.

6.0 Conclusions

1. Participants with MMH experience did not have a heightened ability to verbally estimate their peak dynamic hand forces.
2. The participants' abilities to verbally estimate their peak dynamic hand forces were not improved by an increased amount of feedback training.
3. Participants were better at verbally estimating their exertion levels for pushing than pulling tasks.
4. Participants underestimated their hand forces between two and three times as often as they overestimated them.
5. Participants were most accurate at verbally estimating their hand forces at the low force level, followed by the high force level, and were the least accurate at the medium force level. When using this protocol in the future, more training may be necessary at the medium force level to equalize perception across all force levels.
6. Eight separate prediction equations were generated that had strong relationships between actual and verbally estimated peak dynamic hand forces. They represent female and male one-handed and two-handed pushes and pulls. Although the linear, quadratic, and cubic relationships were similarly predictive, it is recommended that the linear equations be used in the field because they have the fewest terms.

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Vita Auctoris

Name: Amber Lynn Phillips

Place of Birth: Windsor, Ontario

Year of Birth: 1982

Education:

Essex District High School, Essex, Ontario 1996-2001

University of Windsor, Windsor, Ontario 2002-2006 BHK (Movement Science)

University of Windsor, Windsor, Ontario 2006-2009 MHK