A psychophysical investigation of grip types with specific application to job rotation

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public

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Abstract:

Background: Job rotation is recommended to prevent musculoskeletal disorders (MSD). It is implemented as a temporary solution while a permanent answer is being engineered. The premise of a job rotation is that by involving different tissues a "working rest" for other tissues is created. The possible health benefits from this relief created by job rotation have not been investigated with regards to different grips in hand intensive jobs. The purpose of this study is to investigate hand intensive tasks and to determine whether rotating between the power grip and lateral pinch grip can provide a benefit. A psychophysical load adjustment protocol was used. This type of study has benefits because of its relative ease of testing, low cost, and the replication of occupational activity levels.

***Methods*:** To investigate the effect of rotation, three different trials were collected. These trials included: power grip only, lateral pinch only, and a combination, alternating the two grips. Each trial was 60 minutes in duration, with a 12 second cycle time, and 25% duty cycle.

Seven males and seven females were recruited and pre-screened for any upper extremity disorders. Subjects were instructed to "work as hard as you can without straining your hand, wrist or forearm"; by adjusting their resistance settings to achieve a maximum acceptable force. Lateral pinch and power grip forces were exerted on an adjustable system using a hand grip dynamometer. At five minute intervals the resistance was randomly increased or decreased. Ratings of perceived discomfort were reported every 10 minutes.

Electromyography (EMG) was collected on eight forearm muscles to record any difference in activation during the combination trial. Statistical analysis was a repeated measures, two-way ANOVA, with T-tests were performed ($\alpha = 0.05$).

Results and Discussion: The demand for both lateral pinch and power grip tasks were at self selected levels and no fatigue was reported within the selected forces, EMG recordings, and discomfort reports. The rotation between lateral pinch and power grip had no apparent effect on maximum acceptable forces. However, EMG data hinted that there was a rotation of activation between first dorsal interossei and the forearm flexors, although not statistically significant. Less discomfort was reported within the combination trial than the single grip trials; however this was not significant.

Conclusion: The study found no measurable difference in maximum acceptable forces when rotating between the power grip and lateral pinch at low occupational force levels. Considering there was no increase in demand, there is potential benefit to rotation, with trends to rotating activation between muscles, less discomfort being reported, and a general preference for the rotation vs. the no rotation condition. Given the high rates of musculoskeletal injuries, and rotation being an effective tool to lower exposure, further investigations are required to understand relationships between similar muscles groups within hand intensive work environments.

Acknowledgements

I would like to thank my family for their steadfast support throughout these two years. You made me feel like I could achieve this, even during times of doubt

I would also like to thank my advisor Dr Richard Wells, and my committee members, Dr. Mardy Frazer, and Dr. Clark Dickerson, your help has been invaluable and truly appreciated.

And finally, my friends, who have stood by, dropped in, listened and laughed.

I've valued every moment.

You are all wonderful people.

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1.0 Introduction

Job rotation is recommended by various health and safety organizations like the National Institute for Occupational Safety and Health (NIOSH), and the Occupational Safety and Health Administration (OSHA) to decrease exposure to known musculoskeletal disorders (MSD) risk factors (OSHA, 2007; Cal/OSHA Consultant Service, 2007). Physical risk factors for MSD include: forces, repetition and posture (Putz-Anderson, 1988, Silverstien *et al.,* 1986). However the following questions quickly arise:

- How different do tasks have to be to achieve a relief?
- Are job rotations effective in decreasing exposure to MSD risk factors?

In order for a job rotation to be successful, Davis and Jorgensen (2005) state that the schedule should be balanced, meaning stressors are evenly distributed throughout the body; and the most successful schedule involves both static and dynamic tasks. Based on these assumptions, Davis and Jorgensen (2005) mention a scheme solely based on hand intensive tasks would be unbalanced and not effective. This comment of hand intensive rotation as being inadequate is unsupported because of limited documented investigations into hand intensive tasks (Wells *et al.,* 1990; Wells *et al.,* 1995). This outlines a gap in literature as to the possible benefits of rotation to the hands, wrists, and forearms.

In a recent review Mathiassen (2006**)** suggests there are varying levels of rotation. One level is the rotation between areas of the body. An example is switching between manual material handling tasks and inspection tasks. This level has been researched in various occupations (Jonsson, 1988; Hinnen *et al.*, 1992; Kuijer *et al.*, 1999; Synwoldt and Gellerstedt, 2003; Marshall, 2006). However there is still controversy within the literature on the rationale and effectiveness of this type of job rotation.

The next level is between muscles within the same area, which is the focus of this study. This was originally suggested by Palmerud *et al.* (1998), to alternate activity to other muscles within or outside of the groups of primary movers (Mathiassen, 2006; Palmerud *et al.*, 1998). For example a rotation of the muscle groups of the hand muscles could involve the flexors and extensors. It is known from electromyography studies that forearm and hand muscles have different roles in power grip and lateral pinch. However it is unknown how this synergy would be beneficial in low level activation, hand intensive tasks. This rotation between muscles was investigated by McFall and Wells (2007) during a fatiguing isometric protocol involving rotating grips. The researchers determined that the alternating grips are effective in decreasing the rate of fatigue in each of alternating the trials (McFall and Wells, 2007). The most recovery is noted between lateral pinch and power grip. Due to this identified difference between the power grip and lateral pinch, the psychophysical study will focus on these two grips.

The last level of rotation is within a muscle, involving a rotating rest between motor units (Mathiassen, 2006). The theory is that there is a rotation between different units, fiber types, or fascicles. However the actual benefit of rotating between fascicles is unclear in an occupational setting. With these possible levels of rotations it is the focus of this study to increase the knowledge about hand grip rotation investigating the concept that a synergy between forearm and hand muscles might be achieved.

1.1 Research Questions and Hypothesis

Mathiassen and Christmansson (2004) raised the questions of 'What characterizes a complementary relationship with respect to inducing variation? This lead to this study's research questions of:

- What kind of complementary relationship exists between muscle groups of the forearm and hand during gripping?
- In a simulated job scenario, how different do hand tasks (power grip and lateral pinch) have to be in order to reduce fatigue and discomfort and alter force selection

Therefore the purpose of this study was to investigate this postulated relief within a simulated job situation using a psychophysical protocol. There were two hypotheses tested in this study:

i. The rotation between power grip and lateral pinch will have an increase in maximum acceptable power grip and lateral pinch force as opposed to grip or lateral pinch alone.

    Rotating grips will alter the selected force levels in lower contraction levels during a rotation protocol, as indicated in previous fatiguing protocol study (McFall and Wells, 2007).

ii. From the discomfort surveys, higher discomfort will be marked about the finger and thenar portions regardless of rotation or non-rotation.

2.0 Literature Review

2.1 Job Rotation

2.1.1 Claims and benefits

To combat MSD propagation, companies instigate job rotation to decrease exposure to certain forces, positions, and situations. The premise is that rotation reduces a target tissue's cumulative exposure levels by increasing variability within an occupational situation (Jonsson, 1988; Frazer *et al.*, 2003; Davis and Jorgensen, 2005). The reported benefits to workers and management include: psychological, psychosocial, work organization and physiological. It is important to note that in these studies rotational schemes are predominately focusing on switching from static to dynamic tasks, and limited investigations into hand intensive tasks have been conducted to date.

Job rotation implementation has been linked to numerous psychological and psychosocial benefits. These benefits are claimed to include: increased feelings of equality between workers, job satisfaction, motivation, innovation, and morale. Also reported are reductions in boredom, monotony and work stress (Jonsson, 1988; Cosgel and Miceli, 1999; Triggs and King, 2000; Konz and Johnson, 2004; Davis and Jorgensen, 2005; Mathiassen, 2006; Marshall, 2006).

With respect to the work organization, claimed bonuses of job rotation implementation include: increases in production and worker retention, decrease absenteeism, and discretionary break periods, a cross trained workforce, insurance against a labour shortage, low implementation costs, and quick application (Jonsson, 1988; Cosgel and Miceli, 1999; Triggs and King, 2000; Konz and Johnson, 2004; Davis and Jorgensen, 2005; Mathiassen, 2006; Marshall, 2006).

For implementation of job rotation a company can alter: repetitive motions, work duration, monotony, static postures and movement frequencies (cycle time, duty cycles, and work rest ratios) (Winkel and Westgaard, 1992; Kilbom, 1994; Marshall, 2006). Konz and Johnson (2004) suggest that altering any one of the above parameters should induce a working rest. The working rest is defined as a joint/ body area; can repair while other parts are being loaded (Konz and Johnson 2004). However no studies have yet to determine whether a working rest for tissues of the forearm would occur when involving different grips.

Working rests and diverting activities were investigated by Asmussen and Mazin (1978) with respect to elbow flexors in alternating 2 minutes work and rest. This study compared alternating working tasks with activity of different muscle groups or cognitive tasks. Asmussen and Mazin (1978) recorded positive results of increased blood flow and endurance time until exhaustion, with activity of unrelated muscles. By implementing this divergent activity it increased the amount of possible work. Therefore working rests could be beneficial physiologically within elbow flexors, but further investigation into this effect with other muscles is necessary.

In summary, job rotation can be implemented by altering a variety of variables. There is evidence of benefits, although studies have focused on static to dynamic rotations. Limited investigations into hand intensive rotations or rotations involving similar muscle groups have been made.

2.1.2 Evaluation of effectiveness

It is difficult to successfully implement and evaluate job rotation schemes because of numerous factors within the work organization, and the limited knowledge of the causation and prevention of MSD. Maximum acceptable levels or tolerance limits of muscles and joint are beginning to be determined but the variation within an occupational setting make matching them to 'laboratory' values a daunting task. The variation within workplaces, individuals, task and the limited knowledge causes challenges in determining what would be beneficial for whom. This lack of information is one of the causes of the rotation debate in the literature and practice.

Another controversy is the rationale of rotation that was brought into question by Frazer *et al.,* (2003), through their investigation of predicted low back pain in an automotive manufacturing plant. The researchers questioned whether the benefits of rotating from high demand to lower demand tasks outweigh the inherent risks of rotating from low demand to high demand jobs. This raises the concern that job rotation could increases exposure of the entire rotating worker force to peak loads (Frazer *et al.,* 2003); and outlines the importance of the redesign of high demand tasks.

This issue was echoed by Moller *et al.*, (2004) in their investigation of introducing variability within an assembly line. From inducing variability, Moller *et al.*, (2004) reported an increased overall exposure variability of the trapezius, but a negligible or reversed variability for the forearm extensors indicating the complexity of designing a rotation scheme. A grip rotation would have induced an increased variability for the forearm, but this is speculative and further investigation is warranted.

An effectiveness of rotation study was conducted by Jonsson (1988). This research investigated shoulder loads of four different jobs from hand intensive assembly to dynamic work. Jonsson (1988) demonstrated that dynamic and static rotations would have benefits for the trapezius muscle, and there was the likelihood of limited benefit of rotation in light assembly work. This study did not consider the possible benefits to the forearm, wrist, and hand with the rotation of grip types during light assembly tasks, warranting further investigation for forearm affects.

As opposed to focusing on the trapezius, Wells *et al.*, (1990) focused on the forearm and hand in light electronic assembly. In their analysis of four different tasks in a rotation scheme, the scheme was deemed to be beneficial to the forearm muscles by reducing exposure to increased predicted flexor digitorum profundus tendon loads, and increased tendon excursions. In comparison, the trapezius muscle reported activation exceeded the guideline levels in every task in to rotation. Therefore this rotation scheme was likely beneficial to the forearm, but not as effective for the shoulder.

In comparing these three studies focusing only on the trapezius and forearm, it outlines the complexity of determining what is considered effectiveness in a rotation scheme; and that what is deemed effective is determined by the muscle group of interest.

In summary rotation must be preceded by a task redesign to remove high demand tasks. Limited studies have focused on the effects of rotation on the hand and forearm, and evaluation of the effectiveness of a rotation scheme is based on the muscle group. Also, there is controversy about the benefits and claims of job rotation programs by questioning the rationale of exposing all workers to increased peak and cumulative loads.

2.2 Psychophysical studies

2.2.1 Advantages and disadvantages of psychophysical studies

Psychophysical studies can be used when biomechanical or physiological methods are not feasible, enabling investigators to monitor realistic job scenarios for determining exposure levels. Some successful psychophysical scales include: decibels, effective temperatures, and brightness (Snook 1999). In reviews by Snook (1985), Snook (1999) and Ayoub and Dempsey (1999) the following advantages and disadvantages of psychophysical methods were reported:

Advantages:

1. Permits the realistic simulation of industrial work
2. Can measure intermittent tasks in industry
3. Consistent with the industrial engineering concept of a fair days work
4. Reproducible
5. Reasonable relationships established to low back pain

6. Accounts for the whole job and include biomechanical and physiological approach
7. Experiments can include a wide array of tasks
8. Can test under restrictions of jobs, handing limits can be established
9. Less costly and less time requirements than other methods
10. Exposes hazardous tasks without excessive risks
11. Uses occupationally relevant contraction levels and time scales

Disadvantages:

1. Subjective
2. Fast frequencies need more information, or use metabolic data for manual materials handling.
3. Limited sensitivity to bending and twisting for low back pain
4. Assumption that loads selective by subject are below injury threshold has not be validated
5. Maximum acceptable forces may violate some biomechanical criteria

(Snook, 1985; Ayoub and Dempsey, 1999; Snook, 1999)

In verification studies of psychophysical methods, several crucial issues about the use of psychophysical methods have been noted. Gamberale *et al.,* (1987) outlined two issues in their MMH verification study. The first issue is the delivery of instructions to the subjects, noting that instructions in a psychophysical study are crucial and should follow very specific guidelines. During Gamberale *et al*., (1987) experiment one instructor periodically reminded subjects about the instructions (Gamberale *et al*., 1987). The workloads selected by this instructor's group were higher than the other workloads from other instructors (Gamberale *et al*., 1987). Therefore the delivery of instruction is crucial with respect to study design.

Gamberale *et al*., (1987) second issue was workload is not only determined by sensory input but it can be influenced by previous experience. This was demonstrated by differences in a lifting task workloads and ratings of perceived effort between office and industrial workers. The office workers selected significantly higher loads than the industrial workers (Gamberale *et al.*, 1987). However, in a recent paper by Potvin *et al.*, (2000), it was reported that this skilled/ unskilled worker gap could be overcome with adequate training of the subject, with respect to hand and forearm work. This emphasizes population selection as important in psychophysical study design. This study avoids this controversy of subject experience because it focused on characterization of an effect of specific exposures and not guideline establishment.

In summary psychophysical studies are commonly utilized to determine maximum acceptable levels because of the ability to mimic job scenarios, but care must be taken to decrease variability that can be induced by instruction delivery and sample population.

2.2.2 Distal upper extremity psychophysical studies

Upper extremity psychophysical studies have focused on known physical upper extremity risk factors that are suspected of being linked to MSD propagation. This includes: force/ torque, frequency of the task (repetition rate), duration of the contraction (work cycle), and posture.

Two research groups have focused on investigating maximum acceptable forces/ torques (MAF/ MAT) or maximum acceptable frequencies of pinching and griping in various scenarios. Researchers at the Liberty Mutual Research Center investigated the relationship between psychophysical selected forces of the hand combined with wrist motions, and outlined maximum acceptable forces for percentiles of the population. (Snook *et al.*, 1995; Snook *et al.*, 1997; Snook *et al.*, 1999; Ciriello *et al.*, 2001). The Fernandez group focused on frequencies in pinching, gripping and drilling tasks with different wrist postures. Overall these researchers noted that posture and repetition rate affect the maximum acceptable frequency as well as the maximum grip strength (Dahalan and Fernandez, 1993; Kim and Fernandez, 1993; Marley and Fernandez, 1995; Klein and Fernandez, 1997). Care should be taken in order to maintain similar wrist posture and constant repetition rate in any study about the hand.

A work cycle is divided into two sections, a rest time, and a duty cycle. Duty cycle is the contraction time required to complete the task (percent of cycle time), and rest time is when the muscles are not actively required. Each contraction can be measured by the cycle time (total time of the duty cycle and rest cycle).

Moore and Wells (2005) investigated the effect of duty cycle and frequency in a mock in-line screw running task. The duty cycles investigated in their study were 25, 50, and 83%. Cycle times investigated were 3, 6, 12, and 20 seconds. The times and percentages were selected from previous studies to represent line driven activities. The results were that duty cycle was more important in the choice of workload than cycle time (Moore and Wells, 2005). With this in mind, duty cycle is important to consider in designing a psychophysical study.

In summary maximum acceptable limits of the upper extremity are affected by wrist motion, posture and duty cycle.

2.3 Anatomy and electromyography of power grip and lateral pinch

2.3.1 Anatomy of power grip, lateral pinch

Extensive studies have outlined the anatomy of the hand, wrist and forearm with respect to muscular activity in power grip, and lateral pinch. Examples of each grip are in Figure 2.1. The most comprehensive study was by the Ampersand Research Group, directed by Dr. Charles Long II, exploring the kinesiology of the hand, wrist, and shoulder.

Long (1970) collected indwelling EMG from 200 subjects performing power grips and precision handling grips (power grip and lateral pinch). Muscle activity was graded using a three point scale of zero, minimal and significant; a graphical representation of the main findings for the hand muscles is shown in Figure 2.2. The main findings include that the abductors are active in power grip, while adductor pollicis is active in lateral pinch, but opponens pollicis is active in both grips.

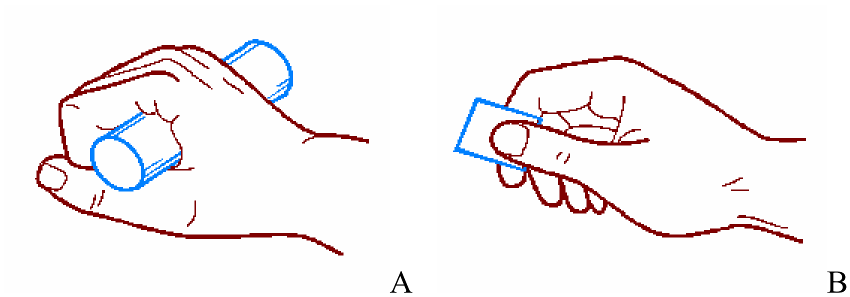


Figure 2.1: Example of power grip and lateral pinch.

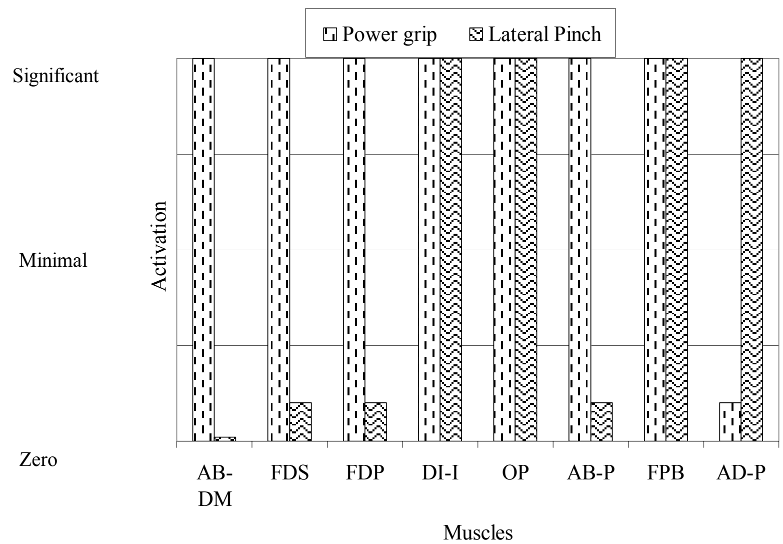


Figure 2.2: Comparison of intrinsic hand muscles and flexor digitorum comparing power grip, lateral pinch, pulp pinch, redrawn from Long data (1970). Legend: AB-DM, abductor digiti minimi, FDS, Flexor digitorum superficialis, FDP, flexor digitorum profundus, DI-I: first dorsal interossei, OP, opponens pollicis, AB-P, abductor pollicis brevis, FPB, flexor pollicis brevis, ADP adductor pollicis (Long 1970).

Long (1970) also investigated forearm electromyography in opening and closing of the hand. When closing the hand, there was a pronounced amount of wrist extensor activity over the flexor activity recorded (Long, 1970). Of the six measured forearm muscles, extensor carpi radialis brevis (ECRB) was the most active followed by extensor carpi ulnaris (ECU) and then extensor carpi radialis longus (ECRL). If there was an increase in force, such as squeezing, then there would be an increase activity in ECU and ECRL. With respect to the flexors, activity was noted in flexor palmaris longus (FPL) and flexor carpi ulnaris (FCU) but not in flexor carpi radialis (FCR) (Long, 1970). Overall this increased activity during closing is indicating an increased role of the forearm muscles when increased compressive forces are required in the hand.

This forearm musculature activity pattern is supported by re-analysis of previous data collected from Greig (2001) of various forearm muscles during power grip and lateral pinch, approximately 70% maximum voluntary contraction (MVC) Figure 2.3). A one-way ANOVA with Bonferroni adjustments was performed to determine main effects. Figure 2.3 indicates substantial differences between ECU, first dorsal interossei (DI-I), FCU and FDS in lateral pinch and power grip. This data has similar findings and conclusions as Long (1970), with increased activity in ECU, FCU and FPL. There are also roles for DI-I, FDS, and FCR within the two grips.

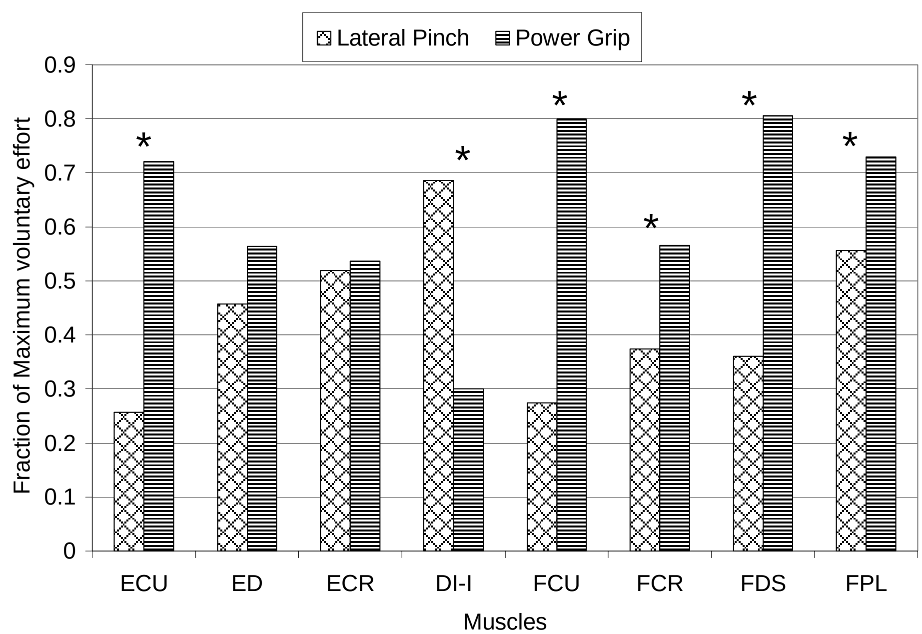


Figure 2.3: Comparison of EMG values of power grip and lateral pinch of eight different forearm muscles performing a contraction at approximately 70%MVC. Legend: ECU, extensor carpi ulnaris, ED, extensor digitorum, ECR, extensor carpi radialis, DI-I, first dorsal interossei, FCU, flexor carpi ulnaris, FCR, flexor carpi radialis, FDS, flexor digitorum superficialis, FPL, flexor pollicis longus. * Indicates significant difference at $\alpha=0.05$ level. (Greig, 2001).

In summary, lateral pinch forces are generated mainly by the intrinsic hand musculature whereas with increased compressive forces for power grip this requires increased activity of the forearm musculature.

2.3.2 Electromyography

Forearm muscle activity during occupational tasks have been reported in numerous studies. Wells *et al.*, (1992) measured forearm flexors and extensors muscles in line paced hand intensive activities and reported peak (90^{th} percentile) activity level were 8.7 to 16.9% maximum voluntary effort (MVE) and 13.4 to 20.1%MVE respectively. This indicates that the extensors are the more active of the two groups in an occupational setting.

Moore (1999) reported increased extensor values during a psychophysical screw driving study. The reported values for mean activity of FCR and FDS were 3.5 to 4.6 %MVE, and ECRB (extensor carpi radialis brevis) was 6.4%MVE, again indicating a higher activation for the extensors. Also reporting higher activation of extensors in a psychophysical study of fastener initiation was Cort *et al.*, (2006), who recorded extensor activity of 12.60 to 14.9%MVE, and flexor activity of 5.40 to 7.31%MVE. Therefore in occupational tasks forearm muscle activation can be expected to be between 5 to 20%MVE.

With this relatively low level of activity there is a concern with the sensitivity of surface EMG in combination with tightly bundled forearm musculature. Mogk and Keir (2003a) calculated that there is a 50% common signal within the extensors, and 60% common signal within the flexors. Along with this common signal issue, Duque *et al.*, (1995**)** noted forearm motion could cause electrode movement; however, they later noted that this could be minimized with maintaining similar hand orientation (Duque *et al*., 1995). Jacobson *et al.*, (1998) compared the values between surface and indwelling EMG and reported good agreement in ECU, ED, FCU an FCR. Therefore with careful electrode placement and minimal hand orientation movement, these effects can be minimized.

In summary, based upon the literature, occupational levels of forearm muscular activation are typically between 5 to 20%MVE. In the collection of forearm surface EMG at these low levels care must be taken with electrode placement and monitoring hand orientation.

3.0 Methods

3.1 Subjects

Seven male and seven female subjects (ages 20 to 31) were recruited. Subjects were students, right handed, and were pre screened for any known upper extremity injuries within the past year and gave informed consent. The protocol was approved by the University of Waterloo ethics committee.

3.2 Data Collection

3.2.1 Procedures

Subjects sat in an adjustable chair in front of the workstation with an adjustable desk height. The right elbow and forearm were supported by the arm rest, to maintain elbow flexion at approximately 90^{o}. The dynamometer was positioned in front of them, and could be easily alternated between the power grip and lateral pinch position. A photo of the testing equipment is in the Appendices (page 66). To maintain a constant hand position for the centre of the power grip, a mark was made at 136mm from the base for a reference.

Throughout the trials the subject had no feedback on absolute load. Visual feedback for the subjects was through a needle gauge with an arbitrary target mark associated with the applied forces. The subjects were instructed to grip the transducer to reach this target mark for each work cycle, and adjust the required load, via a potentiometer attached to a multi-turn knob with no markings. Every five minutes the resistance was randomly increased or decreased by the experimenter (0 to 2 revolutions, increments of 0.5 turns). The readjustments required the subject to reset the load to what they consider was an acceptable level.

The contraction was controlled by the activation of a red light. The duration of the contractions was unknown to the subjects. The selected cycle time and duty cycle were 12 seconds and 25% respectively (three seconds of work, and 9 seconds of rest). These two time measurements were selected to represent an assembly line driven activity, as indicated in previous studies (Moore and Wells, 2005; Snook *et al.*, 1995). A possible example of this duty cycle would be placing a part in the correct spot then a machine would cycle through welding the parts together.

Subjects were given instructions (page 67) that are similar to those used by Snook *et al.*, (1995) to 'work as hard as you can without straining your hand, wrist, or forearm'. Subjects read the instructions at the beginning of each session and instructions were clearly posted throughout the trials. Subjects were reminded to reread the instructions if they reported a discomfort rating of greater than 2 on a 7 point discomfort scale at 10 minute intervals.

Subjects came for training prior to the experiment to become familiar with the protocol, at which time anthropometric measures (Table 4.1) were recorded. Three maximum voluntary force contractions of lateral pinch and power grip were collected during the training session. The peak value of three 5 second trials was deemed to be the maximum and used to normalize force data. If the peak values varied by more the 10% another trial was collected. Between maximum contractions a break was allotted (minimum 2 minutes).

Three trials were tested (60 minutes duration): power grip alone, lateral pinch alone, and a combination of lateral and power grip, alternating between the two grips every ten minutes. Trials were on separate, nonconsecutive days at the same time of the day. Figure 3.1 is a visual timeline of each of the possible trials, including readjustment and discomfort rating times. The trial order was randomized. Individuals were also randomly assigned into two groups for the alternating task to avoiding any possible effect with starting grip in the combination trial. Group LP started with lateral pinch, and group PG started with power grip. On the combination day, EMG was collected on eight forearm muscles. The total time requirement from each subject was approximately six hours, spread over four separate days including the testing and training protocols.

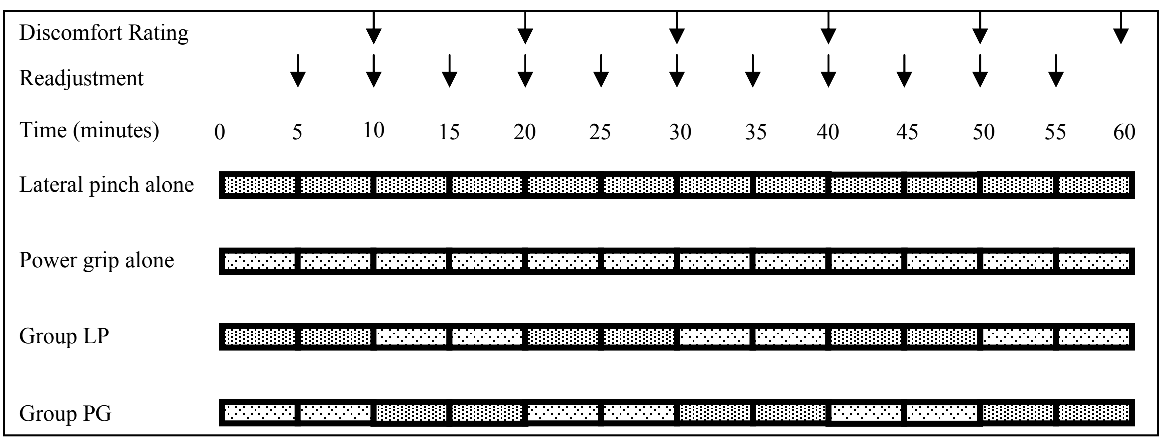


Figure 3.1: Psychophysical protocol time line of different grips, when readjustment occurred, and when discomfort ratings were reported.

3.2.2 Ratings of perceived discomfort and discomfort diagrams

Ratings of perceived discomfort were reported every ten minutes, until completion, using a seven point scale (1 = no discomfort; 2 = very little; 3 = a little; 4 = some discomfort; 5 = much; 6 = very much; 7 = extreme discomfort, (Snook *et al.*, 1995). At completion, a discomfort survey was collected with focus on the hand, wrist and forearm. This used a four point scale (0 = no; 1 = a little; 2 = somewhat; 3 = very) for three sensations of stiffness, soreness and numbness or tingling (Snook *et al.*, 1995). Examples of the discomfort survey and seven point scale are in the Appendices (page 68).

3.3 Equipment

A block diagram and photo of the equipment set up for this protocol is in Appendices (page 66)

3.3.1 Force dynamometer

A MIE force dynamometer (MIE Medical Research Inc, UK) recorded the grip force exerted throughout the trials. The grip span was set at 20mm, giving a circumference of 130mm. Visual feedback for the subject was displayed on a plain needle dial with an arbitrary target mark. The amount of force required to reach the target was controlled by a potentiometer.

Data was recorded by NIAD data collection software, through a 12 bit A/D conversion card, sample rate 60 Hz, soft gain ±5.0V. The entirety of each trial was collected, and the last minute of every five minute interval was analyzed (Matlab 5.3, Mathworks 1999). Bias was removed by collecting a two second 'quiet' trial and all force data was converted into newtons using a shunt calibration (approximately 700N). To calculate force duty cycles, data was filtered using a low pass filter (dual pass, 4^{th} order Butterworth, cut off 5 Hz, Matlab 5.3, Mathworks 1999). A typical example of calculating the duty cycle is graphed in Figure 3.2.

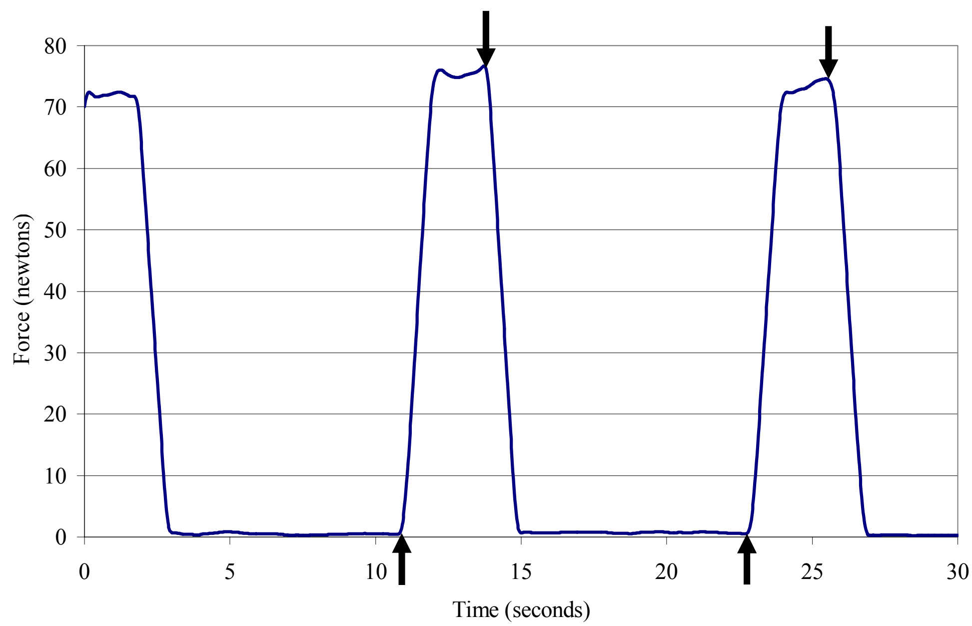


Figure 3.2: An example of how duty cycles were calculated with arrows representing initiation and completion of the contraction.

To calculate maximum acceptable forces, the largest magnitude of a one second moving average window for each contraction over the last minute was calculated (Mathiassen *et al.*, 1995); the average of the last five contractions was then calculated and reported.

3.3.2 Electromyography

Surface electromyography was collected from the following eight muscles: extensor carpi ulnaris, extensor digitorum, extensor carpi radialis, flexor carpi ulnaris, flexor carpi radialis, flexor digitorum superficialis, flexor palmaris longus, and first dorsal interossei. Skin was shaved and abraded by alcohol and water solution. Electrode placement was indicated by Delagi et al (1975), and approximate placements are shown in Figure 3.3.

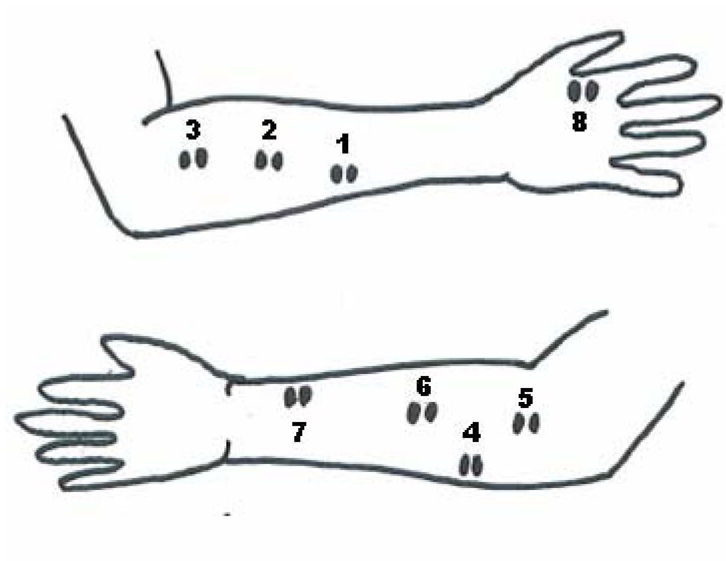


Figure 3.3: Approximate electrode placement for the 8 forearm muscles, top diagram is the anterior view, and bottom is posterior. Legend: 1. Extensor carpi ulnaris, 2. Extensor digitorum, 3. Extensor carpi radialis, 4. Flexor carpi ulnaris, 5. Flexor digitorum superficialis 6. Flexor carpi radialis, 7. Palmaris longus. (Greig, 2001).

Surface EMG was collected only during the grip rotation trial to any determine any difference in activation between two grips. Three maximum voluntary effort trials were collected for power grip and lateral pinch for normalization of each muscle. If a peak value occurred in a trial, this value was recorded and then used as the new maximum value. A bias trial was collected to remove systemic noise within the system.

Silver/ silver chloride electrodes were used (Medicotest Blue Sensor N-00-S electrodes). Data was collected by the Mega system (MEGA Electronics, Finland), Bandwidth 20 to 600Hz, sample rate of 1000Hz, Amplifier range of +/-375mV. The last minute before altering the resistance was collected and analyzed.

EMG data was full waved rectified and low pass filtered (single pass, 2nd order Butterworth, cut off 2.5Hz). The cut off frequency of 2.5Hz was determined by residual analysis as indicated in Figure 3.4 (Winter, 2005). Reported muscle activity was computed by an amplitude probability distribution function (Jonsson, 1978, Matlab 5.3, Mathworks 1999), and the selected values representing static (10th), dynamic (50th), and peak (90th) activity reported. Median power frequencies were calculated on a 60 second window using a Fast Fourier Transform on the raw EMG for each minute analyzed.

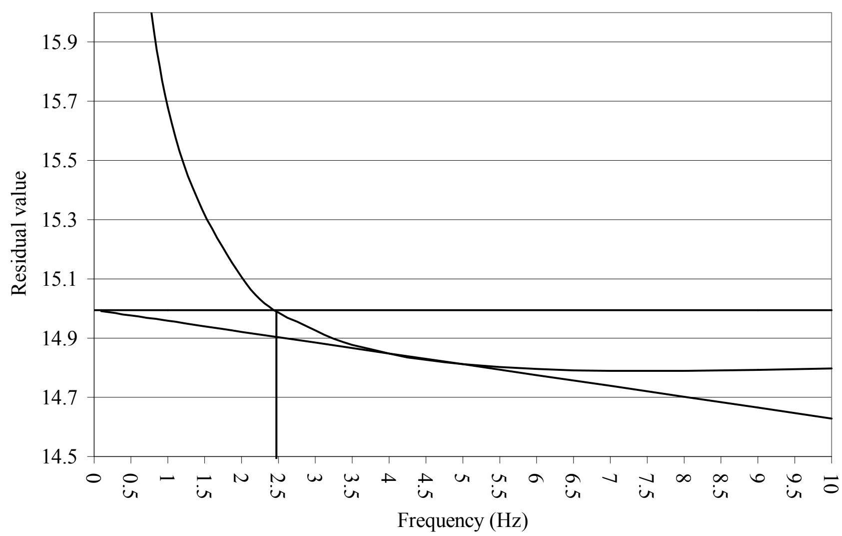


Figure 3.4: An example of a residual analysis for extensor carpi radialis.

3.4 Experimental Design

A randomized block design was used. The independent variable was type of grip (power grip, lateral pinch, or combination of the two) and time. The dependent variables were self-selected force levels, EMG amplitude, and discomfort.

3.5 Statistical Analysis

Dependent variables are selected forces, EMG and discomfort. Three treatment groups tested are: power grip only, lateral pinch only, and combination of lateral pinch and power grip. A power analysis was conducted, and recorded in Table 3.1. To achieve type I error at 0.01, at 80% power, predicting a sample size of 7. Statistical analysis was performed on EMG and force, using a two-way repeated measures ANOVA analysis (treatment group vs. trial time of 60 minutes) at $\alpha = 0.05$ level with T-tests for main effects.

Table 3.1: Power Analysis results using standard deviations from pilot result using standard deviations from pilot results (9.4%) and anticipated minimal mean difference of 20% between the force of one grip only and the force when changing to the alternate grip.

	Type I error = 0.05	Type I error = 0.01	Type I error=0.001
Power = 80%	5	7	11
Power = 90%	6	9	12
Power = 99%	10	13	17

With respect to recorded EMG values, trial time (60 minutes) was determined to have a significant effect (Wilk's Lambda $p = 0.001$), whereas grip had no significant effect (Wilk's Lambda $p = 0.053$). With recorded forces, both time and trial had a significant effect Wilk's Lambda p values are 0.006 and 0.001 respectively.

To test the main effects for the reported forces, paired T-tests were performed. With respect to grip types there was significance between power grip and lateral pinch ($p=0.001$). This significance did not occur between same grips measurements of single grip to combination grip trials. T-test values of comparison of power grips forces p-value ranges were 0.627 to 0.222, and the lateral pinch p-value ranges were 0.240 - 0.112, representing comparisons of alone trial to combination trial.

The ratings of perceived discomfort (RPD) had no significant difference between trials ($p=0.119$). Trial time, RPD over the 60 minute trail, had a significant effect, Wilk's Lambda p value of 0.002, however there was no significant interaction of different trials (lateral pinch alone, power grip alone, and combination trial) with trial time ($p = 0.876$).

4.0 Results and Discussion

4.1 Anthropometrics

Recorded anthropometric measurements are reported in Table 4.1. These measurements are similar to other studies that used a university aged population. No noticeable differences were seen between the group LP and group PG.

Comparison of maximum voluntary contractions for lateral pinch and power grip between this data and strength data reported in the literature are listed in Table 4.2. The power grip and lateral pinch values are within the range recorded within the literature

Table 4.1: Measured anthropometric data (n=14).

Measurement	Males	Females
Height (cm)	178 ± 6.25	162.8 ± 4.59
Weight (kg)	85.2 ± 28.5	63.3 ± 14.7
Biceps circumference relaxed (cm)	30.75 ± 4.58	27.2 ± 3.35
Forearm circumference relaxed (cm)	27.9 ± 3.56	23.5 ± 1.78
Wrist circumference (cm)	12.9 ± 6.05	16.6 ± 3.91
Wrist breadth (cm)	6.62 ± 1.05	5.23 ± 0.175
Hand breadth (cm)	8.5 ± 0.548	7.35 ± 0.259
Hand length (cm)	19.6 ± 1.11	17.4 ± 1.02
Maximum isometric power hand grip (N) (on a 130mm circumference grip dynamometer)	418.9 ± 66.4	279.0 ± 61.5
Maximum isometric lateral pinch grip (N)	91.01 ± 14.67	73.14 ± 9.218

Table 4.2: Comparison of maximum power grip and lateral pinch values from previous studies to those recorded from this study.

Study	**Sample size**	**Gender**	**Maximum grip force (N)**	
			Lateral pinch	**Power Grip**
McFall (2007)	7 7	♂ ♀	91.02 (range 66.95 – 114.5) 73.14 (range 59.75 – 85.04)	418.9 (range 333.0 – 511.1) 279.0 (range 166.7 – 338.7)
Berg *et al.*, (1988)*	19 11	♂ ♀	99.05 67.67	
Mathiowetz *et al.*, (1985)	29 27 27	♂ age 20-24 age 25-29 age30-34	115.72 118.66 117.70	
Swanson *et al.*, (1970)*	50 50	♂ Skilled Sedent ♀ Skilled Sedent	64.73 61.78 43.15 40.2	
Dempsey *et al.*, (1996)	8 8	♂ ♀	86.00 51.48	
Carey and Gallwey (2005)	16	♂		327 (range: 288-416)
Duque *et al.*, (1995)	20	♂		407 (range: 257 - 557)
Eksioglu (2006)	12	♂		451 (range: 353-510)
Hagg and Milerad (1997)	9	♂		361
Imrhan (1991)	30	♂	96.11	483 (range: 314-612.5)
Fernandez and Kim (1993)	15	♂	93.95	279.49 (range: 215.75-323.62)
Imrhan and Loo (1989)	40 30	♂ ♀	92.18 63.74	
Fernandez *et al.*, (1992)*	15	♀	62.66	
Koppelaar and Wells (2005)	9 10	♂ ♀	100.8 68.5	479.0 287.1
Mogk and Keir (2003b)	5 5	♂ ♀		392.6 249.2
Moore and Wells (2005)	8	♀		198 (range: 108 – 324)

- Adapted from Dempsey *et al.*, (1996)

4.2 Electromyography

A Fast Fourier Transform was calculated to determine whether a noticeable shift in median power frequency occurred over the 60 minute trial. There was no measurable change between initiation and completion of the trial as indicated by the values seen during power grip intervals (Figure 4.1) or the lateral pinch intervals (Figure 4.2). The extensor digitorum was omitted from further analysis because of numerous missing data points due to equipment problems.

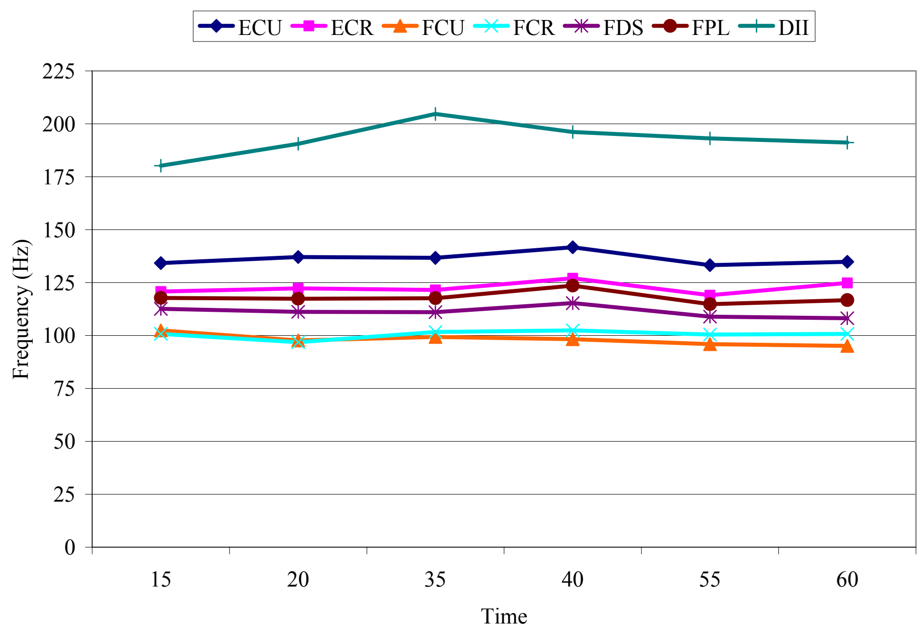


Figure 4.1: Median power frequencies over power grip intervals of seven different forearm muscles during the combination trial. The values are mean of all subjects

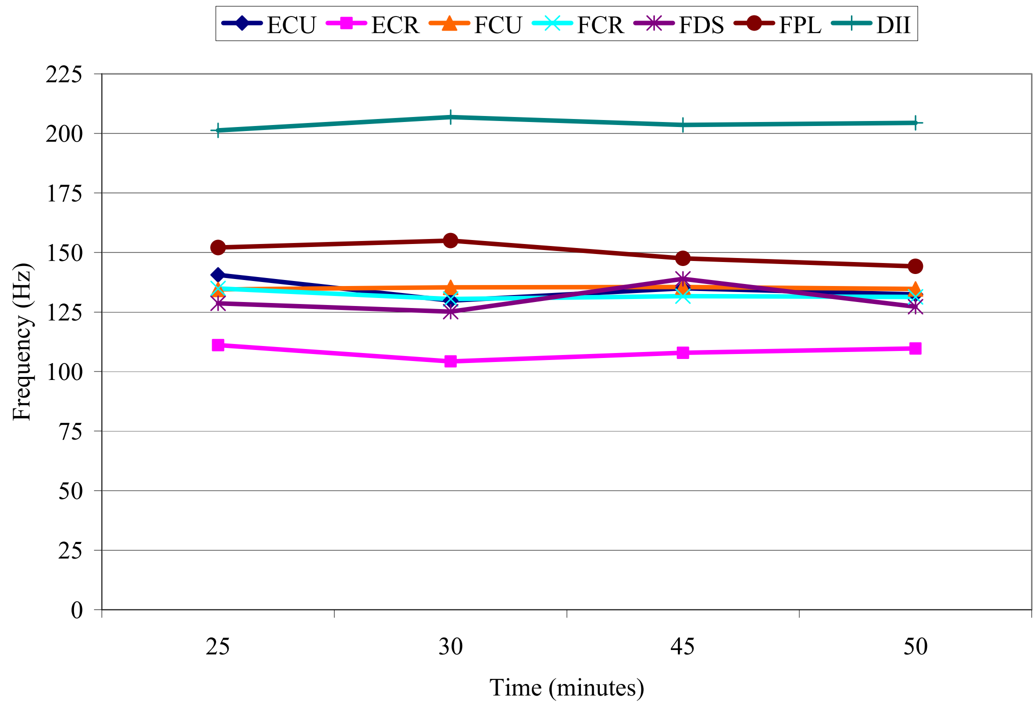


Figure 4.2: Median power frequencies over lateral pinch intervals of seven different forearm muscles during the combination trial. The values are mean of all subjects

Amplitude probability distribution functions (APDF) were completed for each trial and values for the static (10^{th}), dynamic (50^{th}), and peak (90^{th}) were calculated (Jonsson, 1978). The activity levels at the static and dynamic percentiles are predominately below 5.0% MVC; the analysis has focused on the peak activity levels for each muscle, and is listed in Table 4.3. In order to combine group LP and group PG it was by matching the first interval power grip contraction of group PG, with the second interval of power grip for group LP.

An average APDF for all seven muscles in power grip and lateral pinch, over all time intervals, are in Figure 4.3 and Figure 4.4. Although these two figures are averages of one minute intervals for each testing period it can be assumed that with the selected duty cycle (25%) the slopes would steep and the graphs would look similar. Jonsson (1978) report that for long-lasting intermittent activity should not exceed 10 to 14%MVC, as indicated in Figure 4.3 and Figure 4.4 the activation is predominately below this level, and can be considered within these guidelines. Therefore, the subjects are correctly reading and following instructions, and the demands of these two tasks were within acceptable levels.

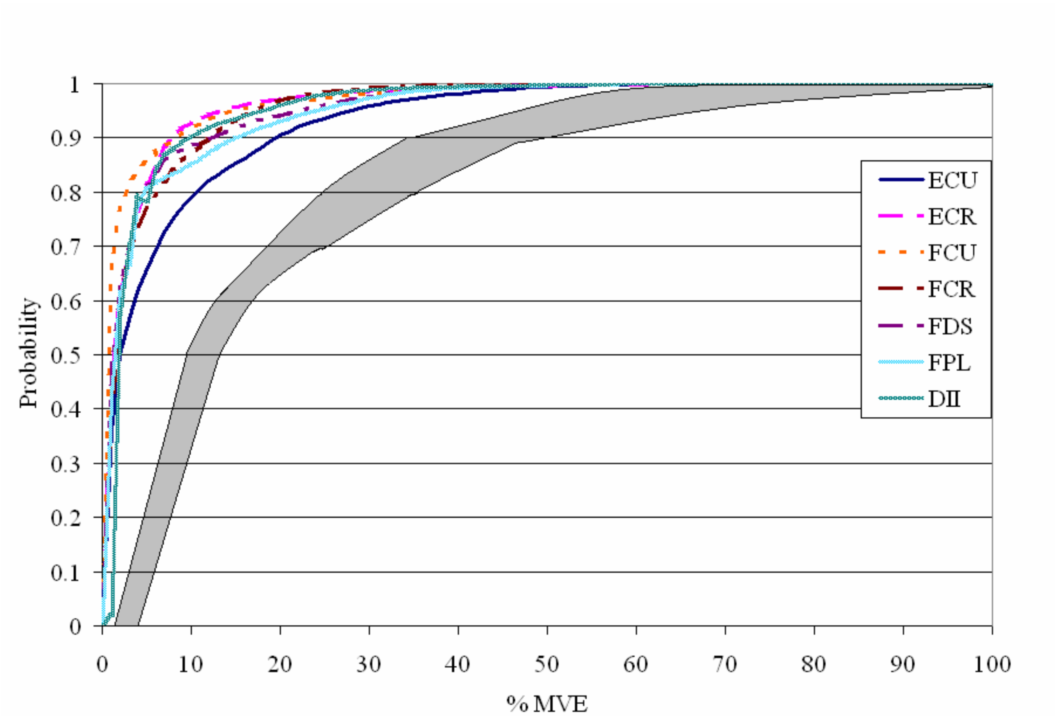


Figure 4.3: Average Amplitude probability distribution function of all power grip intervals for seven different forearm muscles during combination trial. Grey shaded area represents acceptable limits outlined by Jonsson (1978).

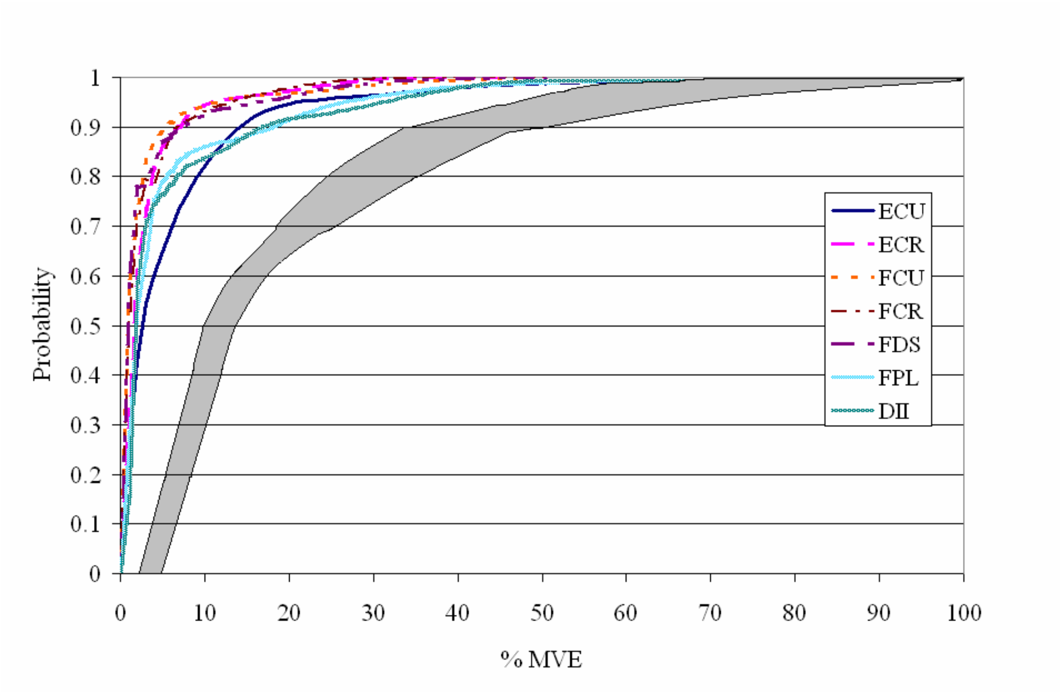


Figure 4.4: Average Amplitude probability distribution function of all lateral pinch intervals for seven different forearm muscles during combination trial. Grey shaded area represents acceptable limits outlined by Jonsson (1978).

Table 4.3: Peak (90th percentile) electromyography activity of seven forearm muscles measured, with reported standard deviations for combined group LP and group PG (n=14). Normalized to maximum activation during power grip and lateral pinch exertions.

Task	Power grip		Power grip		Power grip	
Time (minutes)	15	20	35	40	55	60
ECU	**19.45** *(12.64)*	**19.48** *(14.86)*	**18.20** (12.68)	**22.97** *(13.60)*	**19.89** *(10.36)*	**19.05** *(10.05)*
ECR	**10.57** *(12.73)*	**12.09** *(15.05)*	**10.51** *(11.84)*	**10.23** *(9.798)*	**10.08** *(7.645)*	**10.59** *(9.714)*
FCU	**9.580** *(10.24)*	**12.21** *(13.30)*	**9.700** *(10.38)*	**11.34** *(12.55)*	**10.68** *(12.09)*	**10.81** *(11.42)*
FCR	**12.41** *(7.971)*	**14.13** *(10.76)*	**10.22** *(8.331)*	**11.82** *(8.069)*	**11.07** *(7.462)*	**11.10** *(7.404)*
FDS	**12.76** *(9.967)*	**14.83** *(11.89)*	**12.46** *(11.62)*	**14.41** *(14.23)*	**13.76** *(13.13)*	**13.28** *(11.34)*
FPL	**16.25** *(10.97)*	**18.05** *(14.24)*	**14.34** *(10.87)*	**17.53** *(13.94)*	**15.69** *(11.31)*	**15.45** *(11.51)*
DI-I	**13.27** *(14.68)*	**13.90** *(10.48)*	**9.896** *(7.774)*	**10.97** *(9.003)*	**9.204** *(7.541)*	**10.55** *(8.244)*
Task	Lateral pinch		Lateral pinch			
Time (minutes)	25	30	45	50		
ECU	**16.52** *(16.28)*	**17.18** *(17.42)*	**16.39** *(12.67)*	**14.18** *(11.14)*	*When combining groups the time shifts resulted in two synchronized epochs of data*	
ECR	**8.188** *(7.345)*	**8.866** *(7.769)*	**8.707** *(11.84)*	**8.257** *(7.638)*		
FCU	**8.536** *(11.60)*	**9.027** *(13.53)*	**8.322** *(10.38)*	**6.919** *(7.811)*		
FCR	**7.814** *(7.731)*	**8.651** *(9.274)*	**7.729** *(8.331)*	**5.982** *(4.878)*		
FDS	**9.352** *(10.62)*	**10.33** *(11.62)*	**9.468** *(11.62)*	**8.660** *(7.874)*		
FPL	**17.62** *(15.32)*	**18.12** *(16.33)*	**17.43** *(10.87)*	**15.89** *(11.29)*		
DI-I	**20.19** *(14.72)*	**19.93** *(14.00)*	**20.04** *(7.774)*	**19.29** *(13.15)*		

The extensor activity showed similar amplitude across both power grip and lateral pinch, as indicated in graphical comparison of peak activation for both ECU, ($p=0.498$, Figure 4.5) and to a lesser extent ECR ($p=0.235$, Figure 4.6). There is a trend in the extensors of slightly higher activations during power grip, indicating a role of compressive force generator in the power grip, in accordance with Long (1970) hand control theory. Increased extensor activity in power grip outlines a need for increased stabilization against the increased finger flexion moment. The extensor activity during the lateral pinch intervals indicate the supportive role of this muscle group to stabilize the wrist to resist the moment produced by finger flexion.

The extensor muscles show a trend of having higher activation than the flexors (Table 4.3). Mogk and Keir (2003b) noted increased activity of the extensors during low and mid-level activity, which could possibly explain this trend of increased extensor activity at these low activation levels. The increase activation in the extensors is also noted in other studies in other occupational settings, including keyboarding, mock drilling tasks, and manufacturing mock ups (Wells *et al.*, 1990; Wells *et al.*, 1992; Jacobson *et al.*, 1998; Greig, 2001; Cort *et al.*, 2006). Therefore the trend of increased activity level of the extensors is to be expected and in comparison to the extensor activity of 14%MVE reported in the manufacturing studies of Wells *et al.*, (1992), these results are within reasonable occupational limits.

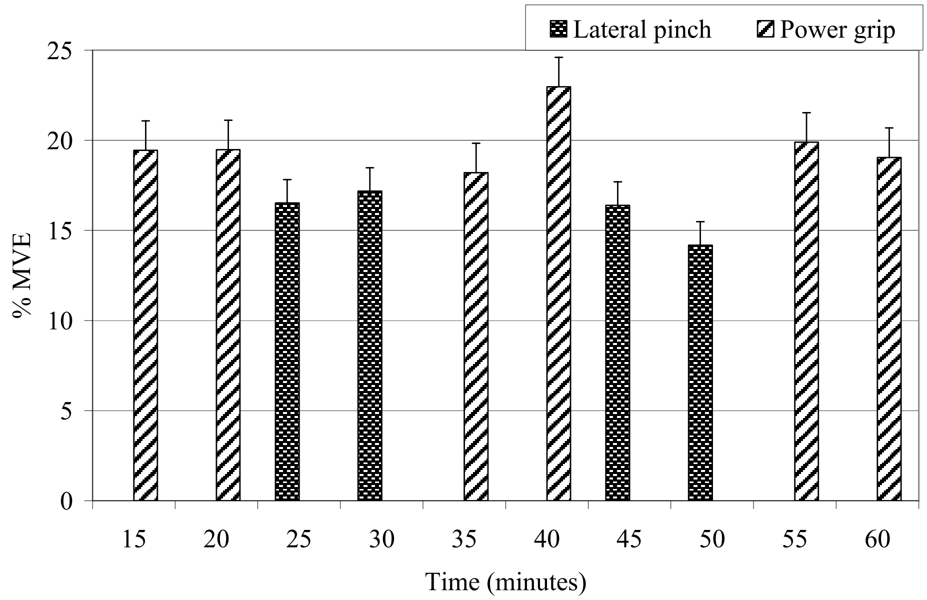


Figure 4.5: Comparison of 90th percentile for ECU for lateral pinch and power grip in the combination trials (n=14), p-value = 0.498. Note: Error bars represent ± 1 standard deviation.

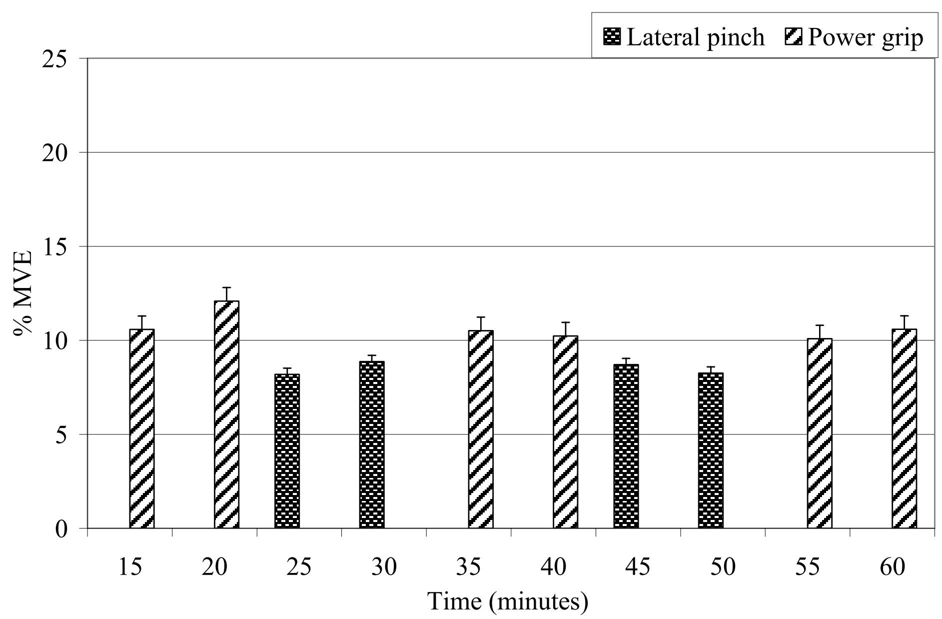


Figure 4.6: Comparison of 90th percentile for ECR for lateral pinch and power grip in the combination trials (n=14), p-value = 0.235. Note: Error bars represent ± 1 standard deviation.

FCU and FCR appear to have a trend to increased activation during the power grip (p=0.526, p=0.063 respectively) suggesting that these are the compressive force generators for the power grip, and are less prominent during the lateral pinch intervals (Table 4.3, Figure 4.7, Figure 4.8).

This apparent lower flexor activation during the lateral pinch, could be considered a possible 'rest' period for these muscles. Hagg and Milerad (1997) noted that FCU had a more dynamic activity pattern in automotive assembly, indicating that the flexors have this potential of creating a synergy, although this did not exhibit statistical significance. The flexor pattern is the opposite compared to the DI-I (Figure 4.9). The DII recorded high activity during lateral pinch, in comparison to power grip intervals (p=0.013). This is to be expected because of this its predominant role in abduction of the 2nd digit (Long, 1970).

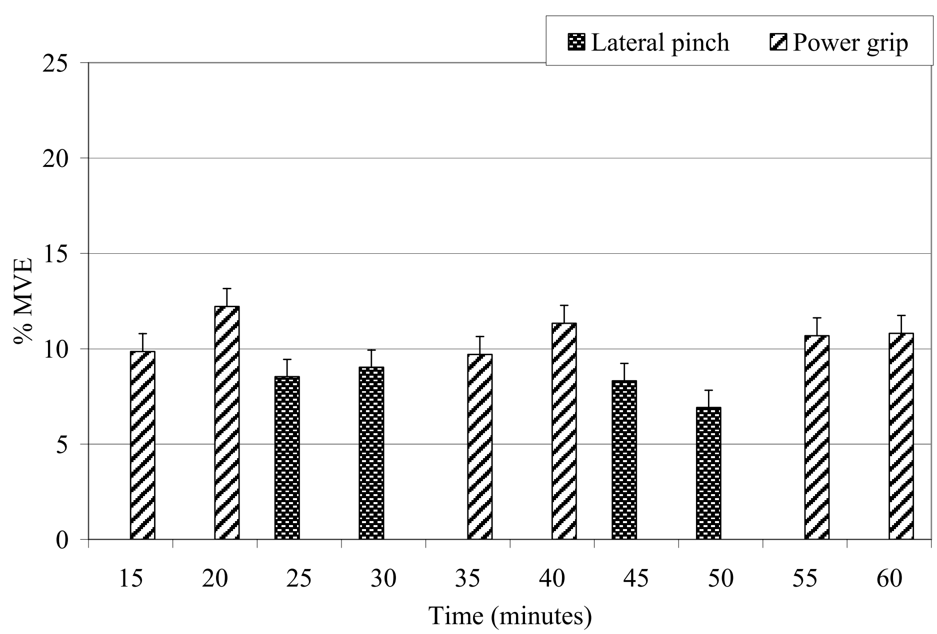


Figure 4.7: Comparison of 90th percentile for FCU for lateral pinch and power grip in the combination trials (n=14), p-value = 0.526. Note: Error bars represent ± 1 standard deviation.

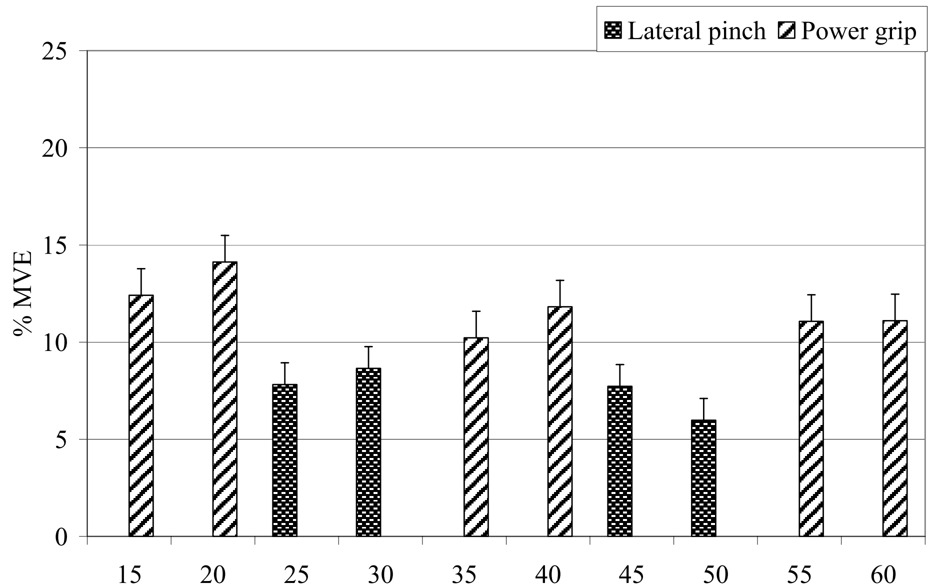


Figure 4.8: Comparison of 90th percentile for FCR for lateral pinch and power grip in the combination trials (n=14), p-value = 0.063. Note: Error bars represent ± 1 standard deviation.

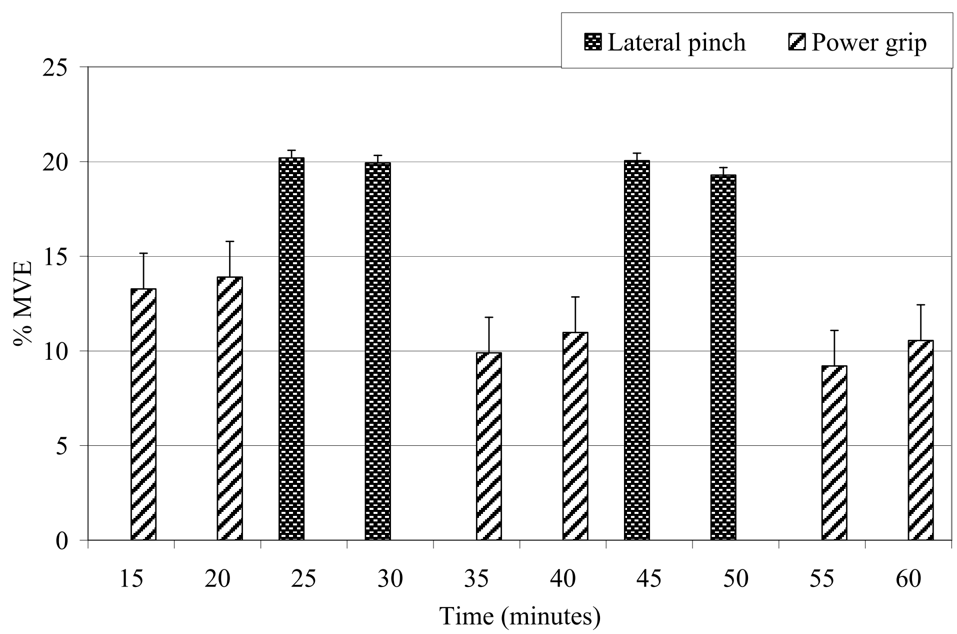


Figure 4.9: Comparison of 90th percentile for DI-I for lateral pinch and power grip in the combination trials (n=14), p-value = 0.013. Note: Error bars represent ± 1 standard deviation.

There was no significant difference in activation between power grip and lateral pinch for FDS ($p = 0.299$). FDS appears to have slightly higher activation in the lateral pinch intervals then FCR and FCU (Figure 4.10). This activity, can possibly be used maintain the lateral pinch posture, with flexion in the 3rd to 5th digits, as indicated in Figure 2.1. Long (1970) reported FDS has pronounced activity when the proximal metacarpal-phalangeal joint and proximal interphalangeal joints are flexing without flexion of the distal interphalangeal. Therefore this activation is not necessarily for grip force but to maintain a semi flexed fingers.

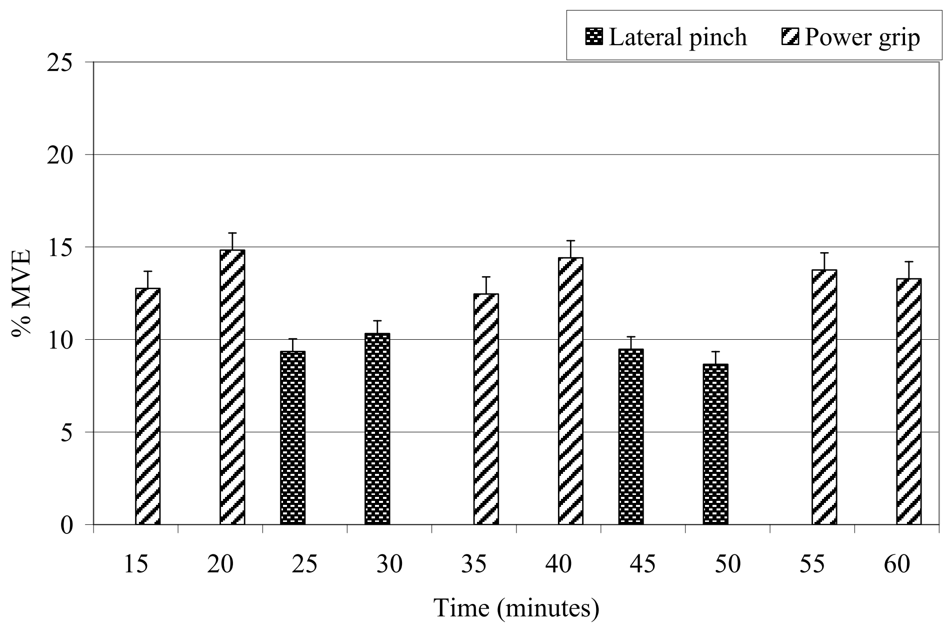


Figure 4.10: Comparison of 90th percentile for FDS for lateral pinch and power grip in the combination trials (n=14), p-value = 0.299. Note: Error bars represent ± 1 standard deviation.

FPL was selected in order to represent thenar muscle activity. This avoids encumbering placement of electrodes on the hand. Activation is constant throughout the rotation trial ($p=0.586$). This is corresponding to the theories suggested by Long (1970), the muscle activity of this muscle is similar between the pinch and power grip (Figure 4.11) indicating a role of the thenar muscles in compressive forces. These compressive forces can be from several different thenar muscles. In power grip this includes opponens pollicis, abductor pollicis, and flexor pollicis brevis. Whereas in lateral pinch the thenar muscles are: adductor pollicis, opponens pollicis, and flexor pollicis brevis (Long, 1970).

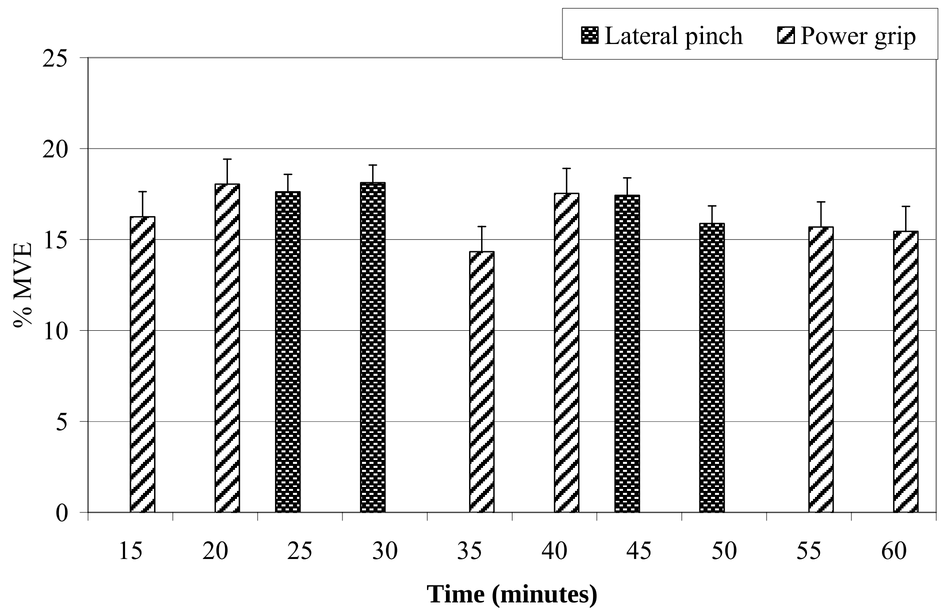


Figure 4.11: Comparison of 90th percentile for FPL for lateral pinch and power grip in the combination trials (n=14), p-value = 0.586. Note: Error bars represent ± 1 standard deviation.

In conclusion an alternating activity between the compressive force generators of power grip (finger flexors) and lateral pinch (DII) is noted (not significant), and extensor activity is required throughout the trial to stabilize the wrist and fingers. There was no significant difference, for the majority of muscles, between activation of lateral pinch and power grip. Flexor activation is needed to maintain the lateral pinch posture of the other digits (3rd to 5th).

Therefore, there is only a small amount of muscle activity trade off occurring between lateral pinch and power grip. The forearm has tightly bundled muscles combined with low activation levels that can result in cross talk contamination. Mogk and Keir (2003a) determined that surface EMG of the forearm could have 50% of a common signal for the extensors, and up to 60% common signal for the flexors. In a comparison study of indwelling to surface EMG by Jacobson *et al.*, (1998), it was determined that peak activation calculated by ADPF has good agreement between surface and indwelling in ED, ECU, FCU and FCR. Therefore broad sweeping statements about clear differences within extensors or flexors should be avoided, but surface EMG can still be considered a good measurement of muscle group activity

4.3 Forces

An example of raw forces and calibrated forces is shown in the Appendices (page 70). Comparison between group LP and group PG for lateral pinch alone (p=0.651), and power grip alone (p=0.383) trials are in Figure 4.12 and Figure 4.13. There is no difference from group LP and group PG for single grip trials, and therefore have been grouped together for force analysis. This similarity in the selected forces of the alone trials (Figure 4.12 and Figure 4.13) remove any speculation that there is a difference in the interpretation of instructions between the two groups, thus avoiding the scenario outlined Gamberale *et al.*, (1987).

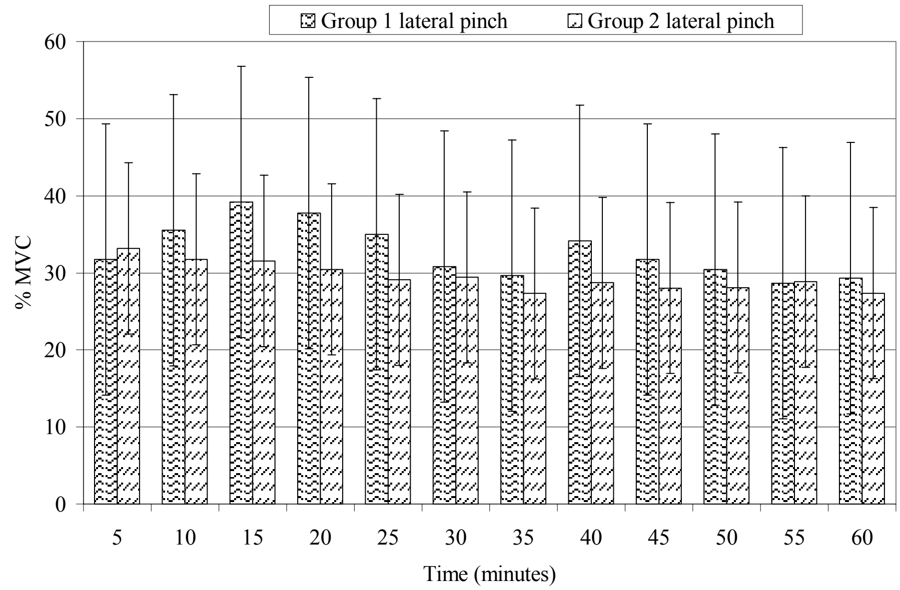


Figure 4.12: Comparison of selected forces for lateral pinch alone trial for group LP and group PG (n=14), p-value = 0.651.Error bars represent ± 1 standard deviation.

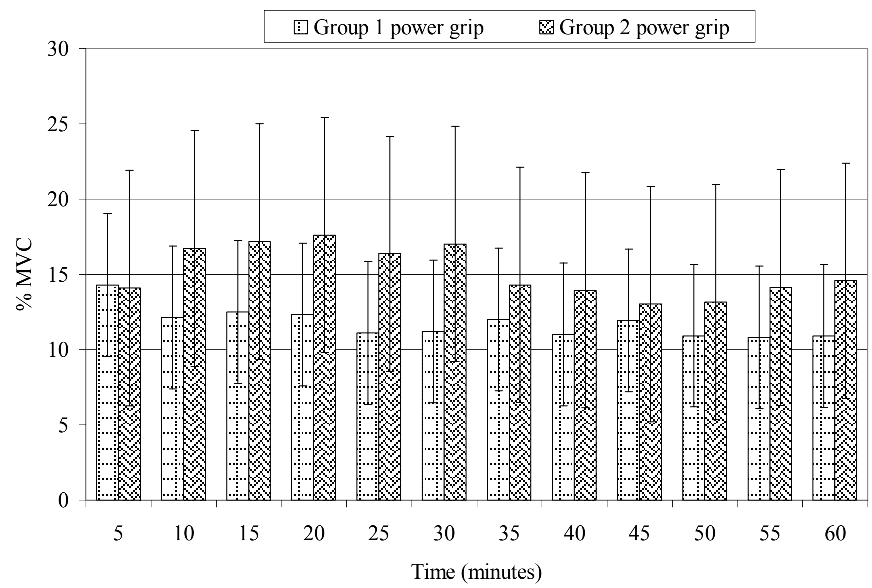


Figure 4.13: Comparison of selected forces for power grip alone trial for group LP and group PG (n=14), p-value = 0.383. Error bars represent ± 1 standard deviation.

Overall, average selected forces are 13.47 ± 6.66% MVC for power grip and 31.16 ± 14.77%MVC for lateral pinch during the alone trials. A stabilization trend is noted in both groups; especially in the last twenty minutes of each alone trial. This suggests that subjects are consistently adjusting back to their acceptable force values after each readjustment, thus adequate training can be assumed along with consistent instruction interpretation.

There are no significant differences within groups over the entirety of the 60 minutes within any trial (Figure 4.12, Figure 4.13, Figure 4.14). This point towards no fatigue being felt to alter the force selection, thus agreeing with the constant median power frequencies reported, as well as the steady activation of the muscles over the each power grip and lateral pinch interval.

To combine group LP and group PG the first interval power grip contraction of group PG was matched with the second interval of power grip for group LP. Figure 4.14 is a graphical comparison between combination and one-grip trials. There was no difference between any scenarios tested with respect to the forces selected for the same grip, thus rotation had little to no effect on the selection of forces.

There was a significant difference between the forces selected for power grip and the forces selected for lateral pinch ($p=0.001$). This significance is shown marked in Figure 4.14 where group A (power grip intervals) are not significantly different from each other, but are significantly different from group B (lateral pinch intervals), and vice versa. It can be concluded that people prefer different force levels for the different grips; however the rotation did not affect the selection of forces for the grips.

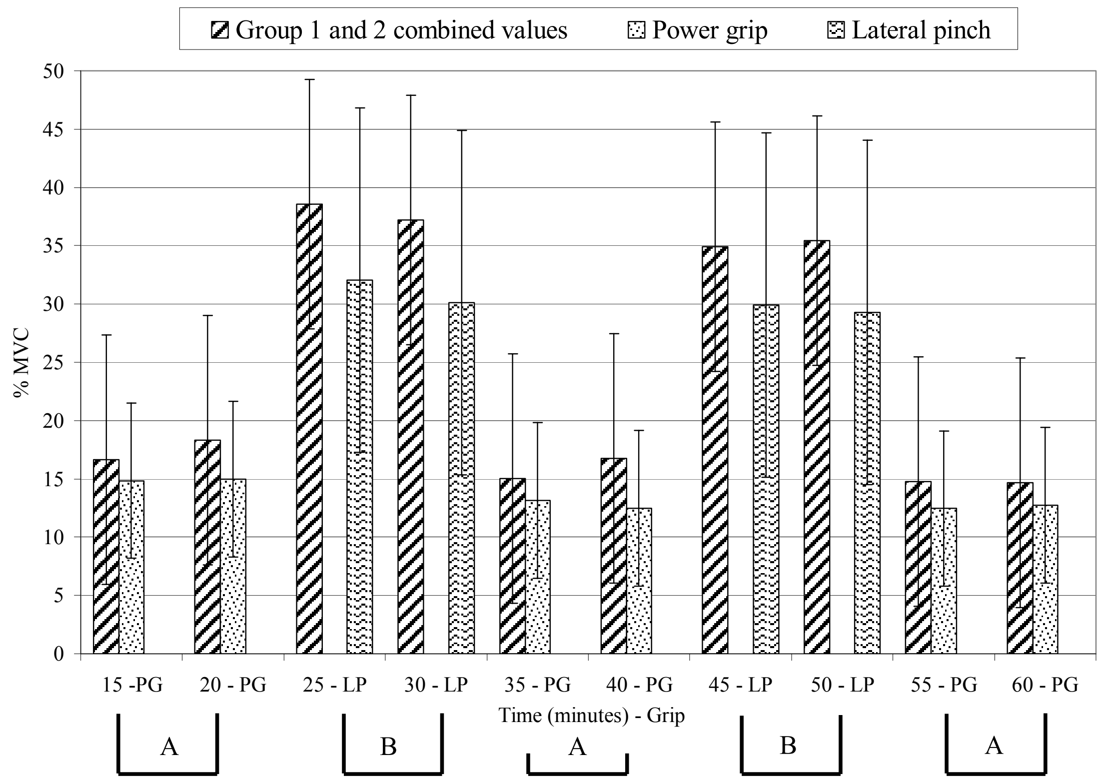


Figure 4.14: Comparison of selected forces for combination trial to power grip alone (PG) and lateral pinch alone (LP) (n=14), p-value = 0.001. Error bars represent ± one standard deviation. Significance is marked in groups of A and B, refer to text for explanation.

Several conjectures can be made about the finding that the differences between the same grips with and without rotating were small and not significant. First, this is contradictory to the relief that occurred during a fatiguing protocol (McFall and Wells, 2007). They found that by rotating grips between lateral pinch and power grip maximum strength could recover by upwards of 25%MVC. This effect may not be strong enough to cause a difference between grips at low, occupational levels of activity.

A possible reason why there is no difference between combination and alone trials is that regardless of what grip is performed, selected forces are limited by some underlying factor. Ciriello *et al.*, (2001) suggest there is a ‘limiting factor’ that pushes subjects towards a particular level, and therefore they would not select a higher level, regardless of what else is occurring. Therefore in this scenario, the subjects could be limited by this set factor in the power grip and lateral pinch alone, and would not be enticed to work at a significantly increased level when rotating. It is unclear what is this driving this factor might be; it could be psychological, physiological, biomechanical or more than likely a combination of the above. Perhaps it is the previously mentioned high activity in the extensors. These muscles are ‘on’ for the entirety in both grips and could be a limiting factor as a generator of force for power grip, and for stabilization during lateral pinch. Another possible limiting factor is the contact/ pressure points between the dynamometer and the hand. This is further discussed in Section 4.5. Further investigation is warranted to outline and define any limiting factor.

There was a large difference in normalized accepted forces for power grip, average 16%MVC, and for lateral pinch, average 36.4%MVC. Within the literature, numerous researchers have utilized psychophysics to determine maximum acceptable forces for different hand grips. Table 4.4 is a comparison of the selected forces selected in this study to other studies. Although a direct comparison cannot be made to many of these studies, similar values are recorded. Grip strength will decrease when involving: deviations from neutral, increased repetition rate and duty cycle (Dahalan and Fernandez, 1993; Kim and Fernandez, 1993; Snook *et al.*, 1995; Abu-Ali *et al.*, 1996; Snook *et al.*, 1997; Klein and Fernandez, 1997; Mital and Kumar, 1998, Snook *et al.*, 1999; Ciriello et al., 2001; Moore and Wells 2005). Lower forces are expected when involving wrist movement, deviations, and decreased cycle times. Therefore it is expected that the results from this study would be higher than the Mutual Liberty group with 15 repetitions per minute and the involvement of deviated wrist motions (Table 4.4).

The Fernandez group reported on maximum acceptable frequencies. Their subjects were instructed to select an acceptable frequency, with a set duration and contraction level. To compare, the frequency selected closest to 5 repetitions per minutes is considered closest to the values reported here. This indicates that the values at 50%MVC for lateral pinch (Klein and Fernandez, 1997) are the closest to this study's lateral pinch values (36.4%). Also Dahalan and Fernandez (1993) repetition rate of 5.77 and per minute at 30%MVC, respectively, are the closest to this study's power grip values of 16%MVC. Overall there is an apparent trend to select higher maximum acceptable forces, in %MVC, for pinches as opposed to power grips. This trend was continued within this study.

Table 4.4: Comparison of maximum acceptable forces from this study to previous reported values. Power grip values are shaded.

Study	Sample Size	Gender	Task, duty cycle, grip	Maximum acceptable force/ tolerance level N (%MVC)			
McFall (2007)	14	♂	Lateral pinch	*32.1 (33.6%MVC)*			
		♀		*21.4 (28.7 %MVC)*			
		♂	Power grip	*48.5 (10.6%MVC)*			
		♀		*45.3 (16.3%MVC)*			
		♂	Combination lateral pinch	*32.1 (32.6%MVC)*			
		♀		*28.2 (37.6%MVC)*			
		♂	Combination power grip	*52.9(11.7%MVC)*			
		♀		*47.2 (19.1%MVC)*			
Klein and Fernandez (1997)	12	♂	Lateral pinch for 3 second duration at:	*Maximum acceptable frequency (per minute)*			
			50%MVC	*5.09(±1.64)* Closest in relation to this study set up*			
Potvin *et al.*, (2006)	24	♀	Pulp pinch (for electrical connectors) 7/min repetition rate	*27.4 (47.0%MVC)*			
Dahalan and Fernandez (1993)	12	♀	Power grip, determining maximum acceptable frequency for 3 second duration at:	*Maximum acceptable frequency (per minute)*			
			30%	*5.77* Closest in relation to this study set up*			
Snook *et al.*, (1995); Snook *et al.*, (1997); Snook et al., (1999); Ciriello *et al., (2001)*	11 16 20 31	♀ (75-ile)	15/min repetition rate	(1995)	(1997)	(1999)	(2001)
			Power grip with flexion	*23.2*			*7.28N*
			Power grip with extension	*13.6*			*7.53N*
			Power grip with ulnar deviation		*14.0*		*4.21N*
			Pinch with flexion	*13.2*			
			Pinch with extension			*25% MVC*	

4.4 Ratings of Perceived Discomfort

Ratings of perceived discomfort were recorded throughout each trial at the end of each ten minute interval. There is no significant difference between ratings of perceived discomfort for Group LP and Group PG, and therefore results are grouped together (p=1.000) (Figure 4.15). No significant difference were noted between combination trial or in alone trials of power grip or lateral pinch (p=0.119) (Figure 4.16). Again, this indicates that subjects were following instructions to avoid fatigue and discomfort. The trend is for lower RPD for the combination trial at the completion indicating that subjectively the combination trial was considered an easier, less taxing trial. This is especially evident in comparing lateral pinch alone to the combination trial (Figure 4.16).

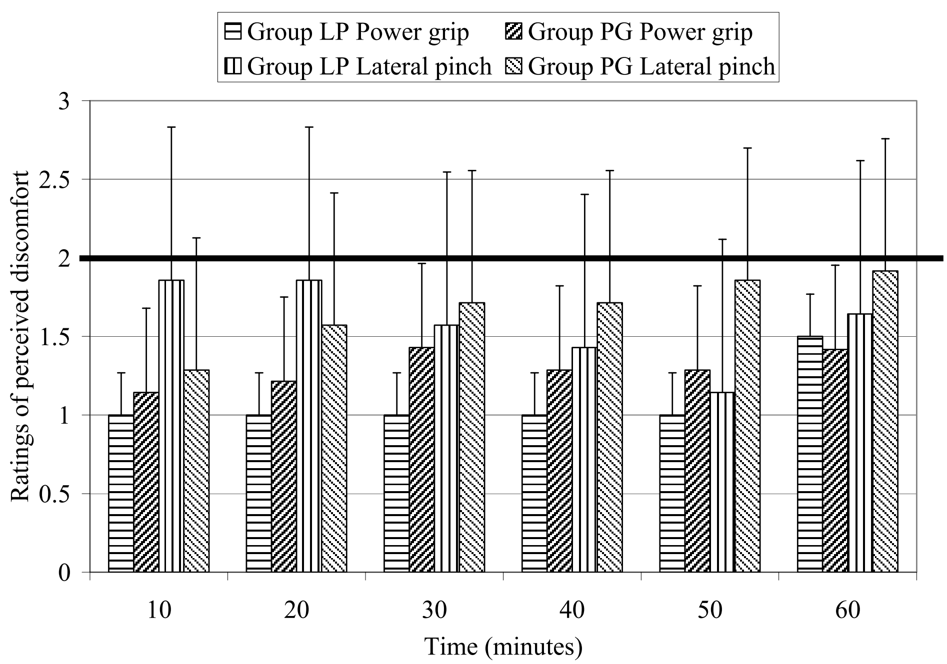


Figure 4.15: Comparison of group LP and group PG ratings of perceived discomfort (7 point scale) for power grip alone, and lateral pinch alone trials. (p=1.000, n=14).

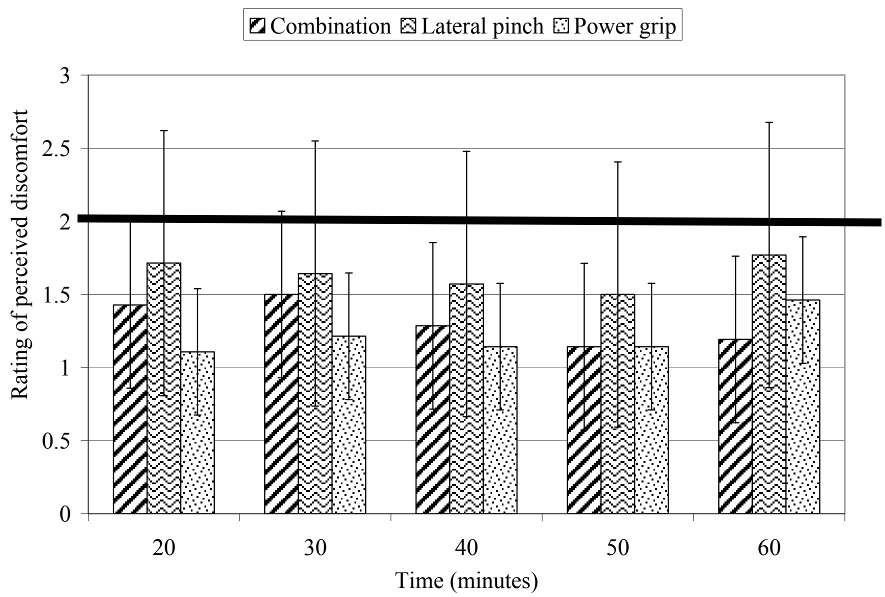


Figure 4.16: Comparison of combination trial ratings of perceived discomfort to lateral pinch and power grip alone trials (7 point scale) (p=0.119, n=14). Weighted line indicates when reminder about instructions would occur.

4.5 Discomfort diagrams

Discomfort is segregated into three categories of soreness, stiffness, and numbness. Figure 4.17 represents the total number of categories that were marked for each trial, expressed as a fraction from the possible 18 categories in six sites, anterior and posterior digits, hand/wrist, and forearm. The expression of this data is similar to the methods used by Moore (1999), and Moore and Wells (2005). The low numbers of reported checked categories indicates that subjects were following the instructions to avoid creating discomfort for themselves. Both the power grip alone and lateral pinch alone trials have an increased number of checked categories than either combination trials (Figure 4.17). The stiffness categories are the most checked when compared to the other categories. This is possible because subjects were requested to maintain the gripping posture for the entire trial length of 60 minutes, which could be sufficient to increase stiffness, but not increase soreness or numbness

The distribution of the total number of categories checked for each of the possible locations for each trial is reported in Figure 4.18. Most discomfort marks are about the thumb and index finger area on both the anterior and posterior sides. These results coincide with those of Fransson-Hall and Kilbom (1993) and Moore (1999) who determined that the most sensitive areas are the thumb, and skin fold between the thumb and finger area.

The increased marking in this area is also to be expected because of this being part of the contact area between the hand and dynamometer in both the lateral pinch and power grip. This can be considered a possible limiting factor in the selection of force levels; however since the discomfort markings are predominantly low it is unclear whether this had an effect.

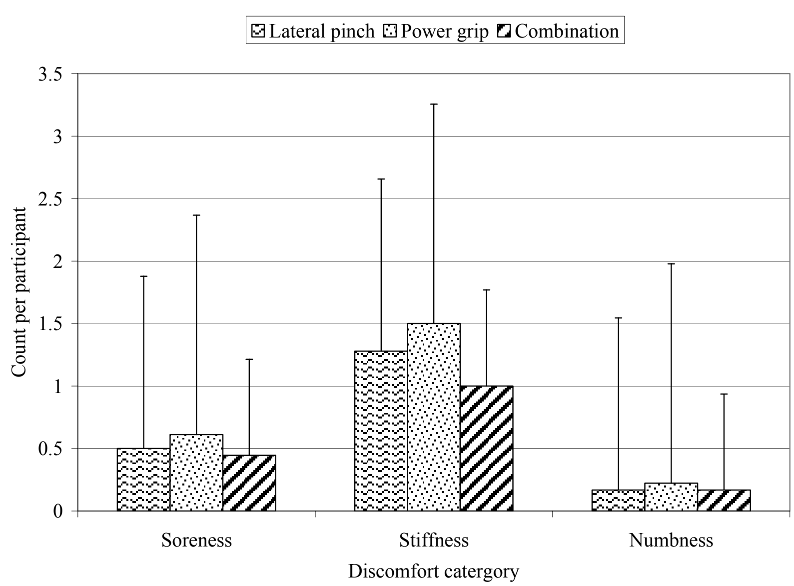
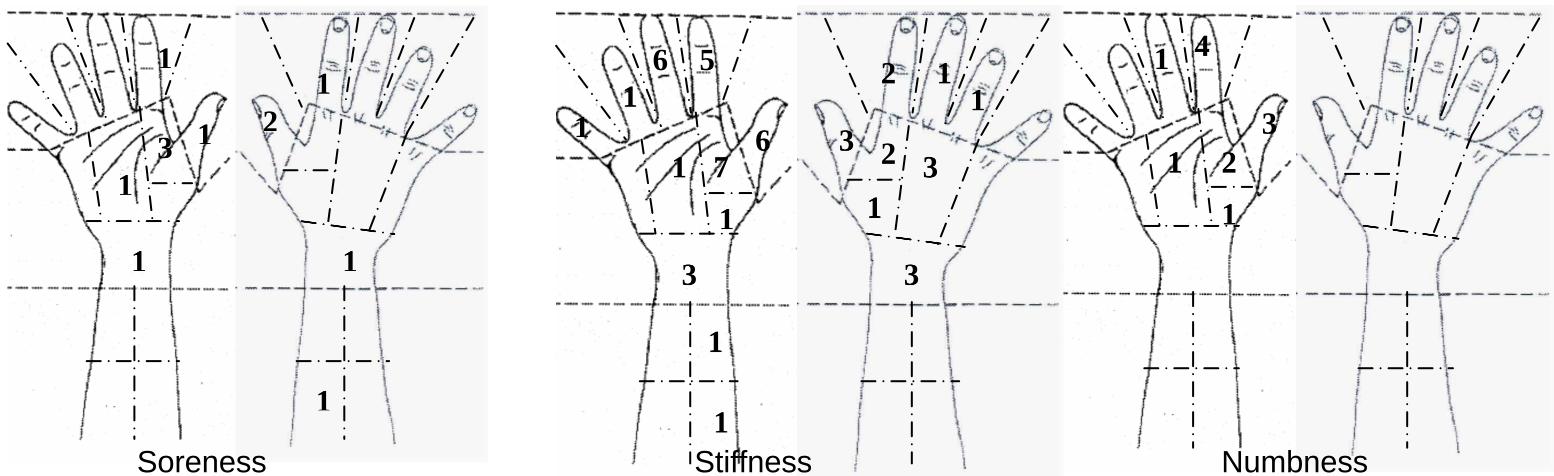
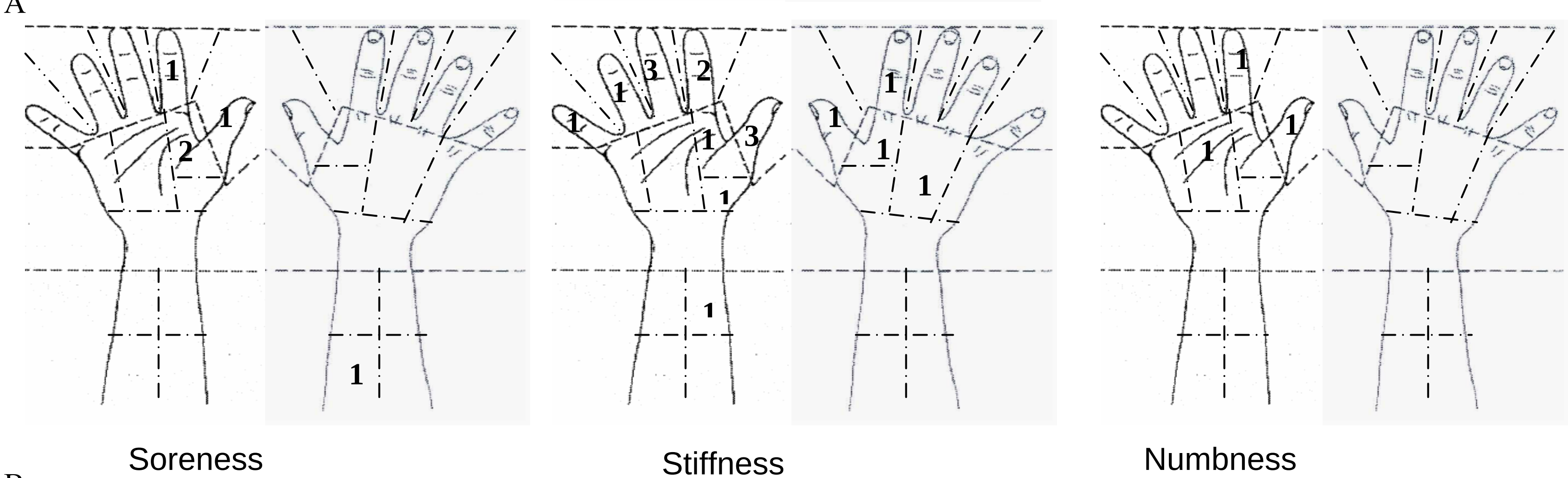


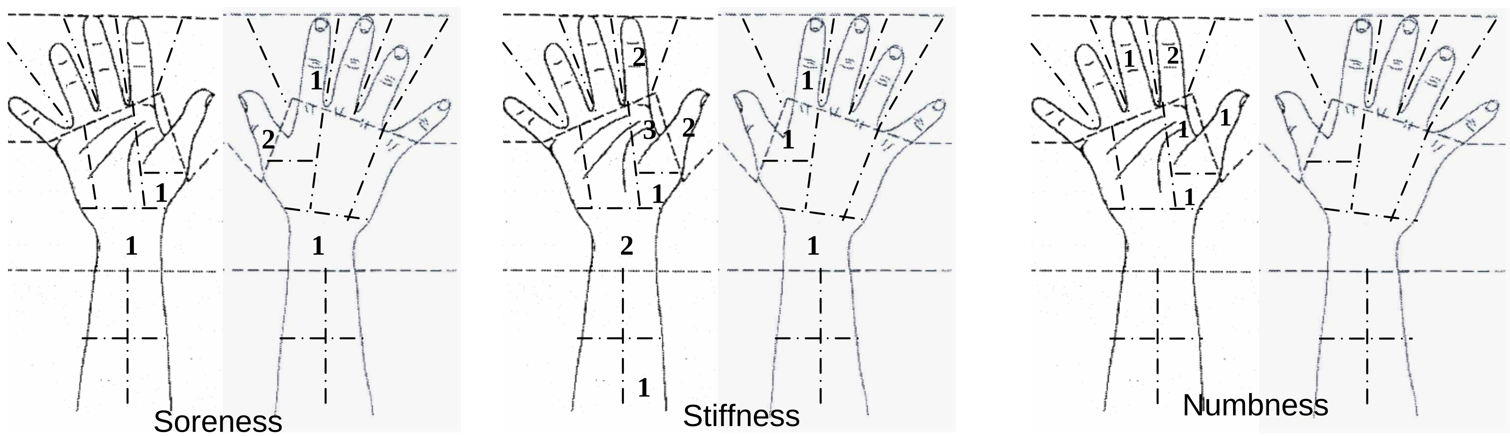
Figure 4.17: Number of discomfort categories checked out of 18 possible sites (anterior and posterior: hand/digits, hand/wrist, and forearm) for three difference categories of: soreness, stiffness and numbness (n=14).


Soreness
Stiffness
Numbness

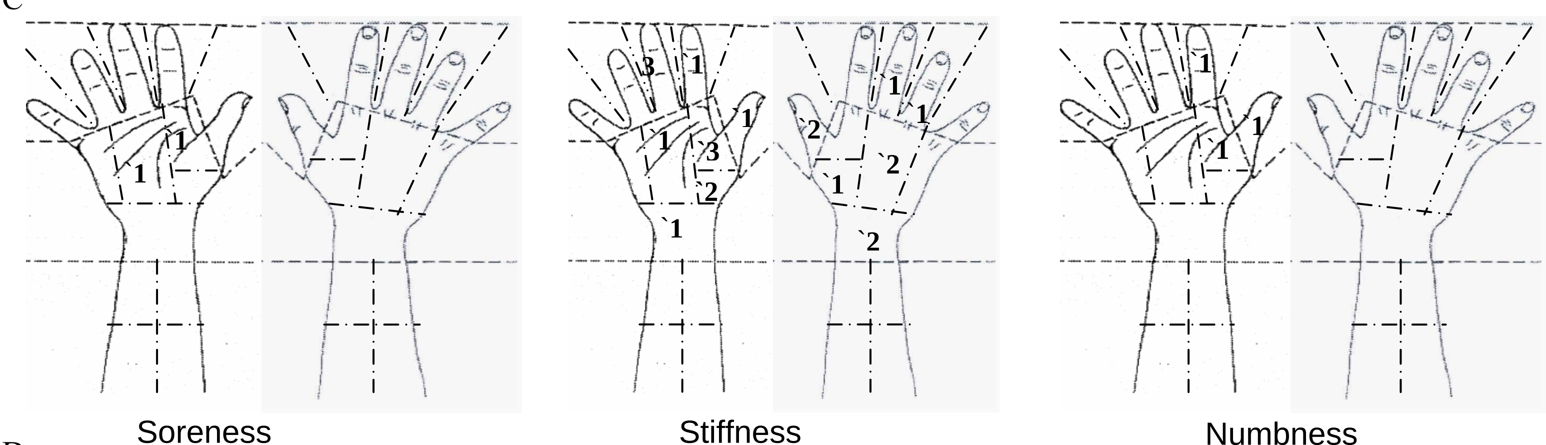
A


Soreness
Stiffness
Numbness

B



C



D

Figure 4.18: Sites of reported discomfort at the completion of the each trial. A) Total count of discomfort markings made over all trials. B) Categories checked at the completion of combination trials. C) Discomfort markings made at completion of lateral pinch alone trial. D) Discomfort markings made at completion of power grip alone trial (n=14).

4.6 Duty Cycle and Cycle time

An example of the timer and a subject's reaction, reflected in force, is graphed in Figure 4.19. The work period was set at 3 seconds, over the 12 second cycle time, thus creating a 25% duty cycle. Figure 4.20 is a comparison of measured contraction times, calculated by the force tracing. There is no significant difference between groups or trials in forces or EMG. The contraction work period calculated from the force trace is 2.98seconds. There was not much difference from the desired actual 3 seconds; therefore subjects were contracting and following the signal correctly.

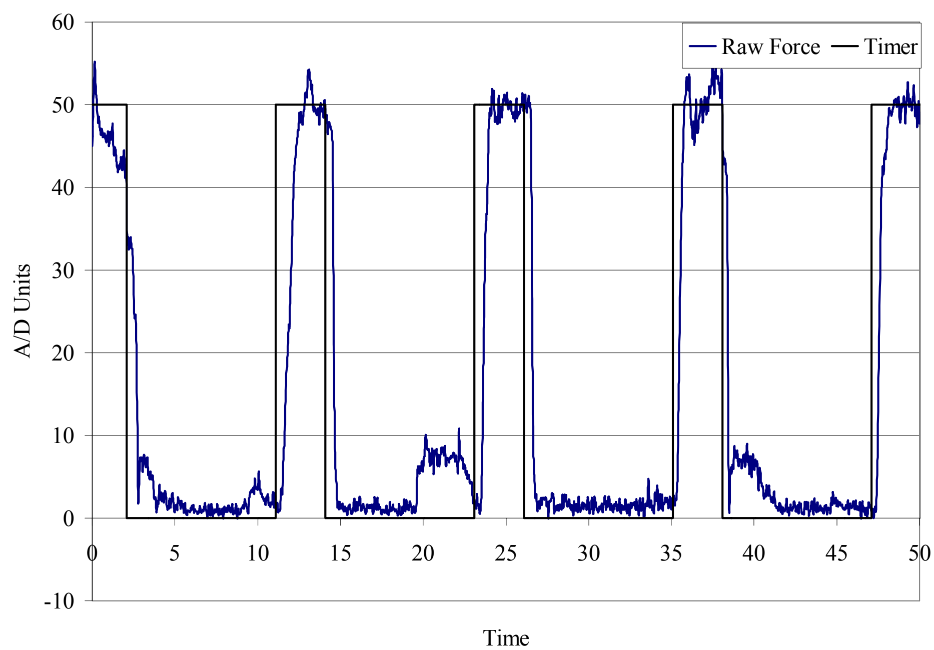


Figure 4.19: An example tracing of the reaction of a subject to the timer recorded by forces. Forces processed by low-pass filtered (dual pass, 4^{th} order Butterworth, cut off 10Hz).

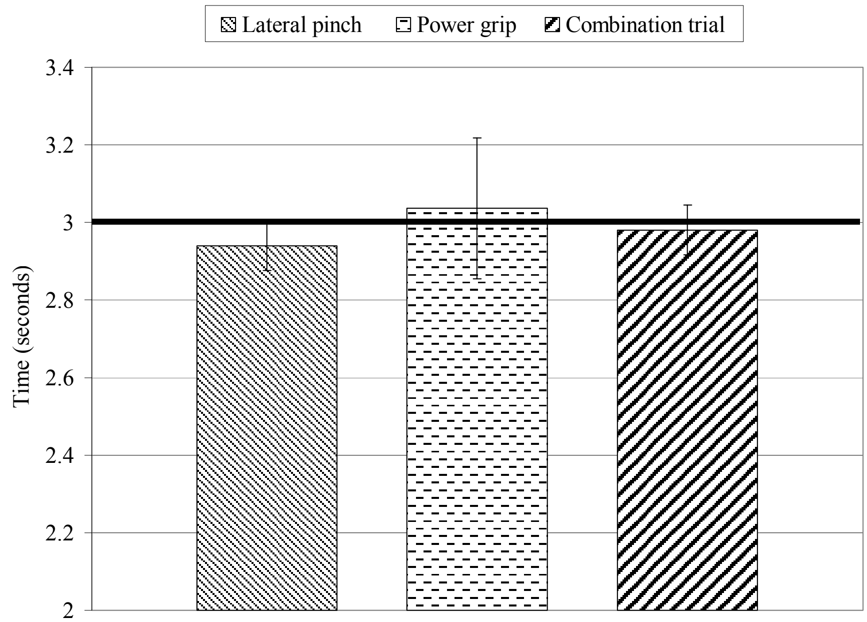


Figure 4.20: Calculated work cycles from force tracings for combination, lateral pinch alone and power grip alone trials (n=14). The line represents the goal of the 3 second work time. Error bar represents ± one standard deviation.

5.0 General Discussion and Conclusions

Many studies have focused on determining maximum acceptable forces and frequencies to aid in job design for guidelines at occupational levels, and studies have also investigated on the effect of a static to dynamic task rotation. Few studies have considered what would occur if rotation was of different grips at occupational levels. The focus of this study was to determine the effects of rotating grips on force selection; and the results from this study were able to answer some of the questions and hypotheses initially posed at the commencement of this study:

- What kind of complementary relationships are there between muscle groups of the forearm and hand?
    - There is potential for a complimentary relationship between the first dorsal interossei and the forearm flexors with respect alternating activity. However regardless of the grip, thenar and extensor muscles are continuously active.
- How different do hand tasks have to be in order to reduce fatigue and discomfort, and alter force selection levels?
    - Hypothesis I: Grip rotation will increase the maximum acceptable forces
        - No significant difference was reported between power grip and lateral pinch alone trials, from the rotating grip trials.

- Hypothesis II: Discomfort will be recorded within the finger and thumb area regardless of rotation or non-rotation trial
  - The most common category marked was stiffness, dispersed about the finger and thumb areas. This indicates that the discomfort was generated by the contact points between the hand and dynamometer but a substantial number were marked on the dorsum of the hands indicating that contact forces were not the only cause of local discomfort.
  - There is a slight difference in subjective ratings when comparing rotation to non-rotation trials, with lower RPD ratings during rotation trials but the effect was not statistically significant.

The results imply that there was no difference in force production in rotation between grips, but what if one considers the relative difference between the combination and alone trials. For lateral pinch the difference is approximately 5%MVC, but with respect to the average selected force for the alone trial of 31.16%MVC this 5% becomes an increase of 16.6%MVC in the capacity of the grip. For power grip the difference of 3%MVC from alone trial average of 13.47%MVC becomes a relative difference of 23%MVC.

During the rotation trials, subjects made comments that it was more 'interesting and fun', and 'it was less boring', and that 'the time when by quicker'; although this information was not systematically collected, it is important to notice that there was a positive feeling towards the rotation. This was also noticed in a study done by Marshall (2006). Her study involved implementing a job rotation system within an automotive seat assembly plant. There was a positive response to implementing the rotation, and the subjects reported that the rotation was easier on the body and that the shift went by quicker (Marshall 2006); which are similar to the sentiment of the participants from this study.

If there is potential for introducing this type of rotation within hand intensive tasks, the opportunity should be taken. The demands of these two tasks can be considered the same because the level selected to work at were self selected, in accordance with the psychophysical method.

Combining the similar task demand with anecdotal positive comments, the small difference in rating of perceived discomfort, and the relative difference in selected forces there is potential for this rotation. This statement is supported by the results from the FFT (with no drop in median power frequency), the consistent return to similar force levels; little ratings of perceived discomfort, and EMG activation deemed within acceptable limits (Jonsson, 1978); all of these point to a safe and occupationally reasonable task. Grip rotation could possibly change mentalities, and have a potential in altering relative force production without dramatically increasing exposure levels.

However, care should be taken to avoid the 'ergonomic pitfall' (Westgaard and Winkel 1996), as there could be a potential for increasing the productivity with grip rotation and so the work rate or required forces to perform the tasks should not be increased. This struggle of increasing production as soon as decreased demand is introduced is an on-going moral problem which requires co-operation from all parties of the company involved.

Within each study there are limitations, as with this study. During a psychophysical study a subject's previous experience is known to affect the levels that they select (Gamberale *et al.*, 1987), but Potvin *et al.*, (2000) determined that with adequate training skilled and unskilled workers would select the same values and this effect could be avoided. It is felt that if individuals were improperly trained a difference would be indicated between initial and final values, which did not occur in this study. Therefore adequate training was provided.

Appropriate psychophysical testing length is contested within the literature. Ciriello *et al.*, (1990) demonstrated that 40 minutes would be accurate for lower frequency tasks and shorter trial times were effectively used by the Fernandez group (Dahalan and Fernandez, 1993; Kim and Fernandez, 1993; Marley and Fernandez, 1995; Klein and Fernandez, 1997). However, other studies have found a difference in selected forces over the duration of a day (Ayoub and Dempsey, 1999; Ciriello *et al.*, 1990**;** Karwowski and Yates, 1986; Mital, 1983; Moore, 1999). For this study it could be that a difference might occur over an entire day. However observing the trends set within the first hour, it is unlikely to cause a difference over a day. A future direction for psychophysical studies would be to focus on appropriate trial lengths.

Another limitation is a subject's interpretation of their instructions. In comparing maximum acceptable force levels, the Liberty Mutual research group, drew comparisons between the same actions within their studies. A significant difference was noted between levels selected by Ciriello *et al.*, (2001) and the previous studies of Snook *et al.* (1995), and Snook *et al.* (1997) (Table 4.5). The researchers go on to suggest that these differences could be driven by the difference in subjects, or their interpretation of the instructions. For this study the trend of power grip being selected at a lower %MVC than the pinches is consistent with what is reported in the literature. It is known that varying testing environments, subject pools, and the interpretation of the instructions could alter results, although this was controlled for it could still be considered.

After completion of this study another post-hoc power analysis was calculated and determined that a sufficient sample size should have been 30 subjects. Considering this result no differences in forces would probably continued however perhaps difference in activation of muscles approaching significance (FDS, ECR) might become significant.

As previously mentioned in section 4.2, EMG of the forearm cannot be discussed without considering contamination from other forearm muscles. Surface EMG has been noted as having a good correlation to indwelling EMG, and therefore can still be used on some superficial muscles (Jacobson *et al.*, 1998). It was felt by the investigators that with careful electrode placement and grouping of extensors and flexors the possible contributions of other muscles can be reduced. The match of the activation patterns with studies using indwelling electrodes supports this position. Also by avoiding making broad within muscle group (extensors or flexors) statements, the limitations of EMG can be controlled.

The cycle time and duty cycle were closely controlled for this study. This is not an accurate representation of the work environment because there is variability present in the workplace. This is supported by Moller *et al.* (2004), who noted a large variance between operator cycle time, and a large between subject and day variance for three occupational tasks. However this variability was avoided by selecting cycle time and duty cycle to mimic a line paced setting (Moore and Wells, 2005; Snook *et al.*, 1995)

These results only consider the hand and forearm region, without considering the possibility that the shoulder, back or neck could influence the selected values and this could be a limiting factor. It was felt that the influences of these areas were addressed by the adjustability of the chair and work station being adjusted to suit each individual.

Further investigations could focus into why there was such a large difference between the maximum acceptable forces of power grip and lateral pinch that were recorded in this study and in the literature. It is known that pinch grips are a risk factor for MSD. Why would individuals select higher percentages of their maximum strength? Another area of focus could be what is contributing to the limiting factor, whether it is psychological, physiological, biomechanical, or any combination of the three. Future investigations should focus on defining the difference required for beneficial rotation and determining whether the benefits of implementing a rotation outweigh the risk of exposing all workers to peak loads.

Studies into differences within grips could continue, perhaps varying postures, for example sitting and standing to understand the influence of other body discomfort on the selection of forces. Deviations in wrist posture should be avoided because it is already known that this will decrease the acceptable force selection. Another possibility is to make the handle more realistic in order to relate to the work environment or involving the hand pushing or pulling within the task to compare values selected to those in the literature.

Overall, this study has shown that there was no direct effect on selected forces when involving a grip rotation. There are potential benefits of grip rotation because of positive feedback, and no noted fatigue between the grips through EMG measures, selected forces or ratings of perceived discomfort. There were positive comments made about the rotation, therefore if there is an opportunity to implement this is should be taken. This was an important first step in determining what level of rotation will increase production, and what level of rotation will be a benefit to the worker in an attempt to lower the propagation of musculoskeletal disorders.

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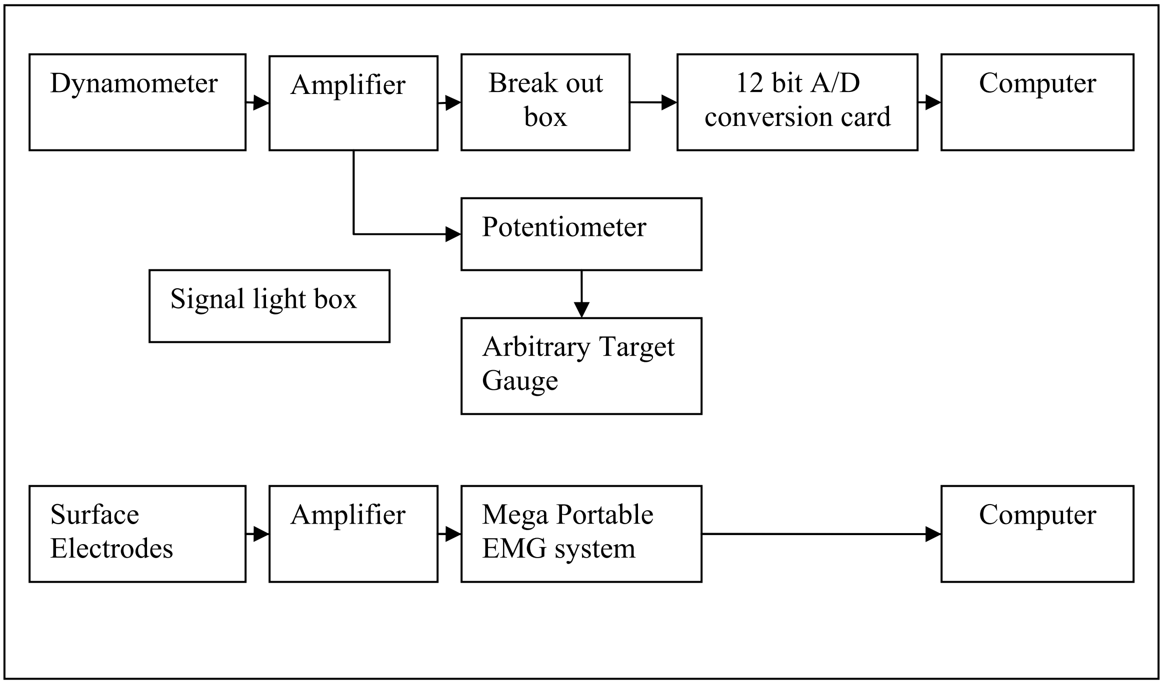
Appendices

A. Equipment Set Up



Box Diagram

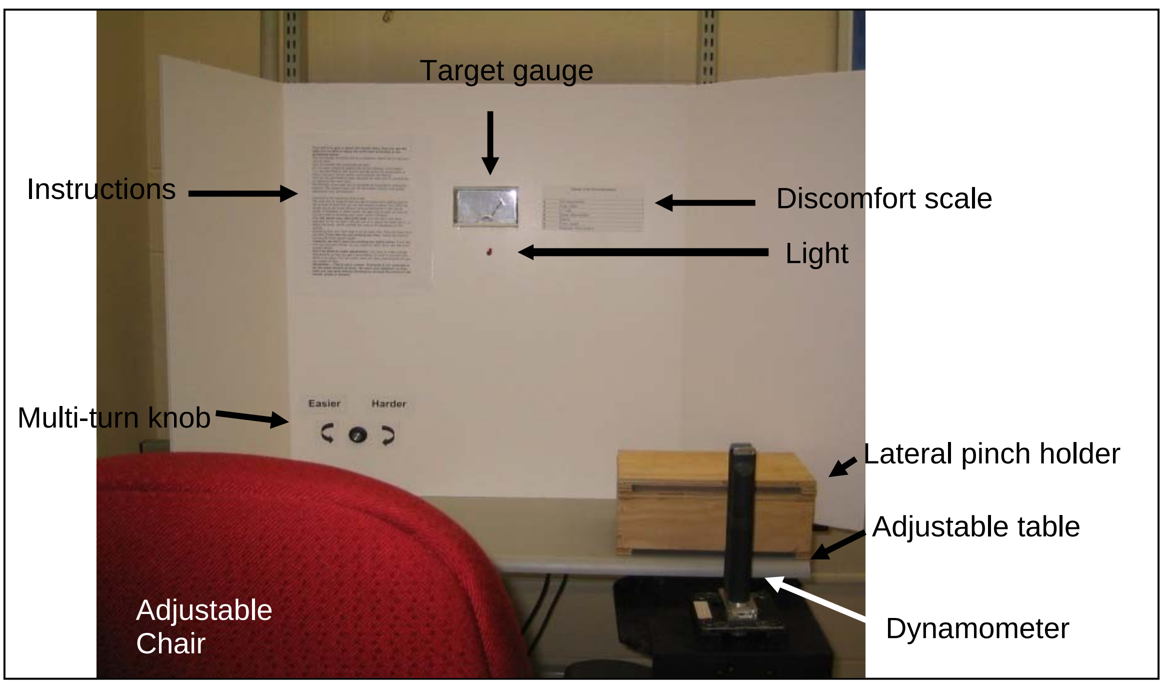


Photo of actual set up

B. Psychophysical Instructions

Based on Ciriello et al. (2001).

Your job is to grip or pinch the handle every time you hear the beep and to adjust the work load according to the guidelines below:
Grip the handle smoothly and at a moderate speed not too fast and not too slow.
Grip the handle only during the red light
Do not apply pressure against the handle between movements.
You are permitted to talk, but do not talk about the experiment, or about how your hands, wrists, and forearms are feeling.
You are not permitted to read, because we want you to concentrate on adjusting the
work load.
We strongly encourage you to complete all movements during the session. We depend
upon you for successful results, and greatly appreciate your participation!

Instructions for Adjusting Work Load
We want you to imagine that you are on piece work getting paid for the amount of work that you do, but working a seven hour shift that allows you to go home without unusual discomfort in the hands, wrists or forearms. In other words, we want you to work as hard as you can without straining your hand, wrist or forearm.
You will adjust your own work load. You will work only when signaled by the red light. Your job will be to adjust the load; that is, to adjust the knob, which controls the amount of resistance on the handle.
Adjusting your own work load is not an easy task. Only you know how you feel.
If you feel you are working too hard, reduce the load by turning the knob toward decrease.
However, we don't want you working too lightly either. If you feel that you can work harder, as you might on piece work, turn the knob toward increase.
Don't be afraid to make adjustments. You have to make enough adjustments so that you get a good feeling for what is too hard and what is too easy. You can never make too many adjustments but you can make too few.
Remember… This is not a contest. Everyone is not expected to do the same amount of work. We want your judgment on how hard you can work without developing unusual discomfort in the hands, wrists or forearm

C. Discomfort Surveys

Based on Snook *et al.*, (1995).

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Participant:______________ Date:________________. Day:________________

RIGHT ARM EVALUATION — Front

Circle the appropriate numbers below for each column.

Fingers and Thumb

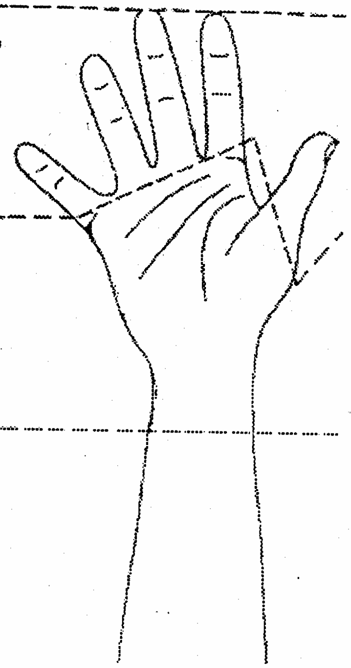
Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Hand and Wrist

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Forearm

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb



Front

Now indicate the location on the drawing. Use:
So for Soreness
St for Stiffness
N for Numbness

Overall Discomfort

1	2	3	4	5	6	7
No Discomfort	Very Little	A Little	Some Discomfort	Much	Very Much	Extreme Discomfort

Participant:__________ Date:__________ Day:__________

RIGHT ARM EVALUATION — Back

Circle the appropriate numbers below for each column.

Fingers and Thumb

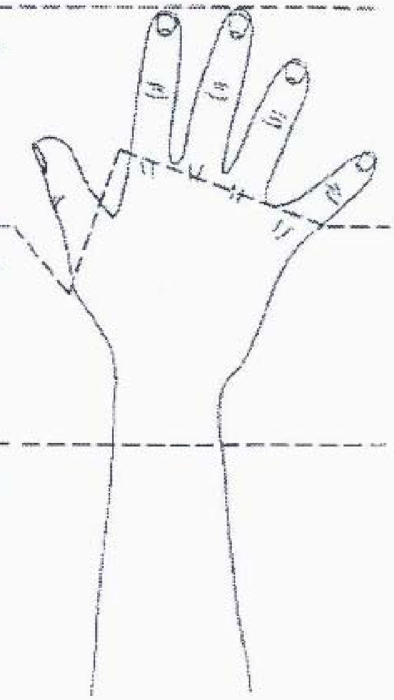
Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Hand and Wrist

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore.	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Forearm

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb



Back

Now indicate the location on the drawing. Use:
So for Soreness
St for Stiffness
N for Numbness

Overall Discomfort

1	2	3	4	5	6	7
No Discomfort	Very Little	A Little	Some Discomfort	Much	Very Much	Extreme Discomfort

D. An example of raw to processed and calibrated force data.