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The Effects of Applied Grip Force, Frequency and Duration on Ratings of Perceived Exertion

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THE EFFECTS OF APPLIED GRIP FORCE, FREQUENCY AND DURATION ON RATINGS OF PERCEIVED EXERTION

by

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ABSTRACT

THE EFFECTS OF APPLIED GRIP FORCE, FREQUENCY AND DURATION ON RATINGS OF PERCEIVED EXERTION

by

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Under the Supervision of Professor Jay M. Kapellusch

This study investigates the interactions of various combinations of frequency and duration that result in the same duty cycle at a given applied grip force (measured in % maximum voluntary contraction (MVC)) to determine their relative effect on perceived exertion. Eight female subjects (median age 20.5 years) performed 27 randomized trials containing combinations of dynamic grips, performing each combination twice. Each session contained three 25 minute trials, with a minimum of 12 minutes of rest between trials. The design used a 3x3x3 factorial protocol: i) 3 grip forces (10%, 25%, 40%) ii) 3 duty cycles (25%, 50%, 75%) iii) 3 durations (1, 4, 7 seconds). Subjects were asked to rate their level of perceived exertion every 2.5 minutes, throughout the entire 25 minute trial (or until it became too difficult to continue) using the Borg CR-10 scale (Borg, 1998). Although force seems to have the strongest effect on increased Borg CR-10 ratings (of all the tested factors), it was only significant as a main effect in a model that tested %MVC * Duty Cycle. The interaction of factors was statistically significant ($p \leq$

0.01) for both models tested: i) % MVC * Duty Cycle ii) % MVC * Frequency * Duration. The model which separated frequency and duration was a slightly better fit, based on a likelihood ratio test. However, from a practical standpoint, it appears that for the tested parameters, duty cycle alone is a sufficient measure of exertion. This study also found that combinations combining high force and high duty cycle were the most difficult for subjects. Combinations of lower force and modest duty cycles (containing modest frequencies) were the easiest for subjects to sustain. Future studies should look at a broader range of durations and higher forces to further define acceptable (i.e., sustainable, safe) repetitive dynamic grip combinations.

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LIST OF ABBREVIATIONS

ADL	Activities of Daily Living
AIC	Akaike Information Criterion
ANOVA	Analysis Of Variance
CTS	Carpal Tunnel Syndrome
DC	Duty Cycle
DUE	Distal Upper Extremity
EMG	Electromyography
IRB	Institutional Review Board
MAE	Maximum Acceptable Effort
MAF	Maximum Acceptable Frequency
MSD	Musculoskeletal Disorders
MVC	Maximum Voluntary Contraction
MVC*D	Maximum Voluntary Contraction * Duration of Exertion
MVC*DC	Maximum Voluntary Contraction * Duty Cycle
MVC*F	Maximum Voluntary Contraction * Frequency of Exertion
MVE	Maximum Voluntary Effort
OT	Occupational Therapist
RPE	Rate of Perceived Exertion
SD	Standard Deviation
UE	Upper Extremity

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Rationale & Significance of Study

We rely on our hands significantly to help us throughout our daily lives. Our hands provide us with the ability to touch and manipulate objects and interact with the world. Opening a container, brushing teeth, putting on clothes, typing on a keyboard, operating hand tools – all of these tasks require some degree of precision that comes from the musculature, strength and fine motor skills that comprise the upper body and hands. The hands alone account for thousands of movements daily (Pendleton & Schultz-Krohn, 2013). The arms, shoulders, and hands are collectively referred to as the "upper extremity" (UE). The UE without shoulder involvement is more specifically considered the "distal upper extremity" (DUE) (Garg & Kapellusch, 2011). This project focused primarily on the DUE since, if the DUE is injured, the potential for a strong negative effect on a person's daily life can be profound.

Injuries to the UE comprise approximately one-third of all acute injuries and 26% of work-related injuries (Pendleton & Schultz-Krohn, 2013). Recent reports indicate that DUE illness or injuries resulted in 257,190 days of missed work in 2014 (Bureau of Labor Statistics, 2015). These reported statistics do not include injuries that go unreported. The true rate of injury is therefore likely higher. The total societal cost associated with these workplace injuries is difficult to assess, as injuries go unreported or may have an unknown source (i.e., overuse injury could be from the workplace or from other Activities of Daily Living (ADLs)). Liberty Mutual Research Institute for Safety (2014) divides workers' compensation costs into the top ten most debilitating categories, of which "other exertions or bodily reactions" is the category most closely related to the research here. The estimate is that this category accounts for $4.27 billion in costs; the category “repetitive motions involving micro-tasks” accounts for $1.84 billion in costs (Liberty Mutual, 2014). These high costs suggest that continued work to improve workplace design and/or ergonomics is warranted in order to reduce workplace injuries. If successful, a reduction in workplace injury and injury severity could improve quality of life for workers (beyond just the workplace) and the societal burden of these costly injuries could be reduced.

Before any type of job design/redesign can occur, the factors which lead to any particular injury must be known and understood. Key factors which are commonly considered as stressors related to DUE injuries are: (i) force (ii) frequency (iii) duration of exertion, and (iv) other job physical exposures (e.g., posture and vibration). These factors, especially in certain combinations such as “high force” and “high repetition” are believed to substantially increase the risk of DUE injury (Garg and Kapellusch 2011).

Results of lab studies that assess how these factors affect a person’s perceived level of exertion are helpful in guiding ergonomists to better define acceptable maximum limits for job design, but this type of lab data are somewhat limited (Garg & Kapellusch, 2011). Although lab studies have been done to explore the impact of each of these independent factors on exertion (Harber, Hsu & Peña, 1994; Grant, Habes, & Putz-Anderson, 1994; Byström, & Kilbom, 1990; Dahalan & Fernandez, 1993; Klein & Fernandez, 1997; Kwon, You & Jung, 2009; Brisben, Hsiao & Johnson, 1999), refinements and supplements to these would be helpful. It is anticipated that this study will help further refine which interactions among key factors are worth considering further.

Since previous studies have explored risk factors independently, the current study was intended to take that concept one step further. A few of these same factors (frequency, duration of exertion, and force) could be not only assessed for their independent effects, but also what occurs when they are considered in combination. The researcher was curious as to what combinations of factors affect subjects' tolerance the most/least. Furthermore, it would be important to determine if each factor plays an equally important role. For example, would a long duration combined with a short frequency have a similar effect as a short duration and a long frequency? These types of questions should be looked at further, and they guided this study.

Purpose

The Objective of this study is to investigate the interactions of various combinations of frequency and duration that result in the same duty cycle at a given applied grip force (measured in % maximum voluntary contraction, % MVC) to determine their relative effect on perceived exertion. The null hypothesis is: *for a given force (% MVC), different combinations of frequency of exertion and duration of exertion, that result in the same duty cycle, have no effect on perceived exertion.* The alternate hypothesis is: *a model that contains force, frequency of exertion, and duration of exertion, will predict perceived exertion better than a model that contains force and duty cycle.*

Significance to Occupational Therapy

Job risks and injuries can be explored from multiple perspectives. Occupational therapists (OT) may help a worker regain functionality and strength after an injury or may modify a work environment to be safer or better biomechanically. An engineer might assess the job equipment and redesign it to be safer. Collectively these and other disciplines contribute to the science of ergonomics. Ergonomics considers the interaction between humans, machines and environments (Human Factors, 2014). Ergonomists can help modify jobs to be safer, and may help workers prevent injury.

Occupational therapists can play a role in preventing DUE injuries through workplace design or plan interventions for treating DUE injuries if they do occur. Occupational therapists are skilled at evaluating and analyzing job tasks, which make them a valuable asset in helping to decrease the risk of injury and workers compensation costs. Occupational therapists can apply prevention methods in the workplace by fabricating splints that will keep the wrist in a neutral position, helping employees perform stretching exercises between tasks, and educating both employers and employees about the use of correct posture and wrist positioning (National Institute of Neurological Disorders and Stroke, 2014). Occupational therapists can also modify workstations, tools, and tasks as well as encourage workers to utilize rest breaks and job rotation schedules to decrease strain from repetitive tasks (National Institute of Neurological Disorders and Stroke, 2014).

The findings of studies like this one can help contribute to the information OTs use to understand the effect various factors have on clients, and how to reduce the appropriate factor(s) to decrease the effects of exertion from both a preventative and treatment standpoint.

Literature Review

Psychophysical studies of the distal upper extremity

Lab studies generally employ psychophysical scales to assess tasks. Psychophysical studies are those which study the relation between human sensations and physical intensities (Fernandez & Marley, 2014). Subjects are generally given a task, and then asked to modify one factor. In several of the studies examined (Lin, Radwin & Snook, 1997; Marley & Fernandez, 1995; Grant, Habes, & Putz-Anderson, 1994; Klein & Fernandez, 1997; Kwon, You, & Jung, 2009); frequency (maximum acceptable frequency, or "MAF") was the modifier. Fernandez & Marley (2014) concluded that frequency is often modified in these studies because it is easier to control in the workplace than posture or force. The modifier is then adjusted by the subject until a level is reached which is deemed "acceptable" to maintain during an eight-hour workday.

Over the past 35 years, there have been a wide number of psychophysical studies done to evaluate various DUE job tasks (under both actual and/or simulated conditions) and the parameters of those tasks. Studies have been done to test everything from generic forces (Abu-Ali, Purswell, & Schlegel, 1996; Byström & Kilbom, 1990; Dahalan & Fernandez, 1993) to the use of specific hand tools (Cochran & Ding, 2007; Björkstén & Jonsson, 1977). Other scenarios include the effects of contraction and rest on force (Björkstén & Jonsson, 1977) and ratings of fatigue on ratings of perceived exertion (RPE) (Byström & Kilbom, 1990). Several studies assess some or all of the key established risk factors (force, posture, duration, frequency and vibration) with some respect to perceived exertion (Harber, Hsu & Peña, 1994; Grant, Habes, & Putz-Anderson, 1994; Byström, & Kilbom, 1990; Dahalan & Fernandez, 1993; Klein & Fernandez, 1997; Kwon, You & Jung, 2009; Brisben, Hsiao & Johnson, 1999).

Assessment of DUE tasks: perceived exertion or electromyography

In a study by Grant, Habes, & Putz-Anderson (1994), the objective was to predict grip force using both electromyography (EMG) and RPE while subjects performed three unique tasks simulating the use of a power tool requiring the grasp of a cylindrical handle. Forty-five male subjects (15 for each of three separate studies) were asked to perform repetitive tasks once every 5 seconds for 2.5 minutes, under various conditions using handles, tools, and rope tensions. Borg CR-10 scores were solicited after each task condition, and EMG readings of forearm muscles (flexor pollicis longus, flexor digitorum superficialis, and extensor digitorum muscles) were taken throughout.

Using a p-value of 0.0001, correlations between peak grip and Borg-CR10 values were statistically significant. As the force increased, the Borg CR-10 values also increased. Since RPE methods are generally easier to use, Grant, Habes, & Putz-Anderson (1994) indicate that it might be the more practical approach in the field rather than EMG readings. Theirs was the first study to show that the RPE ratings correlate with a dynamic task, rather than isometric.

Although Klein & Fernandez (1997) studied pinch force rather than grip force, they similarly found that RPE can be used as an indicator of effort rather than EMG. As task demands increased (by MVC, duration, or a combination of the two), RPE ratings increased, and MAF decreased. A positive correlation was found using RPE as an indicator of increased pinch force level, task duration, and wrist flexion (as compared to MAF ratings); this indicates that the psychophysical approach is a valid method of analysis. A negative correlation was shown between RPE and EMG activity; this also supports the use of the psychophysical approach.

Perceived exertion is extremely relevant in psychophysical studies, because it is generally an indicator of how difficult a task is and the amount of physical strain it is putting on the individual's body (Borg, 1998). Regardless of the number of factors affecting the subject, perceived exertion makes it possible to assign a number to the overall effect. This is especially important in situations such as the assessment of tasks leading to musculoskeletal disorders (MSD), where multiple factors may play a role (Fernandez & Marely, 2014). The Borg CR-10 (or modified versions of it) is one of the most commonly referred-to subjective scales that is used to measure RPE in the field of DUE ergonomics. This was the chosen scale used in this project's methodology.

The Borg CR-10 is a categorical ratio scale, which classifies ratio properties into groupings from 0 (nothing at all) to 10 (almost max), with points in-between, which can roughly estimate a linear relation between the two (Figure 2). The Borg CR-10 is considered very reliable for exertion (split-half correlation of R=.96) and valid (as high as .96 with heart rate) (Borg, 1998). It is also easy to use, making it a popular tool (Borg, 1998).

Key findings from five psychophysical studies

The use of RPE scales (such as the Borg CR-10) is a common dependent variable in assessing the risk factors of force, duration, posture and frequency in psychophysical studies. The interaction among these key factors in DUE is still not clear. When looking at five notable studies (Grant, Habes, & Putz-Anderson, 1994; Klein & Fernandez, 1997; Byström & Kilbom, 1990; Harber, Hsu, & Peña, 1994; Dahalan & Fernandez, 1993), it can be seen that each study assesses these key risk factors independently (Table 1). Additionally, in most of these studies the subjects are controlling one factor (such as the frequency). The current research will be unique in that the subject will not control any of the variables. Instead, there will be a set of fixed parameters for each factor (i.e., frequency will be set for the entire trial and subjects will not be able to change it).The specific combinations of those factors will then be assessed. The researcher is unaware of prior research that studies interactions in this way. By using the data from the five studies cited above we can gain valuable insight into the potential interactions among independent factors, and let it guide the research question for this study.

Importance of rest between exertions

In an effort to determine acceptable rest periods under various efforts, Byström & Kilbom (1990) recruited six subjects (3 male, 3 female) to test various combinations of grip force using a dynamometer. Subjects sat in a chair with arm and forearm supported at 115°, and gripped the dynamometer. Fatigue was measured by blood flow activity, EMG of muscle activity, and subjective ratings of RPE (on a 0-100% difficulty scale) at five points throughout each effort. Each subject performed twelve exercises over a two month period, executing four contraction-rest combinations (10 sec +10 sec, 10 sec +5 sec, 10 sec+ 2 sec, continuous contraction) at three levels of force (10%, 25%, and 40%

MVC). Each session began with a continuous contraction at either 25% or 40% MVC until fatigued. Durations of experiments ranged in time from 3.75 minutes – 30 minutes.

Perceived effort was found to be higher in experiments with continuous exertions, rather than intermittent efforts. Based on the RPE ratings, Byström & Kilbom (1990) were able to show that the intermittent ratings of 10 second contraction +5 second rest and 10 second contraction +2 second rest at 40% MVC were shown to have unacceptable levels that resulted in fatigue. This suggests that subjects are unable to sustain high level forces at acceptable levels without sufficient rest periods. This is important to consider for the current study when setting up the methodology. The highest force chosen for the current study was 40% MVC, and the longest duration was set at 7 seconds; consideration for Byström & Kilbom's findings that higher levels are unacceptable without rest. This research also indicates that sufficient rest should be given between trials.

Effect of MVC, posture, and frequency on RPE

Harber, Hsu, & Peña (1994) asked seven male subjects to rate perceived exertion using a modified Borg CR-10 scale while grasping either a ball or thin card and lifting it upward two inches. Combinations of: two grasps (power grip of 6 cm rubber ball and precision pinch of very thin card), three wrist postures (flexion, neutral, and extension), two levels of force (0.27 lbs. /in and 0.43 lbs. /in), and three levels of repetition (7.5, 20, and 60 grasps/minute) were tested in 4-minute cycles. Subjects provided modified Borg CR-10 ratings at the conclusion of each cycle.

Statistically significant differences were found in the Borg CR-10 ratings for grasp, force, wrist posture, and repetition rate. For posture, wrist flexion was consistently rated harder than wrist extension. For frequency, faster rates generally received harder ratings; however, only 60 efforts per minute trials were statistically rated as harder, perhaps demonstrating an inability to sustain a rate of exertion that high.

Dahalan & Fernandez (1993) designed a study which was intended to mimic a wire-crimping task. They asked twelve female subjects to grip a modified dynamometer and apply a targeted amount of force (20, 30, 50, or 70% MVC) for a given duration (1.5, 3, 5, or 7 seconds) and then modify their own frequency. Subjects then gave Borg CR-10 RPE ratings for the hand, wrist, forearm, and the whole body. Generally, as the gripping force increased, so did the RPE levels. Force showed a more significant effect on RPE than duration in all cases of the resultant Analysis of Variance (ANOVA). Interaction effects between force and duration were not found to be significant. However, it was found that a low force (low %MVC) combined with a short duration resulted in the subject choosing higher frequencies; high force combined with long duration resulted in low chosen frequencies. These findings suggest that while there was not a significant interaction found between force and duration, the subjects were possibly adjusting the frequency to accommodate for these changes.

Factor parameters from previous studies as a guideline for the current research

When assessing the above five key studies (Grant, Habes, & Putz-Anderson, 1994; Klein & Fernandez, 1997; Byström & Kilbom, 1990; Harber, Hsu, & Peña, 1994; Dahalan & Fernandez, 1993) collectively (Table 1), it is found that there is a varied range of data for the key factors being considered. Tested durations within the studies were between 1 – 10 seconds, which is not surprising, since high durations are far less common in ADLs than low durations. The frequencies within the studies are more widespread, with a range of 2 – 20 grips/minute. Borg CR-10 ratings are quite expansive; numbers range from 0.6 (extremely weak) – 7.5 (very strong). MVC ranges were also quite wide (5-70%), which could explain such broad Borg CR-10 ratings (i.e., high forces generally result in high Borg CR-10 ratings that are not feasible to complete for long durations). Although the current research question is not psychophysical in nature, it utilizes the Borg CR-10 ratings to assess these parameters. These studies by others, combined with our pilot study results, helped to set the factor parameters for the current research.

Duty Cycle as a measure of repetition

Recently, there has been a renewed emphasis on considering a combination of the key parameters as one descriptive mathematical factor. This measure is known as "duty cycle" (DC). The simplest way to describe this measure is as the amount of time the hands are busy. For those working in the field of ergonomics, DC is a fairly easy way to access work through simple observation. The formula which is used to calculate DC is: frequency (grips/min) * duration (exertion duration in seconds)/60s. Duty cycle combines frequency and duration in such a way that it can also be described as a percentage of work (when multiplied by 100), which is a common way to describe DC.

In order to compare the five above studies with each other in a similar manner (considering DC), some conversions of variables to similar formats needed to occur.

DC ranges were found to be 8.8 -100%. This wide array of DCs also reflects what is found in both work and ADLs. Table 1 shows the data (for the factors of interest) from these studies. In general, preliminary analysis of the studies suggests that as duty cycle increases, RPE generally decreases. This is surprising, but it may be related to the nature of the studies where subjects were able to adjust parameters to make tasks sustainable.

Potvin's (2012) study was based on the objective of developing "an equation for repetitive tasks that uses frequency and/or duty cycle to predict maximum acceptable efforts relative to maximum voluntary efforts (p. 175)". Potvin (2012) stated that previous studies have sufficient data to support single exertion efforts, but much less data exists for multiple exertions (as would be more likely expected in a work setting). Since many ergonomists are asked to suggest maximum task loads, an equation for repetitive hand tasks would be beneficial. Therefore, a meta-analysis was done on 8 studies (one hundred seventeen female subjects) with a total of 69 psychophysical values. There were 7 distinct criteria to be included in the analysis, a major factor being that duty cycle (DC) could be determined from the information provided by each publication. The resulting ranges of included independent variables were: 1) DC ranging from 0.5% - 83.3% 2) frequency from 1-20/min and 3) duration between 0.160-16.667 seconds. Maximum acceptable effort (MAE) was the dependent factor, but the method (i.e., RPE scaling) for determining those maximums was not defined in detail. The tasks were varied for each of the studies; wrist flexion, wrist extension, ulnar deviation, hose insertion, power grips and pinch grips were included. After analysis, Potvin (2012) concluded that DC played a larger part in overall effect towards MAE than frequency alone. It was found that there was a strong, negative exponential relation (r2 = 0.87) between DC and MAE. Frequency had a moderate correlation with MAE (r2 = 0.49). Thus, the final equation was based on DC, as follows:

$$\text{MAE} = 1 - \left[DC - \frac{1}{28{,}800}\right]^{0.24}$$

Advantages and disadvantages of the duty cycle approach

There are certainly advantages to using the DC approach. As stated earlier, it is readily observable for cyclic work. It is simple to use and relatively quick to determine how much a subject's hands are moving. Therefore, if equations such as Potvin's (2012) can be used to predict safe/unsafe work, it would be quite beneficial to the field. Given some of the limitations, it may be beneficial to further explore this line of thinking and consider a few of the weaknesses which could alter the ultimate assessment of a job as safe or not.

While it is useful to have an equation such as Potvin's (2012) as a basis for determining potential maximal efforts, there are some restrictions; for example, there are over- and under-predictions of average MAEs up to 11.4% and 18.2% maximum voluntary effort (MVE). Since all of the contributing studies contained only female subjects, the equation cannot be generalized to the male population without further assessment. Most relevant to my current research is the following: "…it appears that an equation based only on DC, although simple and convenient to use, does not capture all of the variables that influence MAE" (Potvin, 2012, p. 186). Potvin (2012) himself admits that using DC to predict MAE does not fully capture all the variables that are contributing. Further research should be done to validate his equation as well as determine additional variables which impede predictions of MAE, and to determine MAEs for those DC values over 50%.

Potvin's (2012) study highlights some of the gaps in existing research, and further directs my experimentation. The simple fact that frequency and DC resulted in different resultant correlations suggests that DC alone may not explain MAEs. It also provides some evidence which shows that combining the factors may mask independent effects. It is important to recall that DC combines frequency and duration; duration was not shown to be considered as an isolated variable in Potvin's analysis, whereas frequency was. Therefore, it would be difficult at this point to say to what extent frequency or duration independently contribute to overall MAE when variables are combined, rather than isolated.

My study fixes each variable into set parameters. This was done in a way that will require subjects to complete entire combinations for a set amount of time, without the opportunity to adjust parameters. This methodology therefore allows for analysis on a wide variety of set combinations, and factors can be assessed in isolation or in combination. This is important in addressing the research question: a comparison between effects of independent variables or the interaction among those factors.

Further, regarding the current research question, the most important thing to consider is the fact that all DC (with the same percentage) may not be treated as equals. Very different combinations of frequency and duration can result in the same duty cycle. For example, one 30-second effort per minute results in a 50% DC. Thirty 1-second efforts per minute also result in a 50% DC. Those are clearly not the same.

What is unknown is how combinations that result in the same DC affect a person's perception of exertion.

Table 1 Analysis of five studies' factor parameters/results, sorted by duty cycle (DC), and including Borg CR-10 ratings (perceived exertion scale from 1-10). Highest/lowest DC and Borg CR-10 ratings highlighted

% MVC	Duration (sec)	Frequency (MAF) (grips/minute)	Duty Cycle (Freq*Dur)	Borg CR-10 Ratings *	Study name
70	1.5	3.51	8.8	6.25	Dahalan 1993
70	3	2	10	7.5	Dahalan 1993
5	1	7.5	12.5	2.2	Harber 1994
7	1	7.5	12.5	2.4	Harber 1994
5	1	7.5	12.5	2.5	Harber 1994
15	1	7.5	12.5	4.9	Harber 1994
50	1.5	5.29	13.2	3.62	Dahalan 1993
50	1	7.95	13.3	6	Klein 1997
30	1	8.88	14.8	1.5	Klein 1997
70	5	2.08	17.3	7.17	Dahalan 1993
30	1.5	7.46	18.7	4	Dahalan 1993
15	1	11.3	18.8	1.5	Klein 1997
50	3	3.99	20	5.33	Dahalan 1993
70	7	1.93	22.5	7.17	Dahalan 1993
50	5	2.73	22.8	6.57	Dahalan 1993
20	1.5	9.55	23.9	2.14	Dahalan 1993
50	3	5.09	25.5	6	Klein 1997
50	7	2.32	27.1	6.42	Dahalan 1993
30	3	5.77	28.9	3.83	Dahalan 1993
20	3	6.1	30.5	3.17	Dahalan 1993
50	7	2.69	31.4	6	Klein 1997
30	5	3.87	32.3	3.86	Dahalan 1993
30	3	6.53	32.7	1.5	Klein 1997

5	1	20	33.3	2.7	Harber 1994
5	1	20	33.3	2.8	Harber 1994
7	1	20	33.3	3.4	Harber 1994
15	1	20	33.3	4.9	Harber 1994
30	7	3.04	35.5	3.83	Dahalan 1993
15	3	7.42	37.1	1.5	Klein 1997
30	7	3.35	39.1	6	Klein 1997
20	5	4.88	40.7	3.42	Dahalan 1993
20	7	3.66	42.7	4.5	Dahalan 1993
15	7	4.11	48	6	Klein 1997
10	10	3	50	0.7	Bystrom 1990
25	10	3	50	1.8	Bystrom 1990
40	10	3	50	4.1	Bystrom 1990
10	10	4	66.7	1.2	Bystrom 1990
25	10	4	66.7	2	Bystrom 1990
40	10	4	66.7	5.3	Bystrom 1990
10	10	5	83.3	1.4	Bystrom 1990
25	10	5	83.3	3.2	Bystrom 1990
40	10	5	83.3	4.8	Bystrom 1990
14.13	5	12	100	0.6	Grant 1994
15.02	5	12	100	0.8	Grant 1994
13.44	5	12	100	1	Grant 1994
23.33	5	12	100	1.3	Grant 1994
17.5	5	12	100	1.7	Grant 1994
21.27	5	12	100	1.8	Grant 1994
21.19	5	12	100	2.3	Grant 1994

30.78	5	12	100	2.6	Grant 1994
25.12	5	12	100	2.9	Grant 1994

***Borg CR-10 ratings beyond 3 for lifting tasks have been shown to be too difficult to sustain (Capodaglio, Capodaglio, & Bazzini, 1995) and is being used as a basis in this study for tasks that cannot be sustained for an eight-hour workday**

Methods

Subjects

Eight adult female subjects were recruited for this study. To participate, subjects were required to fit the Inclusion criteria. Subjects needed to be female, between 18-35 years of age, speak and understand English, and hear auditory cues. Subjects were excluded from the study if they had reported disabilities or reduced function in their dominant arm, had physician's orders to not exert force in their dominant arm or could not provide written informed consent. Subjects were recruited through word of mouth and via a flyer posted in the Engineering and Mathematical Sciences (EMS) and Enderis Hall buildings on the University of Wisconsin-Milwaukee campus. Participation in the study was voluntary and data collection occurred in Enderis Hall Room 980.Approval from the University of Wisconsin - Milwaukee Institutional Review Board (IRB) was obtained prior to the start of experimentation (see Appendix B).

Equipment

For this experiment, all forces were applied using a custom-built dynamic-grip device (Figure 1), with the exception of obtaining subjects' maximum static grip force in the neutral position. The device shown in Figure 1 was created for a prior project by Dr. Jay Kapellusch and students who were studying isotonic grip strength. A Jamar grip dynamometer was used to determine the subject's maximum isometric grip force and this gave researchers an initial indication of the amount of load to place on the dynamic device. Maximum isotonic grip strength was determined using the dynamic device. A dynamic device ensures that subjects are performing an isotonic contraction, rather than a static one. This is particularly important for a study on workplace conditions, as dynamic tasks are more representative of that environment.

Researchers began by loading the dynamic device with 85% of the subject’s isometric maximum voluntary contraction (MVC). Subjects were then asked to squeeze the handles on the device using a neutral posture (arm at 90° angle) until a 4.5 cm gap between the handles was closed. Closing the handles lifted calibrated weights, which were placed on the device by the investigator, via a pulley system. If the subject could not close the handle and keep it closed for a minimum of 3 seconds, the investigator removed weights from the device. If the subject could keep the handles closed for more than 5 seconds, the investigator added weights to the device. When the subject was able to close the handles for at least 3, but not more than 5 seconds, for three consecutive exertions, a dynamic 100% MVC baseline was achieved. Subjects were provided a minimum of five minutes of rest between consecutive exertions during 100% MVC testing.

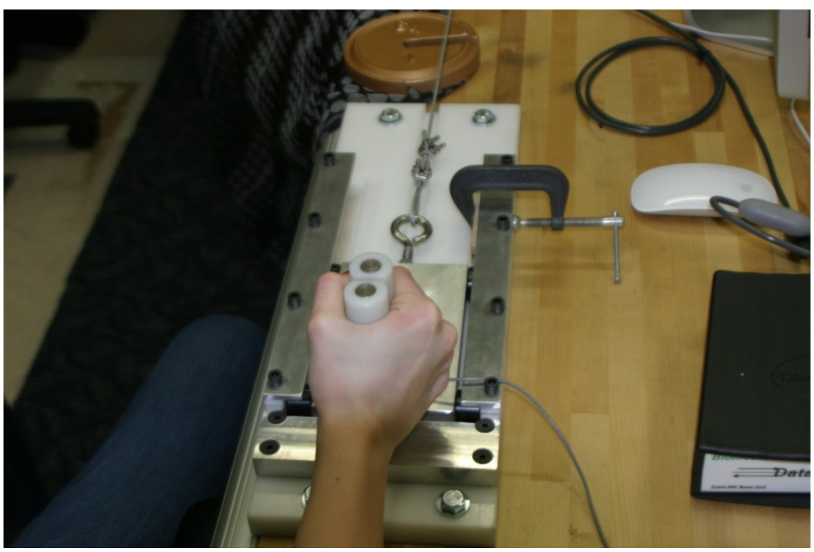

Figure 1 Dynamic Grip Device

Study Design

This study used a 3x3x3 replicated factorial design. The three power grip intensities were: 10%, 25%, and 40% of each subject's MVC isotonic strength. There were three tested durations of exertion: 1, 4, and 7 seconds; and 3 tested duty cycles (i.e., percent duration of exertion: where 25% DC means 25% of each minute is spent gripping): 25%, 50%, and 75%. Thus, subjects underwent 27 total factorial combinations of grip intensities, durations and frequencies (Table 2). Frequencies of exertion (i.e., efforts per minute) were defined by the specific combinations of duration of exertion and duty cycle (Table 3). All 27 combinations were randomized and then repeated by all subjects, resulting in 54 total trials for each subject. Each trial lasted 25 minutes. Every 2.5 minutes subjects were asked to rate their level of perceived exertion on the Borg CR-10" scale (Figure 2).

Table 2 Study's Experimental Combinations

Combination #	Duty Cycle (%)	Force (% MVC)	Duration (seconds)
1	25	10	1
2	25	10	4
3	25	10	7
4	25	25	1
5	25	25	4
6	25	25	7
7	25	40	1
8	25	40	4
9	25	40	7
10	50	10	1
11	50	10	4
12	50	10	7
13	50	25	1
14	50	25	4
15	50	25	7

16	50	40	1
17	50	40	4
18	50	40	7
19	75	10	1
20	75	10	4
21	75	10	7
22	75	25	1
23	75	25	4
24	75	25	7
25	75	40	1
26	75	40	4
27	75	40	7

Table 3 Effective Frequencies Resulting from Duty Cycle and Duration Combinations

Duty Cycle (%)	Duration (seconds)	Frequency (grips/minute)
25	1	15
25	4	3.75
25	7	2.14
50	1	30
50	4	7.5
50	7	4.29
75	1	45
75	4	11.25
75	7	6.43

0	Nothing at all	"No P"
0.3		
0.5	Extremely weak	Just noticeable
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very strong	
8		
9		
10	**Extremely strong**	**"Max P"**
11		
●	Absolute maximum	Highest possible

Borg CR10 scale

Figure 2 Borg CR-10 scale (Borg, 1998)

Procedure

Subjects participated in eighteen two-hour sessions and two one-hour sessions (Figure 3); this resulted in a 38-hour time commitment from each subject. Sessions were held on different days, with a minimum of 12 hours between sessions, to allow subjects adequate recovery time. The first session (one hour) was an introduction to the study, to obtain informed consent, and to determine the subject's maximum hand-grip strength. The second session (one hour) was a practice session to confirm maximum isotonic grip strength, and allow the subject to become familiar with the study design. Each subject then performed four pre-determined combinations during the practice session: (i) MVC 15%, DC 25%, duration 4 seconds (ii) MVC 30%, DC 25%, duration 4 seconds (iii) MVC 15%, DC 75%, duration 1 second, and (iv) MVC 30%, DC 75%, duration 1 second. These quantities were chosen to produce a similar effect that various combinations in the actual experiment would have. Each practice combination lasted 7 minutes, with 5-minutes of rest between tests. Borg CR-10 ratings were taken every minute. Sessions three through twenty (18, two-hour sessions) were randomized and each session contained three 25-minute trials. Borg CR-10 ratings were recorded every 2.5 minutes during each trial, and 12-minutes of rest were provided between each trial, to be sure that subjects were always beginning each trial, each day, at a set Borg CR-10 rating of 0. During trials, subjects were alerted to squeeze the device handles by an auditory tone. The length and frequency of the tone corresponded to the test combination duration and frequency of exertion. A separate auditory beep (different tone) sounded every 2.5 minutes to indicate that it was time to provide Borg CR-10 ratings.

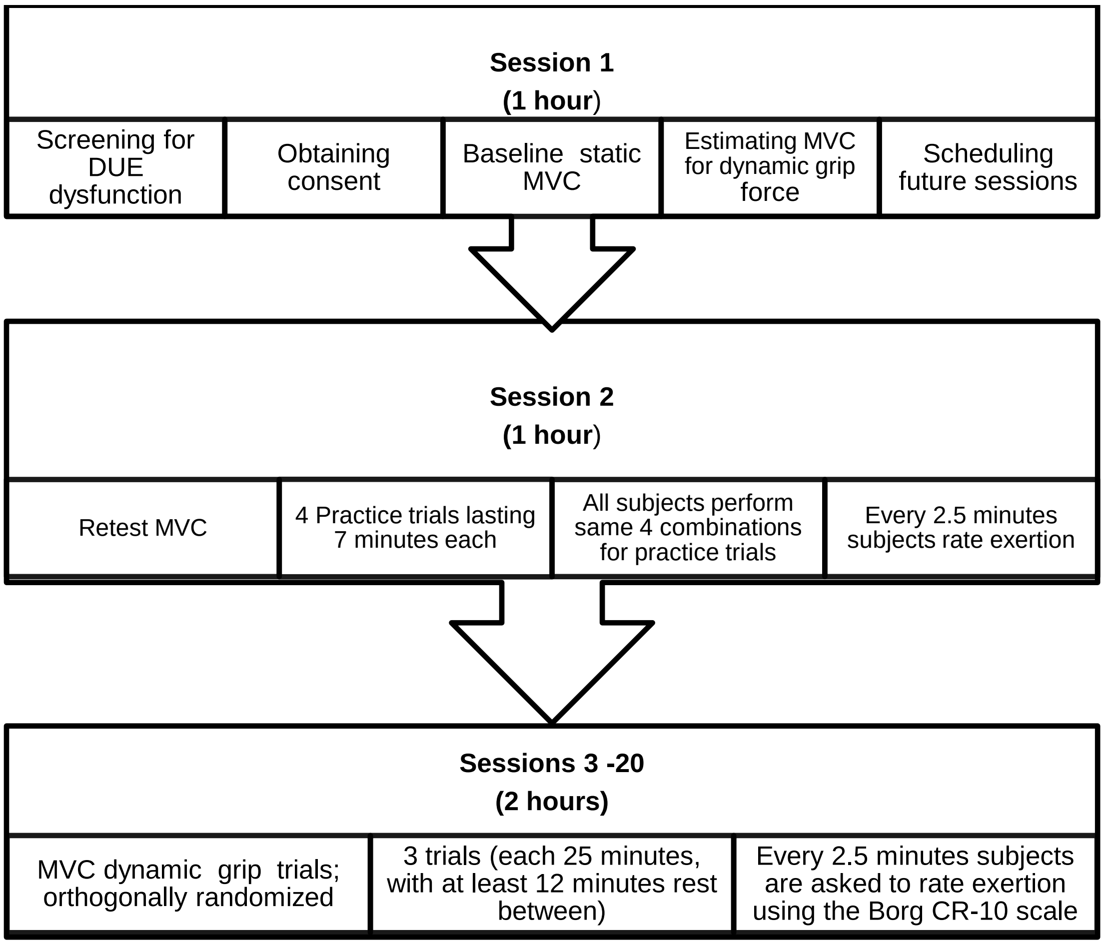

Figure 3 Session Details

Analysis

Descriptive Analyses. Summary statistics of the subjects' last reported Borg CR-10 mean for each combination (standard deviations (SD)) and minimum to maximum ranges were calculated. The data were also analyzed by graphing each experimental combination so that temporal trends in ratings could be visualized. Borg CR-10 ratings were compared to trial time (in minutes) for all 27 combinations. This resulted in three separate MVC graphs, each with the 9 experimental combinations of duty cycle x duration represented as separate lines. Additional graphs were created for both the 10% MVC and the 25% MVC which condenses the Y axis, making small variations in ratings easier to decipher. These graphs were used to identify temporal trends in ratings. Through visual analysis, it is possible to see whether Borg CR-10 ratings increase, decrease, or remain unchanged over time. These clues help gauge whether the tasks were being maintained (sustainable) for 25 minutes or becoming increasingly difficult (not sustainable over time).

Statistical Analyses. Mixed effects linear regression models with Borg CR-10 rating as the outcome, and subjects as a random effect were used to directly address the hypothesis of this study. Two separate models were built: (i) using % MVC and DC as independent variables, and (ii) using % MVC, frequency of exertion, and duration of exertion as independent variables. In model one, duty cycle is used and thus frequency and duty cycle of exertion are accounted for by the mathematical definition of duty cycle. In model two frequency and duty cycle of exertion are included as separate variables. Two- and three-way Interactions between %MVC and DC (model 1) and %MVC, Frequency, and Duration (model 2) were included as appropriate. Statistical differences between the models were determined using the likelihood ratio test. Akaike Information Criterion (AIC) scores and adjusted r-square values for the models were also compared to assess whether there was a practical difference in performance between the two models. All statistical analyses were performed in R-64.

Results

Descriptive Statistics

Eight female subjects completed this study. The age range was 18-27, with a median of 20.5 years. Height and weight, along with hand anthropometric data were collected (Table 4, additional anthropometric data are provided in Appendix D). Maximum power grip strength was measured for each subject and used as 100 % of MVC. MVCs ranged from 21-39 kilograms of isotonic strength. All subjects were right-hand dominant and had no limiting DUE disorders.

Incomplete Sessions

Subjects completed 27 trial combinations of MVC * Duty Cycle (DC) * Duration of exertion, twice (54 total trials). Some combinations of force, DC, and exertion duration were too difficult for all subjects to complete. In these cases, subjects stopped the trial before 25 minutes were complete, and the last Borg CR-10 ratings they provided were used for analyses. Twelve of the 27 total experimental combinations had a least one subject unable to complete at least one trial. No combination resulted in every subject dropping out. One combination resulted in subject(s) dropping-out at 25% DC, five combinations resulted in drop-outs at 50% DC, and seven combinations resulted in drop-outs at 75% DC. Regarding force, seven combinations containing 40% MVCs resulted in drop-outs, four combinations with 25% MVC had drop-outs, and only one combination with a 10% MVC had drop-outs. For duration, the most drop-outs occurred when the duration was 1 second (five drop-outs), followed by a duration of 7 seconds (four drop-outs), and 4 seconds (3 drop-outs). The most difficult experimental combinations appeared to be 40% of MVC, 75% Duty Cycle, 7s exertion duration, and 40% of MVC, 75% Duty Cycle, and 1s exertion duration. For both of these combinations, at least one subject could not complete 5 of the 25 minutes. Table 5 summarizes subject dropouts for these 12 difficult to perform experimental combinations. Note that the maximum ‘n’ is 16 (8 subjects x 2 trials per subject).

Final Borg CR-10 Ratings

Each trial was performed for up to 25 minutes and subjects reported their Borg CR-10 ratings every 2.5 minutes until 25 minutes elapsed, or the subject could no longer continue the prescribed trial combination. Tables 6 through 8 provide a summary of the last reported Borg CR-10 ratings for all trial combinations. For example, if a subject dropped out at 2.5 minutes, their final rating for that combination was provided at 2.5 minutes. Likewise, if a subject completed the trial, their final rating was recorded at the 25 minute mark. Means and ranges (along with standard deviations) are included in Tables 6 through 8.

Using the results reported in Tables 6 through 8, average increase (or decrease) in Borg CR-10 ratings was calculated for each of the three factors tested. These results are reported in Tables 9 through 14 as follows: (i) as force increases from 10-25% MVC (Table 9), and from 25 to 40% MVC (Table 10), (ii) as DC increases from 25 to 50% (Table 11), and from 50 to 75% (Table 12), and (iii) as exertion duration increases from 1 to 4 seconds (Table 13) and from 4 to 7 seconds (Table 14).

Force appears to have the largest effect on Borg CR-10 ratings. From Tables 6 through 8 we see that as force (%MVC) increases, average Borg CR-10 ratings also increase, and do so in a near-linear fashion. For example, as %MVC increases from 10-25%, Borg CR-10 ratings increase by an average of 1.9 units (range: 1.0 to 3.1) (Table 9). Similarly, as %MVC increases from 25% to 40%, Borg CR-10 ratings increase by an average of 2.2 units (range: 1.5-2.9) (Table 10). Figure 4 graphically shows the relation between average Borg CR-10 ratings and %MVC, including the range of Borg CR-10 ratings at each MVC level. From this figure we can see that an approximately 7-8 unit change in %MVC results in an approximately one unit change in Borg CR-10 rating, assuming all other factors (e.g., duty cycle) are the same.

DC shows a similar trend where average Borg CR-10 ratings increase as DC increases (Tables 6 through 8). As DC increases from 25 to 50%, Borg CR-10 ratings increase by an average of 1.1 units (range: 0.1 to 2.3) (Table 11), and as DC increases from 50 to 75%, Borg CR-10 ratings increase by an average of 1.4 units (range: 0.3 to 2.4) (Table 12). Figure 5 shows that there is an essentially linear relation between DC and Borg CR-10 rating, but that the Borg CR-10 ratings vary widely depending on the force and/or exertion durations involved. Further, from Figure 5 we see that an approximately 18 to 23 unit change in DC is required to see an approximately 1 unit change in Borg CR-10, assuming all other factors are constant.

In contrast to force and DC, exertion duration shows almost no relation with Borg CR-10 ratings (Tables 13 and 14, and Figure 6). As exertion duration increases from 1 to 4 seconds, Borg CR-10 ratings decrease by an average of 0.6 units (range: -0.1 to -1.4). Conversely, as exertion duration increases from 4 to 7 seconds, there is almost no change in average Borg CR-10 ratings (mean: 0.1, range: -0.4 to +0.7). Further, the range in average Borg CR-10 ratings is very wide regardless of exertion duration (Figure 6).

Patterns of Borg CR-10 Rating Increases During Trials

For all experimental combinations, Borg CR-10 Ratings increased between the beginning and the end of the trial. The patterns of these increases are shown in Figures 5 through 9. Each of these graphs shows the average Borg CR-10 ratings among all 8 subjects and for both trials (i.e., average of up to n=16 total Borg CR-10 ratings), at each 2.5 minute increment during the experiment. Each individual graph shows all nine combinations of DC and exertion duration for a given force level. It should be noted that there were combinations which resulted in subjects being unable to complete the trial for the full 25 minutes (Table 5). These drop-outs sometimes result in sharp dips in Borg CR-10 ratings, giving the appearance that the combination suddenly became easier (e.g., Figure 11). This is due to the remaining subjects having relatively lower ratings, at that time, than the subjects that had just dropped out. A clear example of this phenomenon is seen with 40% MVC, 75% DC, 1 second duration, from 2.5 minutes to 10 minutes (Figure 12).

When comparing the graphs from the standpoint of force as the primary focus, we see that as force increases, so do the average Borg CR-10 ratings. At 10% MVC (Figures 7 and 8), the ratings are between 0.5 (just noticeable/extremely weak) and 2.0 (light/ weak). At 25% MVC (Figures 9 and 10), the range is from about 1.5 (light/weak) to 4.0 (high end of moderate). At the greatest force of 40% MVC (Figure 11), ratings across combinations are from about 2.5 (low end of moderate) to 6 (low end of very strong).

On each of the graphs, DC is indicated by line type. For all given force levels, the lowest DC (solid lines) is initially rated as the easiest, followed by 50% DC (dashed lines), and 75% DC (dotted lines). At all force levels, 75% DC at 1 second duration is the most difficult. Similarly, at all force levels, 25% DC at 4 seconds ends with the lowest average Borg CR-10 rating.

When looking at each given force separately, there are patterns which occur over time as it relates to DC. At the lowest force (10% MVC), all combinations generally followed in parallel alignment (no crossover of lines) throughout the trials, with a slight increase in slope over time. The only crossover that occurs is at 7.5 minutes, when 50% MVC (1 second) surpasses 75% DC (7 second). Although the general patterns are similar across the higher forces, drop-out becomes more evident on these graphs (Figures 9 through 11). It appears that 75% DC rises the quickest and steepest, followed by 50% DC and 25%DC, but the highest rated at the early time periods is not necessarily the highest at the final time periods. This “cross-over” of average Borg CR-10 ratings is likely the result of subjects dropping out of the combination.

On each of the graphs, exertion duration is indicated by line color, with 1s durations colored red, 4 second durations colored blue, and 7s durations colored green. Trends in average Borg CR-10 rating increases are not as consistent as they are for %MVC and DC. Shorter durations tend to be rated as more difficult, but this is not always the case. At the lowest force (10% MVC), short durations seem to result in higher Borg CR-10 ratings than at the other forces. At a moderate force (25% MVC) the shorter durations were the most difficult for subjects at both 75 and 50% DCs. However, at 25% DC, the shortest duration was rated the easiest for the first 15 minutes, and the 4 second combination is rated the hardest. At 15 minutes, we see a crossover occur, where 4 seconds becomes the combination with the lowest Borg CR-10 rating. All three durations level off at around 15 minutes (through to the end) and are all rated around 2.0 on the Borg CR-10 scale. At the highest force (40% MVC), the graph becomes more unclear as more drop-outs occur. At 75% and 50% DC, the shortest durations continue to be most difficult. Yet, at 25% DC, a long duration is most difficult. At all levels, the 4s exertion duration is rated as the easiest (at each given DC) for a majority of the 25 minute trials.

Statistical Comparison of Duty Cycle vs. Duration and Frequency of Exertion

Separate linear regression models were built to test the hypothesis that there was no difference in the ability to predict Borg CR-10 value whether %MVC and Duty Cycle were used (model 1), or %MVC, Duration, and Frequency of Exertion were used (model 2). For model 1, %MVC was statistically significant as a main effect ($p \leq 0.01$), and the interaction between %MVC and Duty Cycle was significant ($p \leq 0.01$). Duty cycle was not significant as a main effect ($p = 0.61$) (Table 15). For model 2, the three way interaction between %MVC, Duration of exertion, and Frequency of exertion was statistically significant ($p \leq 0.01$), and %MVC was marginally significant as a main effect ($p = 0.07$). All other main effects and two-way interactions were not significant ($p \geq 0.47$) (Table 15).

AIC scores for the two models were1598.922 and 1591.732 for model 1 and model 2, respectively (Table 15). Similarly, the adjusted R-squared values were 0.632 and 0.641 for model 1 and model 2, respectively (Table 15). AIC scores and R-squared values suggest that model 2 has a better fit than model 1. Further, the likelihood ratio test showed that model 2 had a statistically superior fit as compared to model 1 ($p \leq 0.01$).

Table 4 Population data

Subject #	Age (in years)	Stature(in)	100% MVC (kg)
1	20	68.5	33.5
2	21	65	29
3	19	62	24
4	18	63	35
5	27	62.5	33
6	23	73	39
7	20	67	29
8	21	63	21
Maximum	27	73	39
Minimum	18	62	21
Average	21.13	65.50	30.44
SD	2.80	3.81	5.91

Table 5 N values at 2.5 minute time segments for twelve combinations with subject drop-outs. Each subject rating is equivalent to "n" (n=8 subjects x 2 trials =16 total without drop-outs). Highlighted areas represent drop-outs.

MVC	Duration	DC	Minutes									
			2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
40	1	75	16	11	8	6	5	4	4	3	3	3
40	7	75	16	15	15	10	6	3	3	3	3	3
40	4	75	16	16	14	8	5	5	5	4	3	3
25	1	75	16	16	15	12	11	8	7	7	7	7
40	1	50	16	16	16	16	14	11	10	7	7	6
25	4	75	16	16	16	16	15	14	14	13	12	12
40	7	25	16	16	16	16	15	14	13	13	13	13

25	**1**	**50**	16	16	16	16	**15**	**15**	**15**	**15**	**15**	**15**
25	**7**	**75**	16	16	16	16	16	**15**	**15**	**13**	**12**	**11**
40	**4**	**50**	16	16	16	16	16	16	**15**	**14**	**12**	**12**
40	**7**	**50**	16	16	16	16	16	16	16	16	**15**	**15**
10	**1**	**75**	16	16	16	16	16	16	16	16	**15**	**15**

Table 6 Borg CR-10 means, standard deviations, and ranges (minimum – maximum) for all combinations at 10% MVC. All ratings (including ranges) are the last Borg CR-10 rating provided by subjects.

Duration		**Duty Cycle**		
		25%	**50%**	**75%**
1 second	**Borg CR-10 Mean ± SD**	1.2 ± .079	1.9 ± 1.23	2.3 ± 1.86
	Min-Max (Borg CR-10)	0.2 - 2.5	0 - 4	0 - 7
4 seconds	**Borg CR-10 Mean ± SD**	0.7 ± 0.53	1.2 ± 0.89	1.5 ± 1.09
	Min-Max (Borg CR-10)	0 - 2	0 - 3	0 - 4
7 seconds	**Borg CR-10 Mean ± SD**	0.9 ± 0.49	1.0 ± 0.61	1.7 ± 1.14
	Min-Max (Borg CR-10)	0.2 - 2	0.1 - 2.5	0 - 4

Table 7 Borg CR-10 means, standard deviations, and ranges (minimum – maximum) for all combinations at 25% MVC. All ratings (including ranges) are the last Borg CR-10 rating provided by subjects.

Duration		**Duty Cycle**		
		25%	**50%**	**75%**
1 second	**Borg CR-10 Mean ± SD**	2.2 ± 1.18	3.5 ± 1.07	4.9 ± 2.45
	Min-Max (Borg CR-10)	0 -4	1 - 5	1 - 10
4 seconds	**Borg CR-10 Mean ± SD**	2.1 ± 1.09	3.1 ± 1.36	4.6 ± 2.15
	Min-Max (Borg CR-10)	0 - 3	0.5 - 6	0.5 - 10
7 seconds	**Borg CR-10 Mean ± SD**	2.2 ± 1.02	2.7 ± 0.87	4.5 ± 2.5
	Min-Max (Borg CR-10)	0 - 4	0.5 - 4	0 - 10

Table 8 Borg CR-10 means, standard deviations, and ranges (minimum – maximum) for all combinations at 40% MVC. All ratings (including ranges) are the last Borg CR-10 rating provided by subjects.

Duration		Duty Cycle		
		25%	50%	75%
1 second	Borg CR-10 Mean ± SD	3.9 ± 1.57	6.2 ± 1.91	7.8 ± 1.94
	Min-Max (Borg CR-10)	0 - 7	3 - 9	4 - 10
4 seconds	Borg CR-10 Mean ± SD	3.6 ± 1.49	4.8 ± 2.09	7.2 ± 2.07
	Min-Max (Borg CR-10)	0 -5	0.5 - 9	4 - 10
7 seconds	Borg CR-10 Mean ± SD	4.3 ± 1.96	4.8 ± 1.12	7.1 ± 2.3
	Min-Max (Borg CR-10)	0 -8	3 - 7	3 - 10

Table 9 Difference in Borg CR-10 ratings as force increases from 10 to 25% MVC.

	25% DC	50% DC	75% DC	Means
1 second	1.0	1.6	2.6	1.7
4 seconds	1.4	1.9	3.1	2.1
7 seconds	1.3	1.7	2.8	1.9
Means	1.2	1.7	2.8	1.9

Table 10 Difference in Borg CR-10 ratings as force increases from 25 to 40% MVC.

	25% DC	50% DC	75% DC	Means
1 second	1.7	2.7	2.9	2.4
4 seconds	1.5	1.5	2.6	1.8
7 seconds	2.1	2.1	2.6	2.3
Means	1.8	2.1	2.7	2.2

Table 11 Difference in Borg CR-10 ratings as DC increases from 25 to 50%.

	10% MVC	25% MVC	40% MVC	Means
1 second	0.4	1.4	1.6	1.1
4 seconds	0.3	1.5	2.4	1.4
7 seconds	0.7	1.8	2.3	1.6
Means	0.5	1.6	2.1	1.4

Table 12 Difference in Borg CR-10 ratings as DC increases from 50 to 75%.

	10% MVC	25% MVC	40% MVC	Means
1 second	0.4	1.4	1.6	1.1
4 seconds	0.3	1.5	2.4	1.4
7 seconds	0.7	1.8	2.3	1.6
Means	0.5	1.6	2.1	1.4

Table 13 Difference in Borg CR-10 ratings as duration increases from 1 to 4 seconds.

	25% DC	50% DC	75% DC	Means
10% MVC	-0.5	-0.7	-0.8	-0.7
25% MVC	-0.1	-0.4	-0.3	-0.3
40% MVC	-0.3	-1.4	-0.6	-0.8
Means	-0.3	-0.8	-0.6	-0.6

Table 14 Difference in Borg CR-10 ratings as duration increases from 4 to 7 seconds.

	25% DC	50% DC	75% DC	Means
10% MVC	0.2	-0.2	0.2	0.1
25% MVC	0.1	-0.4	-0.1	-0.1
40% MVC	0.7	0.0	-0.1	0.2
Means	0.3	-0.2	0.0	0.1

Table 15 P-values, AIC scores, and adjusted R-squared values for linear regression models with final Borg CR-10 rating as the dependent variable

Parameter	Model 1	Model 2
%MVC	$p \leq 0.01$	$p = 0.07$
Duty Cycle (DC)	$p = 0.61$	---
Duration of Exertion (D)	---	$p = 0.64$
Frequency of Exertion (F)	---	$p = 0.73$
%MVC * DC	$p \leq 0.01$	---
%MVC * F	---	$p = 0.47$
%MVC * D	---	$p = 0.49$
%MVC * F * D	---	$p \leq 0.01$
Subject*	$p \leq 0.01$	$p \leq 0.01$
Trial	$p = 0.18$	$p = 0.17$
Adjusted R-Squared	0.632	0.641
AIC Score	1598.922	1591.732

*Subjects were treated as a random effect in each model.

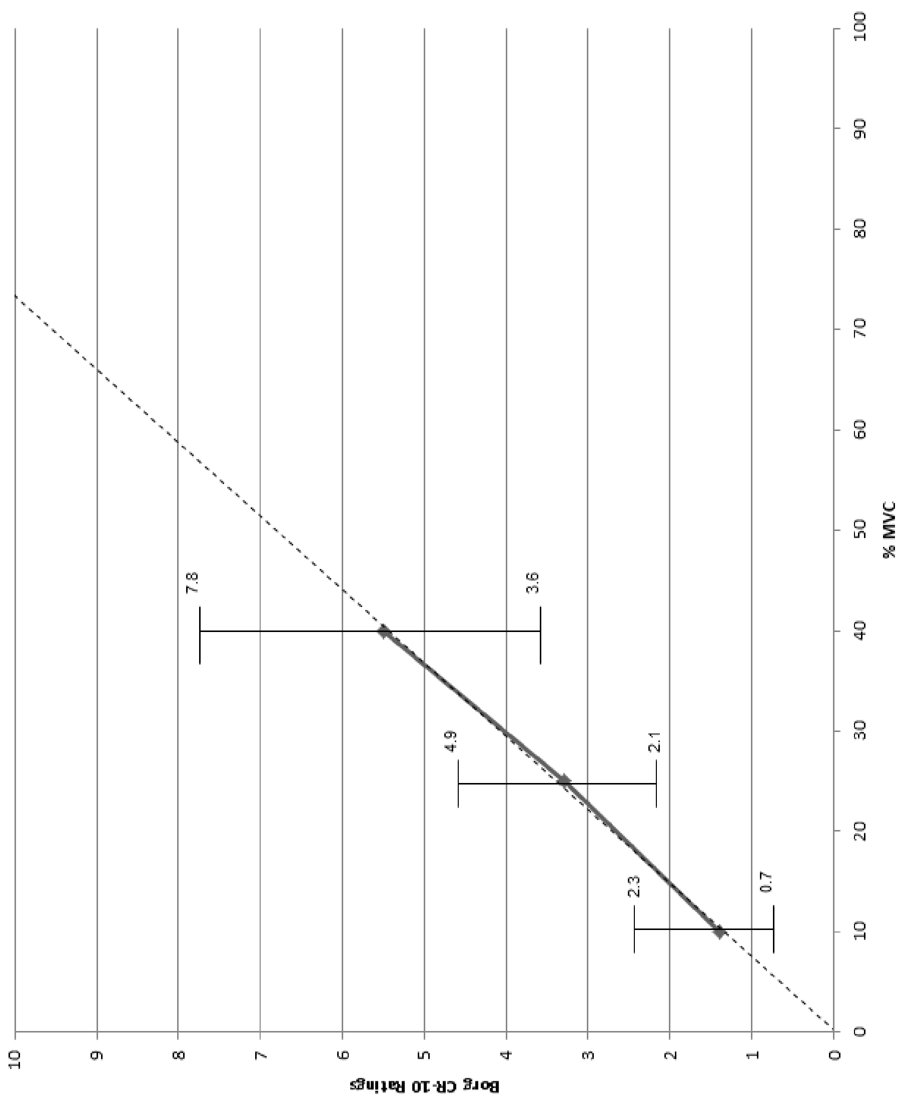

Figure 4 Relation between % MVC & average Borg CR-10 ratings

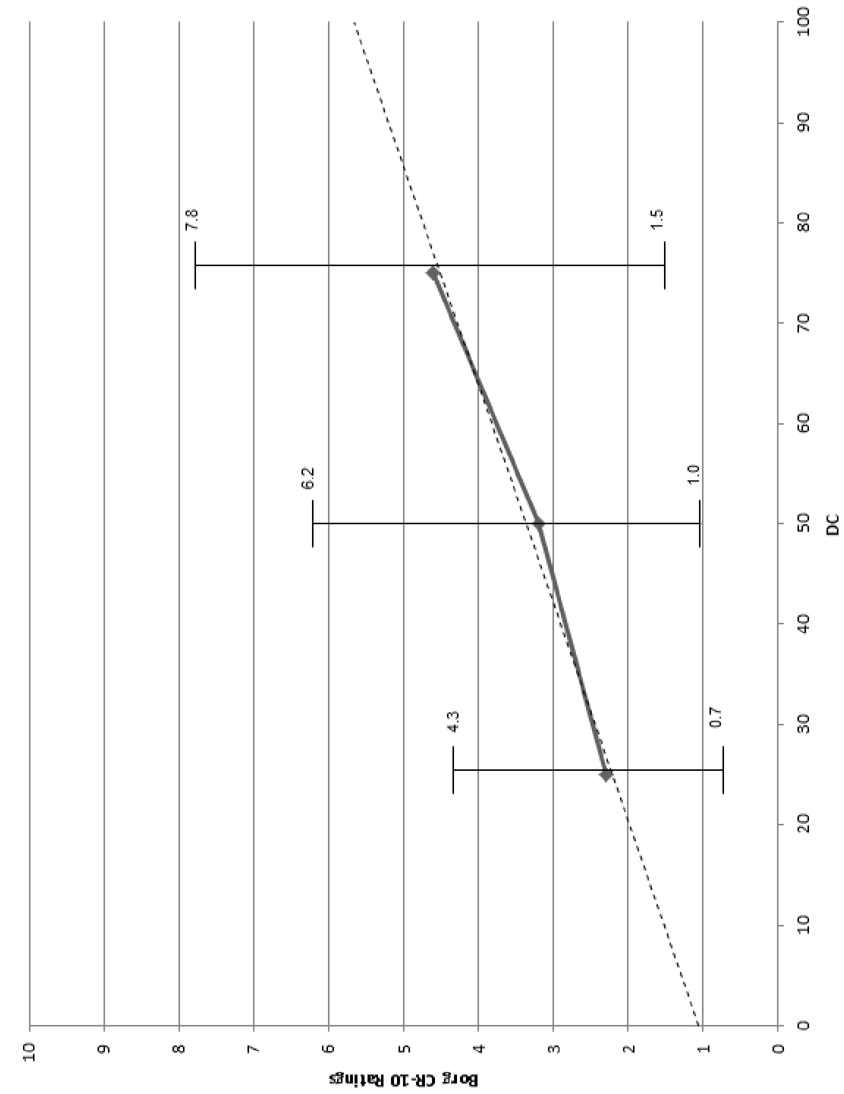

Figure 5 Relation between DC & average Borg CR-10 ratings

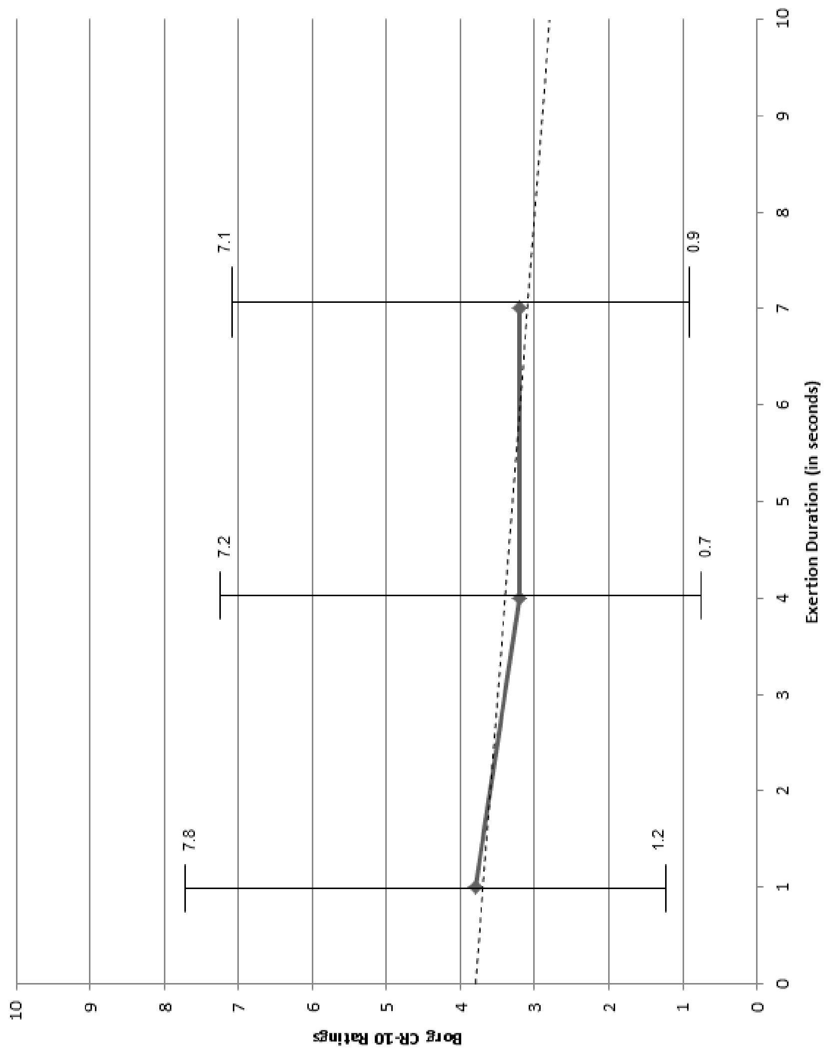

Figure 6 Relation between Duration of Exertion & average Borg CR-10 ratings

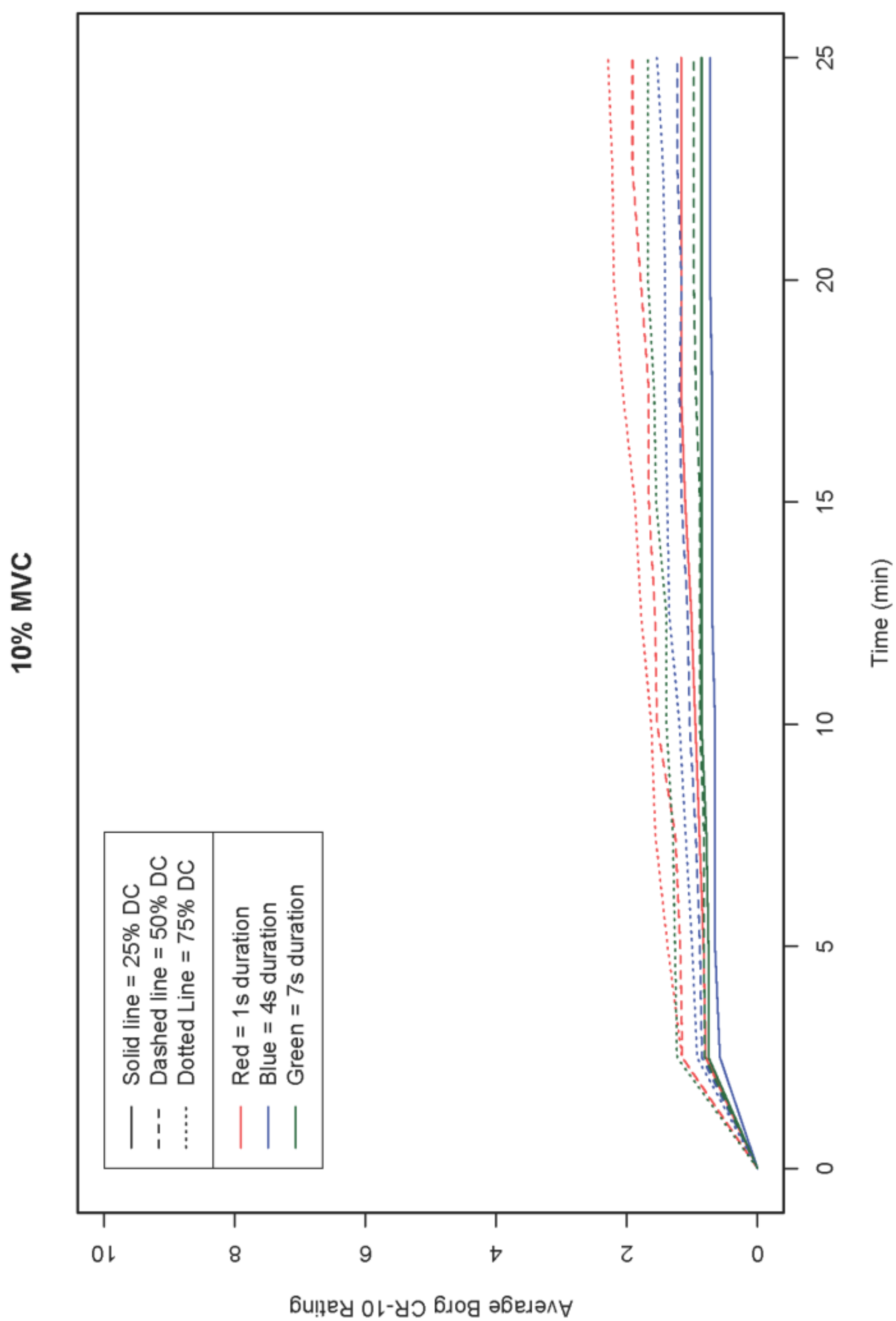

Figure 7 10% MVC: Time in minutes vs. Borg CR-10 Ratings (full scale)

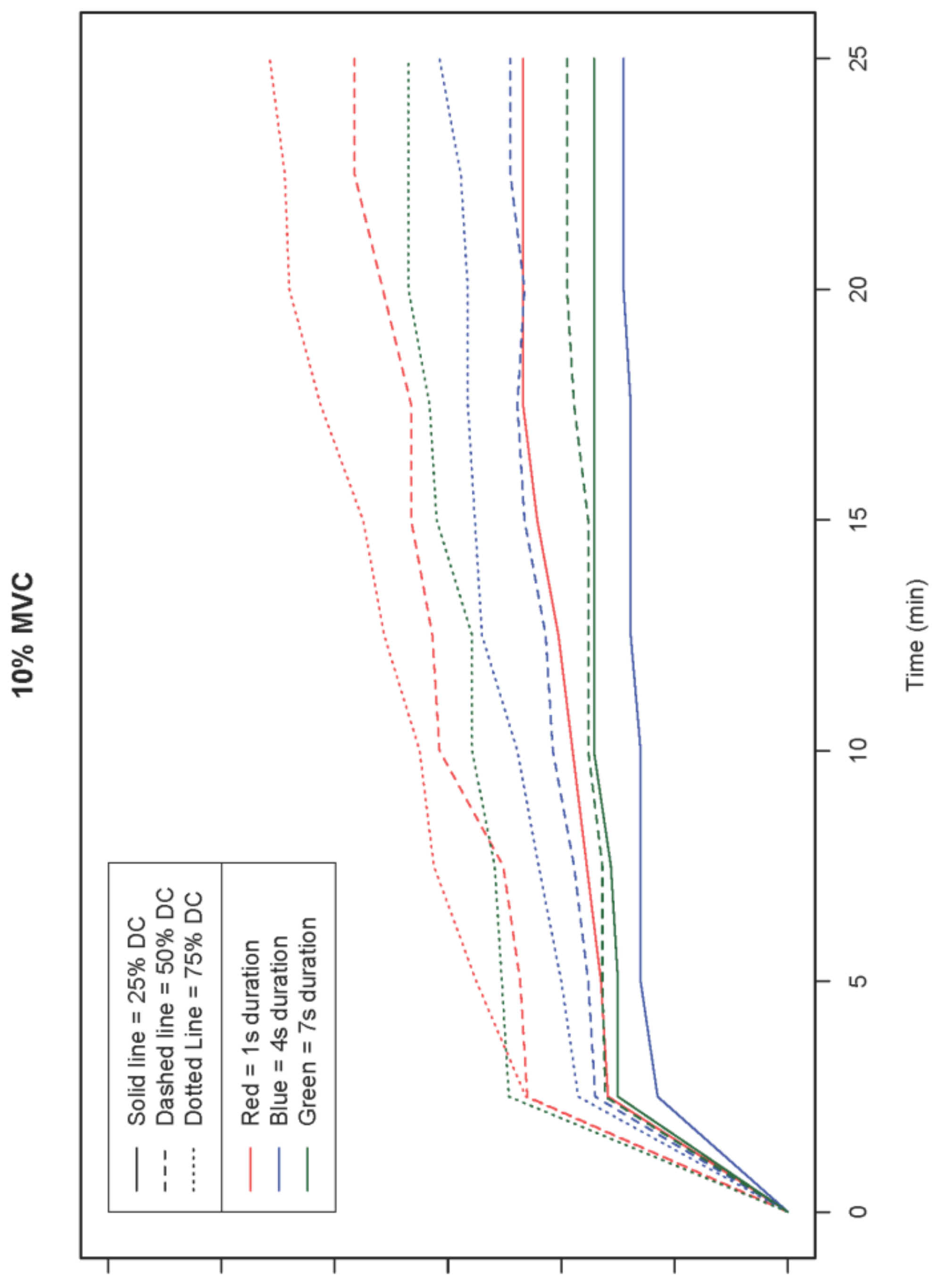

Figure 8 10% MVC: Time in minutes vs. Borg CR-10 Ratings (partial scale)

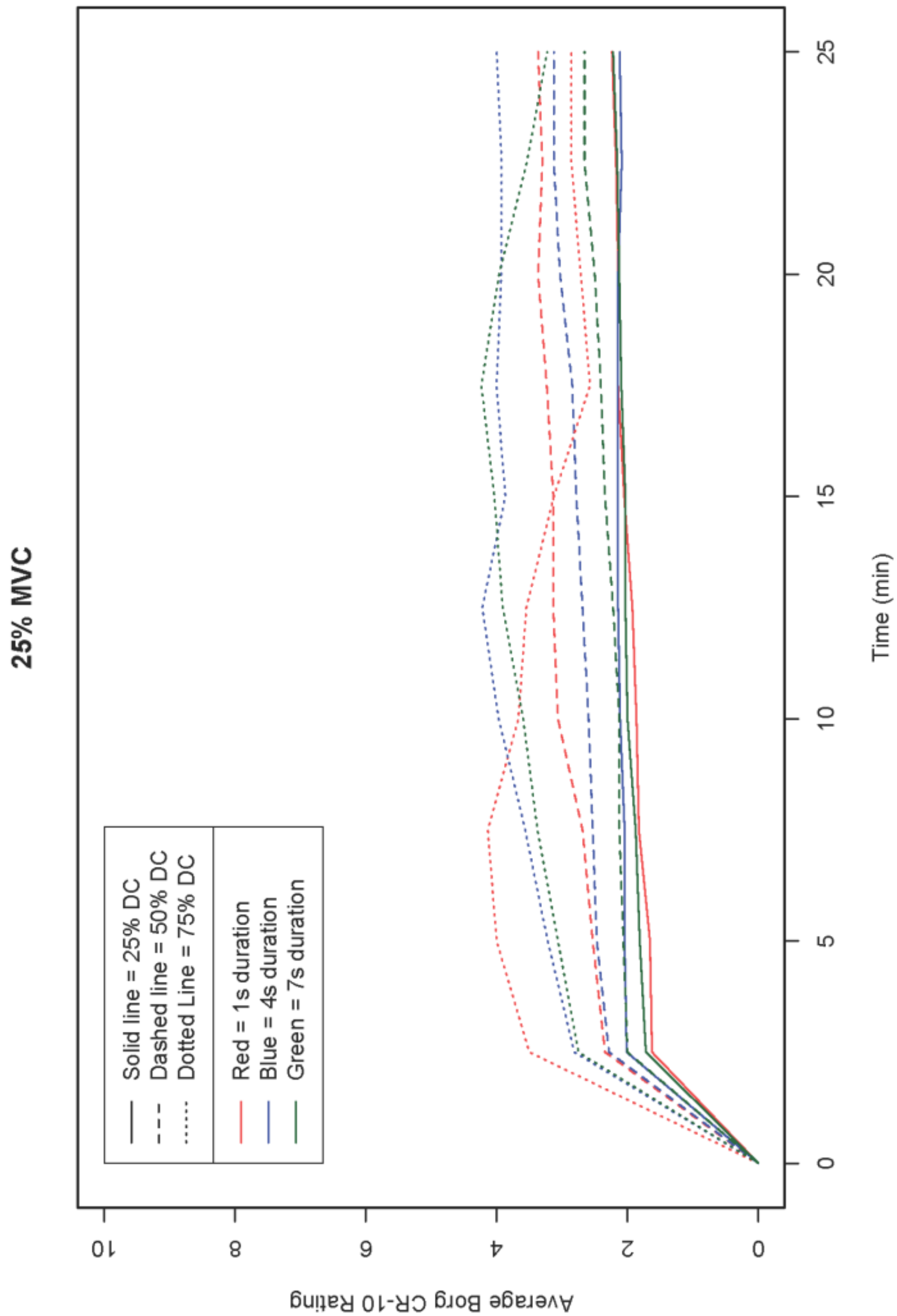

Figure 9 25% MVC: Time in minutes vs. Borg CR-10 Ratings (full scale)

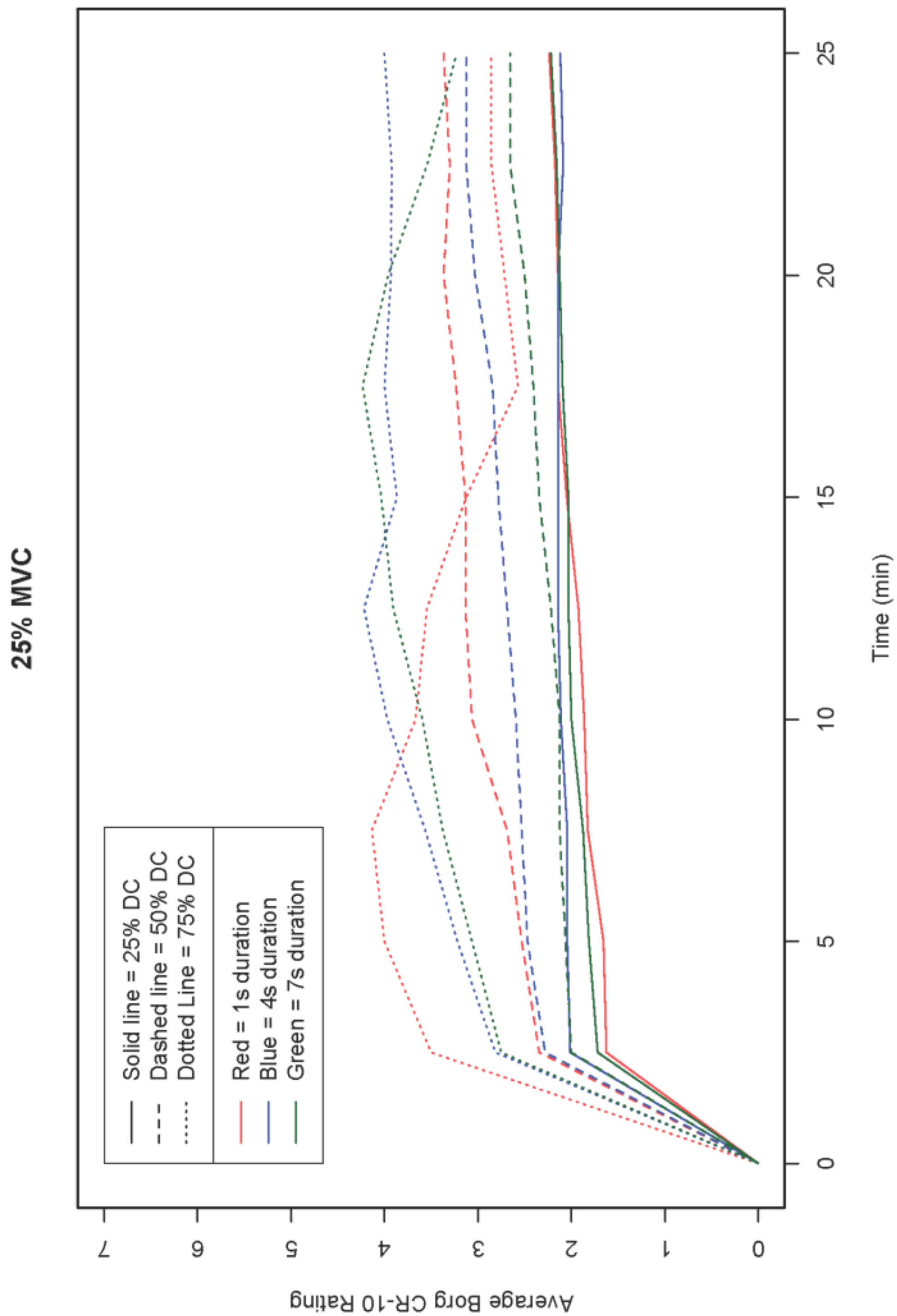

Figure 10 25% MVC: Time in minutes vs. Borg CR-10 Ratings (partial scale)

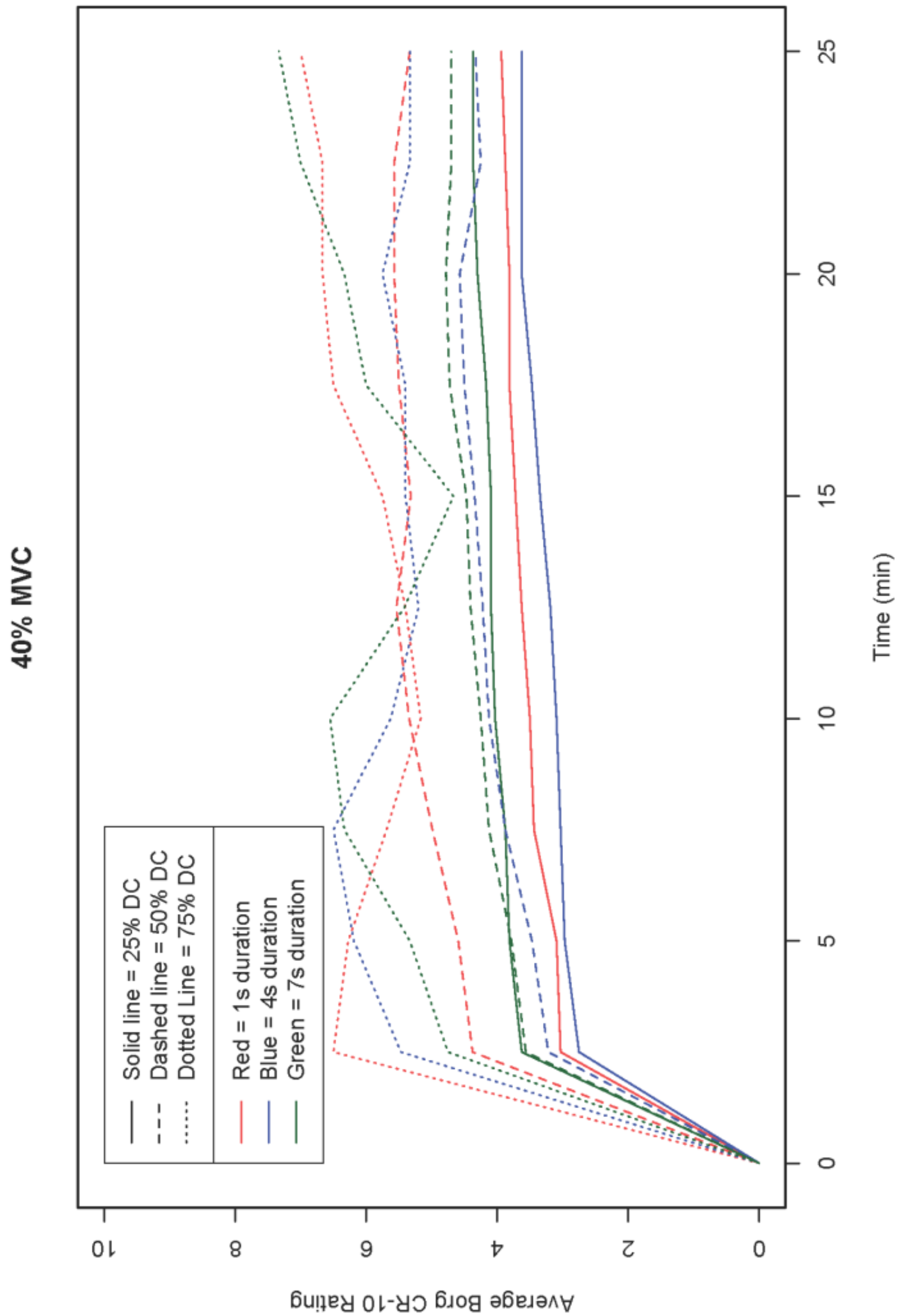

Figure 11 40% MVC: Time in minutes vs. Borg CR-10 Ratings (full scale)

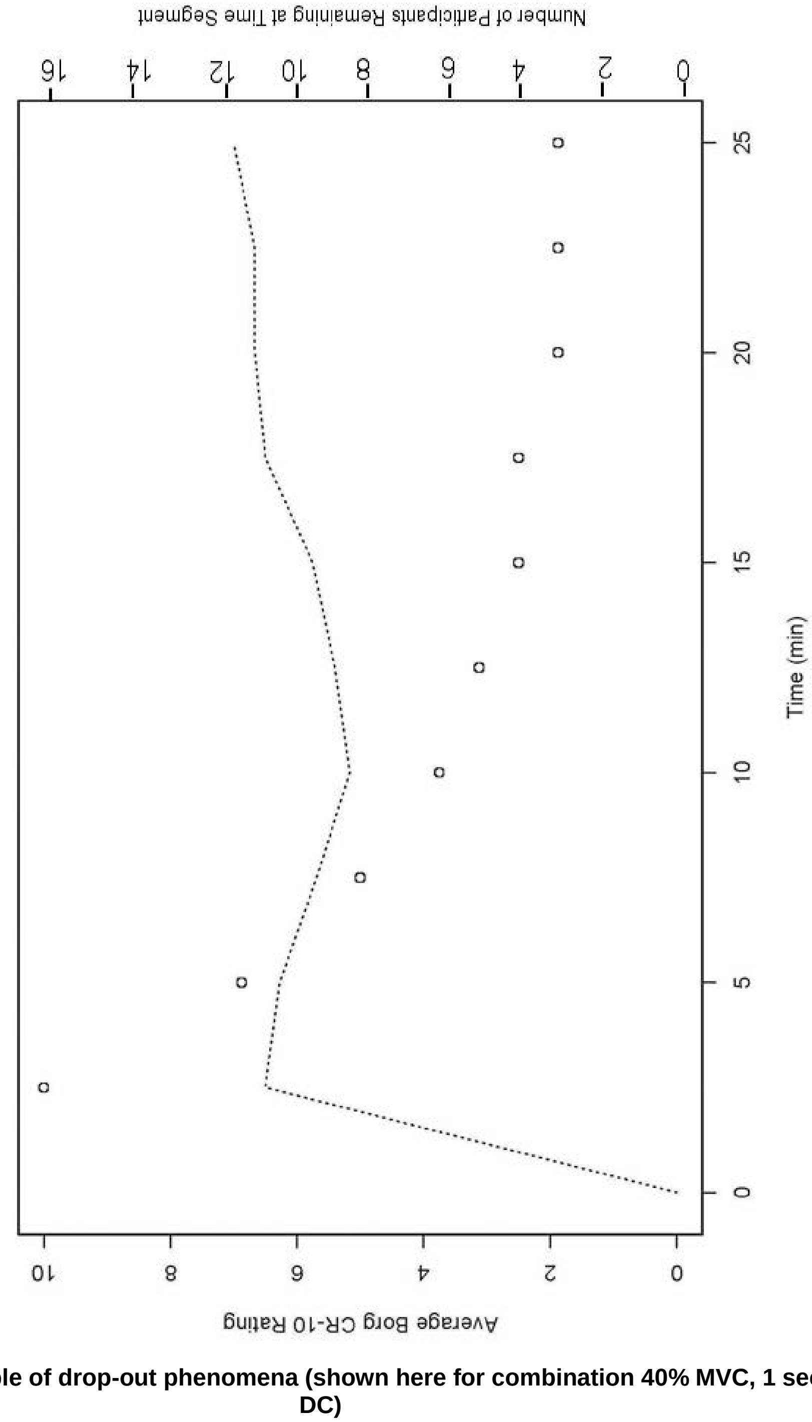

Figure 12 Example of drop-out phenomena (shown here for combination 40% MVC, 1 second, 75% DC)

Discussion

Consideration of Factors Independently

The results of this study clearly show force as the dominant factor affecting exertion ratings. Borg CR-10 ratings increased in a fairly linear fashion as force increased from lower to higher test parameters and force appears to be a generally good predictor of perceived exertion. This implies that higher forces should be avoided and lower force requirements should be the general objective in job design. This finding is consistent with several studies showing that, as power grip force increases, perceived exertion also increases (Li & Yu, 2011; Grant et al., 1994; 1996; Buchholz et al., 2008).

The relation between % MVC and average Borg CR-10 ratings (shown in Figure 4) results in a fairly steep slope. For the current study, at 10% MVC, subjects found the exertion somewhere between an “extremely weak” and slightly beyond a “weak” exertion at the final given rating. The range varies more when compared with other studies also done at low MVCs (5 -15%) (Table 1); perceived exertions were similarly rated as low as “extremely weak” but ratings went as high as “strong.” The probable reason for such a high rating at a low MVC is because the “strong” rating (Harber, 1994) was for a precision grip, rather than a power grip. All other power grips from previous studies at this level were comparable. In the current study, at 25% MVC, subjects found the exertion to be anywhere from “weak” to “strong” at the final rating. Studies at similar % MVCs (17.5 – 30.78%) began as low as “very weak” (Grant et al., 1994) and went as high as “strong +” (Klein & Fernandez, 1997). The high rating is once again due to being a precision pinch. The “very weak” rating could be in part due to the type of task being performed in the study, as subjects were required to transfer a 1.1 kg object (using a lifting motion) once every 5 seconds for 2.5 minutes (Grant et al., 1994). Although Grant et al. (1994) was similar to the current study in that subjects performed a dynamic task, the study differed in that the amount of time for their task was only 10% of that of the current study (2.5 versus 25 minutes). Lastly, at the highest tested MVC (40%) for the current study, subjects rated the exertions between "somewhat strong" and "very strong." This is congruent with what was found in the literature at similar force levels of 40-50% MVC (Byström & Kilbom, 1990; Dahalan & Fernandez, 1993; Klein & Fernandez, 1997).

The results of this study also showed that, at a given force level, perceived exertion generally increase as DC increases. This is supported by a meta-analysis done by Potvin (2012) which found that there is a negative exponential relationship between duty cycle and maximum voluntary effort in UE tasks. Potvin's work therefore suggests that as duty cycle increases, the amount of effort a subject can produce decreases. The current study found similar results at the given test parameters. Figure 5 shows that like force, DC has essentially a linear relation with exertion – ratings of perceived exertion increased as DC also increased and lower DCs showed lower ratings of perceived exertion. However, the slope is not as steep, and there is more variability in the mean ratings at each DC (as compared to the slopes and ratings for MVC in Figure 4), suggesting that that force alone is a somewhat more reliable predictor of perceived exertion than DC alone. For example, based on results of the current study, DC needs to increase by 18-23 units to see a 1 unit increase in Borg CR-10 rating, whereas only a 7-8 unit increase in %MVC results in a 1 unit change in Borg CR-10.

At given DCs, the final perceived exertion ratings ranged as follows: i) at 25% DC: “very weak” to “somewhat strong” ii) 50% DC: “very weak” to “strong +” iii) 75 % DC: “very weak” to “very strong.” These results are similar to other studies when broken down into similar DCs (Table 1), with the exception of the lowest DC. Dahalan & Fernandez (1993) found that subjects rated a wire crimping task at DCs around 20% to be “very strong.” These ratings were given for 50% and 70% MVC - higher than the parameters of the current study – and suggests that subjects might have been responding to high force levels as opposed to the effects of DC.

Exertion time (duration) seems to have almost no effect on perceived exertion levels for a given force and duty cycle – this can be seen by the almost straight line relation between average Borg CR-10 ratings and duration (Figure 6), as well as the broad range of ratings. For all tested durations, the Borg CR-10 ratings ranged from “very weak” to “very strong,” regardless of whether it was a 1, 2, or 7 second duration. When considering duration in other studies, the results also reflected the same wide range of exertion ratings at similar durations (Table 1).

Interaction among Factors

Although higher forces (and to a lesser extent, higher DCs) seem to have a distinct role in increasing Borg CR-10 ratings, examining these factors independently does not give a full picture as to what is happening during physical exertions. For example, when looking at individual combinations in this study, there were combinations which could not be completed, despite being at lower forces (i.e., 10 % MVC, duration 1 second, DC 75%), and conversely, not all combinations at the highest force level resulted in high ratings or drop-outs. Likewise, there were combinations at higher DCs that did not result in drop-outs. If one factor alone could predict exertion levels, it would be expected that subject ratings and drop-outs would have been essentially the same for all combinations at that tested parameter. However, this was not the case, and implies that focus should not be entirely on one factor, but rather on the interaction among the factors. Statistical analysis for the current study supports this interpretation. For both statistical models tested, the interaction among factors was statistically significant ($p \leq 0.01$). Model one showed that the interaction among % MVC and DC was significant; model two showed that the interaction among % MVC, duration of exertion, and frequency of exertion were significant.

Prior lab studies have not studied the three-way interaction between force, DC, and duration of exertion; however, a few studies have studied interactions between force and either frequency, or DC, or duration of exertion. Potvin et al. (2006) found a correlation between force and frequency of grip with higher force by frequency exertions resulting in lower acceptable levels of work output. Byström & Kilbom (1990) showed that levels of force combined with rest (regardless of the amount of rest) result in lower levels of perceived exertion, as compared to continuous durations of exertion. Finneran & O'Sullivan (2010) also found an interaction between force and duration of exertion with higher forces combined with shorter durations resulting in greater discomfort among subjects. DC (which combines frequency and duration) has also been shown to have a stronger effect on predicting maximal effort from subjects, as compared to frequency alone (Potvin, 2012). All of these conclusions are congruent with the current study in showing that while each factor is playing a role in a subject's perceived level of exertion, combinations of these factors result in superior associations and thus, perceived exertion should not be predicted based on duration, DC, or force alone, but rather on the combination of those factors.

When looking at Figures 7 through 12, it is evident that different combinations result in different levels of perceived exertion. Furthermore, comparing the figures at different force levels shows that there is a complexity to the interaction of factors. While the trend is that higher forces and higher DCs tend to result in higher Borg CR-10 ratings, the relationship is not entirely consistent, particularly when duration is factored in. For example, at the lowest force tested in this study, two of the three most difficult combinations were both at 1 second in duration, even given a moderate DC. In contrast, at the lowest force level, two of the three easiest combinations are 7 seconds in duration, regardless of DC. As force increases, it seems that DC rather than duration has a more predominant effect on exertion ratings. For both 25% and 40% MVC, the 3 most difficult combinations are all at 75% DC (all durations), whereas the three easiest are at 25% DC (all durations). This suggests that at lower forces, shorter exertion durations may increase ratings of perceived exertion to a greater extent than DC; at higher forces, DC becomes increasingly important as compared to duration. Since DC combines frequency and duration, all of the short durations (1 second) in all cases of this study represent the 3 highest frequencies (45 grips/minute, 30 grips/minute, and 15 grips/minute). Therefore, it is somewhat surprising that at the lowest force, high frequency played a stronger role than at higher forces in this study. At higher forces, DC showed a greater effect than frequency alone (based on visual analysis of Figures 7 –

12). Again, since DC combines duration and frequency, this contributes to the idea that the interaction of factors is stronger than considering one factor by itself.

Although the current study was not addressing the question of injury directly, it is important to note that data from epidemiological studies also suggest that an interaction among key physical stressors are more likely to lead to certain DUE injuries. High force combined with high frequency, for example, is shown to have a greater effect than either factor alone on increasing DUE musculoskeletal injury (Garg & Kapellusch, 2011). This is somewhat different than what the current study found, but that could be because the relative forces tested in this study were all low, even at the highest tested force – 40% MVC. Specific to carpal tunnel syndrome (CTS) in the workplace, Fan et al. (2015) found that high frequency alone was not associated with an increased risk of CTS; however, a combination of forceful exertions and high frequency were associated with CTS. Similarly, an interaction of increased duty cycle, posture, and forceful exertion were shown to be predictors of lateral epicondylitis (Fan et al., 2014). These findings combined with the current study are further validation of the concept that interaction should be considered when assessing jobs as being safe or not.

Sustainability of Tasks

Sustainability of work refers to whether or not a subject can continue to perform a trial combination at relatively low level of perceived exertion, for a given amount of time. Both drop-outs and high Borg CR-10 ratings give insight into whether or not a combination is sustainable. As mentioned earlier, there were certain combinations in the current study that resulted in drop-outs and/or relatively high Borg CR-10 ratings. Based on findings from Capodaglio, Capodaglio, & Bazzini (1995), the threshold for prolonged lifting tasks correlate to a “moderate” level, or 3, on the Borg CR-10 scale. Using this guideline, it can be assumed that Borg CR-10 ratings of 4 or higher suggest a combination cannot be sustained for a prolonged period of time. In the current study, mean exertion ratings at the lowest tested force level and after 25 minutes were at most rated as “light/weak” (Borg CR-10 of 2.3), whereas at the highest force were considered to be “very strong” (Borg CR-10 of 7.8). Since some of the Borg CR-10 ratings are beyond 4 after only 25 minutes, we can conclude that these combinations are not feasible for long periods of time.

Drop-outs during the current study also suggest which combinations were not sustainable. Traditional psychophysical studies generally do not consider this phenomenon of “drop-outs” because subjects are able to adjust some parameter of the study in order to continue for the duration of the trial. For example, subjects perform a trial for a given amount of time and adjust a parameter such as frequency (MAF) until it is felt that it could be performed for an eight-hour workday (Fernandez & Marley, 2014). This study was unique in that the parameters were set, and subjects would simply stop when they felt it was too difficult to continue (“drop-out”). This difference in approach makes it difficult to compare sustainability across studies. However, we can evaluate which combinations subjects gravitate towards in both types of studies.

Twelve of the twenty-seven combinations of this study resulted in drop-outs; no combination resulted in all subjects dropping out (Table 5). Yet, every subject dropped out of at least one trial at some point. These combined findings lead to a belief that not all combinations have the same effect on everyone. Generally, increased force and higher DC were the least sustainable. Seven of the nine combinations at the highest test force resulted in drop-outs. Furthermore, the top three combinations with drop-outs were at the highest force/highest DC and resulted in 82% of subjects dropping out before the end of the 25 minute trial. Also, at every force level, 75% DC at 1 second duration resulted in drop-outs. Certainly this would suggest that these high DC and short duration combinations are not sustainable. On the other hand, at the highest tested force, the two combinations that did not result in drop-outs were at the lowest DC and longer durations (4 and 7 seconds).

Overall, there is still debate in the literature as to what levels/combinations of factors are indeed safe or sustainable from the standpoint of job design. Garg & Kapellusch (2011) have stated that there are inconsistencies in what is considered “high force” or “high repetition” in job design and what levels are safe. Currently, ergonomists use various methods to assess jobs, and depending on the method used, or the definitions of what is considered “high” or “low” in relation to stress factors could result in very different conclusions regarding job analysis (Garg & Kapellusch, 2011). Regardless, the relatively low force levels that resulted in clearly unsustainable work conditions suggest that the physical exposures associated with truly sustainable (i.e., safe) work, are relatively low.

Discussion Related to Hypothesis & Clinical Significance

There is a statistically significant difference between the two models used for testing the null hypothesis. This indicates that the null hypothesis should be rejected, and the alternate hypothesis accepted. Therefore, different combinations of frequency and exertion time (duration) do have an effect on ratings of perceived exertion (Borg CR-10 rating) above and beyond what DC alone is able to describe. However, while there is a statistical difference between the models, it is relatively small. Considering the factors independently (as Model 2 does) may give more descriptive details about the levels of exertion, but given that the adjusted R-squared values between models differs by only about 1%, the difference may not be worth the additional measurement requirements needed to obtain the modest increase in precision. As mentioned earlier, DC is a practical and convenient method for assessing jobs and the results of this study suggest that DC is sufficient for a wide variety of fairly common durations and frequencies of exertions. However, it should be noted that, while somewhat high frequencies of exertion were tested, the longest duration was 7 second and this might not be representative of stresses associated with prolonged static exertions in some jobs.

Limitations & Suggestions for Future Research

Although the current study design did use a wide range of frequencies (2.14 - 45 grips/minute) within the duty cycle combinations, the durations were not as broad. The small range of durations tested (1, 4, 7 seconds) is a limitation. Perhaps with a greater range, we may begin to see a stronger effect of this variable on perceived exertion. The durations for the study were chosen to reflect previous studies as well as more common workplace efforts. Further research may sample more extreme duration ranges to more fully observe the effects of higher durations. For instance, in an earlier example, a duty cycle (DC) of 50% could be the result of thirty 1-second efforts, or one 30-second effort. Testing extreme scenarios such as this one could add depth to the current research.

The current study considered 40% MVC as its highest force. Even at this relatively modest level, the study resulted in some task combinations that were too difficult for subjects to complete for a full 25 minutes. It is likely that higher forces would result in an even greater challenge; however, since they were not tested, this paper could not generalize to forces beyond 40% MVC. It is recommended that more data be collected at higher forces, and with mixes of high and low forces to better understand the effects of force in real-world conditions.

The subjects in this study were the result of convenience sampling on a college campus. As such, the resulting demographics are not representative of a typical workforce. This is a limitation of the study, and an older subject-base would add depth to the generalizability of these results into the workplace.

Conclusion

In job analysis, there is a need to more accurately define what factors affect a worker's potential risk for distal upper extremity injury. Ergonomists may use duty cycle (a mathematical combination of frequency * duration) as a convenient way to measure the percent of work being done by the hands during a work task. This lab study tested three duty cycles comprised of different combinations of frequencies and durations, to see if factors needed to be considered separately or if duty cycle alone could determine exertion levels. Results found that independent effects were not statistically significant and that interactions between force and duty cycle, or force, duration and frequency of exertion are needed. As independent factors, force appeared to have the strongest association with perceived exertion levels, followed by duty cycle (DC). Duration alone did not appear to be associated with perceived exertion. Interaction effects were found to have statistically significant effects for: i) % MVC * DC and ii) % MVC * frequency * duration. Subjects were unable to sustain certain tasks, particularly those with combinations of high DC and high force. At the tested levels, it appears that DC alone can be used to assess exertion levels; however, caution should be used when either frequency or duration are at extreme levels within the given DC. Based on sustainability and perceived exertion ratings, combinations of high force combined with high DC should be avoided, as they are likely not sustainable for even a couple hours, much less an entire workday. Combinations that are more sustainable are those which combine lower forces with low to moderate DCs.

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Appendix A: Flyer

Opportunity

Be a participant for an experiment!

We do research on the 9th floor of Enderis (END 980), and we need subjects to participate in our study involving hand grip. Participants are asked to take part in 2 one-hour sessions and 18 two-hour sessions, over the course of the spring semester. You have the potential to earn $354 upon completion of all sessions!

In order to participate you must:

- Be a female between 18-35 years old.
- Be English speaking.
- Be able to hear auditory cues.
- Not have any disabilities or recent surgeries of the neck, shoulder, arm, forearm, or wrist.

Email jgall@uwm.edu for more information.

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Appendix B: IRB Approval

UNIVERSITY of WISCONSIN
UWMILWAUKEE

Department of University Safety & Assurances

Melissa Spadanuda
IRB Manager
Institutional Review Board
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Milwaukee, WI 53201-0413
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New Study - Notice of IRB Expedited Approval

Date: January 23, 2015

To: Jay Kapellusch, PhD
Dept: Occupational Science and Technology

Cc: Jessica Gall

IRB#: 15.199
Title: The effects of applied grip force on ratings of perceived exertion for frequencies and durations of exertions that result in the same duty cycles

After review of your research protocol by the University of Wisconsin – Milwaukee Institutional Review Board, your protocol has been approved as minimal risk Expedited under Category 4 and 7 as governed by 45 CFR 46.110.

This protocol has been approved on **January 23, 2015** for one year. IRB approval will expire on **January 22, 2016**. If you plan to continue any research related activities (e.g., enrollment of subjects, study interventions, data analysis, etc.) past the date of IRB expiration, a continuation for IRB approval must be filed by the submission deadline. If the study is closed or completed before the IRB expiration date, please notify the IRB by completing and submitting the Continuing Review form found in IRBManager.

Any proposed changes to the protocol must be reviewed by the IRB before implementation, unless the change is specifically necessary to eliminate apparent immediate hazards to the subjects. It is the principal investigator's responsibility to adhere to the policies and guidelines set forth by the UWM IRB, maintain proper documentation of study records and promptly report to the IRB any adverse events which require reporting. The principal investigator is also responsible for ensuring that all study staff receive appropriate training in the ethical guidelines of conducting human subjects research.

As Principal Investigator, it is your responsibility to adhere to UWM and UW System Policies, and any applicable state and federal laws governing activities which are independent of IRB review/approval (e.g., FERPA, Radiation Safety, UWM Data Security, UW System policy on Prizes, Awards and Gifts, state gambling laws, etc.). When conducting research at institutions outside of UWM, be sure to obtain permission and/or approval as required by their policies.

Contact the IRB office if you have any further questions. Thank you for your cooperation and best wishes for a successful project.

Respectfully,
Melissa C Spadanuda
Melissa C. Spadanuda
IRB Manager

Appendix C: Informed Consent

Informed Consent | IRB Protocol Number:
Version: | IRB Approval Date:

UNIVERSITY OF WISCONSIN – MILWAUKEE
CONSENT TO PARTICIPATE IN RESEARCH

1. General Information

Study title:
The effects of applied grip force on ratings of perceived exertion for frequencies and durations of exertions that result in the same duty cycles.

Person in Charge of Study (Principal Investigator):
Supervising Professor
Jay Kapellusch
Assistant Professor: Occupational Science and Technology
Student Researcher
Jessica Gall, Graduate student in Occupational Therapy at UWM

2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

Study description:
The purpose of this study is to determine your perceptions of force, fatigue, and pain while applying grip force. This information is useful to practitioners that design jobs, and products that require intensive use of hands.

If you choose to participate you will perform various combinations of force, frequency of exertion and duration of exertion over a total of 18 sessions. Each session will consist of 3 trials. Each trial will last 25 minutes and will be followed by at least 12 minutes of rest. Every 2.5 minutes during a trial you will be asked to rate your sensation of force, pain, and fatigue on verbal-anchor scales.

Prior to conducting these 18 sessions, you will participate in two, 1-hour sessions. The first session will determine your maximum grip strength. The second session will confirm your maximum grip strength and provide you with an opportunity to practice using the repetitive grip-device and to provide force, pain, and fatigue ratings using the verbal-anchor scales.

The study will take place on the 9th floor of Enderis, in the Ergonomic Laboratory, room END 980. You will be one of 12 female subjects (aged 18- 35 years) that will complete the study. You will come to the lab on twenty separate occasions for testing sessions. Each session will be separated by a minimum of 12 hours to ensure adequate rest time. The first two sessions will be one hour, and the remaining 18 sessions will be two hours each. Thus, it is anticipated that you will participate for a total of 38 hours, though it is possible that you might need to repeat a test session, or break a session into multiple parts due to unusual hand/arm fatigue. However, this is unlikely. The experiment timeline requires the sessions to be completed before the end of the summer (August, 2015). Please do not participate if you believe you will not be able to complete the study by that time.

3. Study Procedures

What will I be asked to do if I participate in the study?
If you agree to participate you will be asked to come to END 980 at scheduled time slots to participate in the study. You will be asked to participate in 18 two-hour sessions and 2 one-hour sessions. Sessions will be held on different days, with a minimum of 12 hours between sessions, to allow adequate recovery time.

1. The first session (one hour) will be an introduction to the study, to obtain informed consent, and to determine your maximum grip strength. We will also take measurements of your hand to determine it's size, and record your age in years.
2. The second session (one hour) will be a practice session to confirm your maximum grip strength, and give you time to practice the study. During this practice session you will be asked to perform 4 separate grip combinations. During testing, you will grip when you hear a beep, and will continue gripping until the beep stops. Each combination will last 7 minutes, with 5-minute rests between. Ratings of perceived force, pain and fatigue will be taken every minute.
3. Sessions 3 to 18 (two-hour sessions) will each consist of three random 25-minute trials. These trials will be similar to those in practice except that they will be 25 minutes long and you will provide ratings every 2.5 minutes during the trial. Following each trial you will be given a minimum of 12 minutes of rest. However, you can take more rest if needed.
4. Some trial combinations may be too physically difficult for you to complete. In this case, you will perform the trial for as long as you are able and then tell the researcher that you need to stop the trial. You will be offered additional rest following these trials.

4. Risks and Minimizing Risks

What risks will I face by participating in this study?
There are no foreseeable, long-term risks associated with participating in this study. You will likely experience some hand/arm pain or discomfort during certain test combinations. This pain is expected to fully resolve after a few minutes of rest. Following each trial your hand/arm muscles will likely feel tired or fatigued. We have provided rest breaks during testing that should be sufficient to minimize most of this fatigue. However, we expect that many subjects will experience some minor hand/arm fatigue similar to a workout at the gym following each session. In rare circumstances, this tiredness might interfere with other hand activities, such as writing with a pen, for up to a few hours following a session.

If you perform a job or activity that requires heavy use of your hands, such as restaurant server, or playing racquetball, we encourage you to schedule your sessions so that they will not interfere with those activities. If this is not possible, please do not participate in this study.

If at any time you feel unusual pain, discomfort, or fatigue, please inform the researcher so that we can stop your testing.

For your own safety, please do not participate in this study if you have a disability or reduced function in your dominant arm, or physician's orders to not exert force with your dominant arm.

5. Benefits

Will I receive any benefit from my participation in this study?
There are no direct benefits to you for participating in this study other than monetary compensation as described below.

6. Study Costs and Compensation

Will I be charged anything for participating in this study?
You will not be responsible for any of the costs from taking part in this research study.

Are subjects paid or given anything for being in the study?
For participating in this study you will receive $8 per one-hour session and $16 per two-hour session for an anticipated $304. Additionally you will receive $50 upon completion of all sessions. Thus your total compensation is anticipated to be $354. Due to UWM policy and IRS regulations, we are required to have you complete a W-9 form (which includes your name, address, social security number (or tax ID number), and signature, in order for Accounts Payable to issue a check to you. Please note: UWM employees will be paid through the payroll process.

7. Confidentiality

What happens to the information collected?
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others, or publish our results in scientific journals or at scientific conferences. Information that identifies you personally will not be released without your written permission. Only Dr. Kapellusch, and his research assistants will have access to the information. However, the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records.

All subject information will be coded during testing. Only a unique code will be used to identify your information. Once the study is complete, the key linking your name to this code will be destroyed. All paper files will be stored in locked file cabinets and all electronic records will be stored on password protected computers. Only Dr. Kapellusch and his research staff will have access to these files. Data containing your name and unique code will be kept for up to 6 years following study completion (7 years total). After that time, your subject code will be replaced with a random identifier (ie, de-identified) within our dataset that contains your age, subjective ratings, hand/arm measurements, and height and weight. All other records, including consent forms will be destroyed. This will effectively eliminate all links to you as an individual. The final, de-identified dataset will be kept indefinitely for future analyses.

8. Alternatives

Are there alternatives to participating in the study?
There are no known alternatives available to you other than not taking part in this study.

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?
Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee. If you decide to withdraw from the study, we will use the information collected to that point.

10. Questions

Who do I contact for questions about this study?
For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Principal Investigator
Jay Kapellusch
Assistant Professor
Enderis Hall 961
(414)229-5292

Student Investigator
Jessica Gall
1023 Augusta Ave
Wausau, WI 54403
(715) 432-1146

Investigators' Emails
kap@uwm.edu
jgall@uwm.edu

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?
The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:
To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

____
Printed Name of Subject/ Legally Authorized Representative

____________________________________ ________________
Signature of Subject/Legally Authorized Representative Date

Principal Investigator (or Designee)
I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

____________________________________ ________________
Printed Name of Person Obtaining Consent Study Role

____________________________________ ________________
Signature of Person Obtaining Consent Date

Appendix D: Anthropometric Data of all Subjects

Subject #	Hand Length (in)	Hand Width (in)	Thumb Length (in)	Index Finger Length (in)	Middle Finger Length (in)	Ring Finger Length (in)	Little Finger Length (in)	Wrist Width (in)	Wrist Depth (in)
1	7.75	3.75	2.5	3.25	3.75	3.375	2.75	2.125	1.375
2	6.75	3.625	2.375	3	3.375	3	2.25	2	1
3	5.5	3	2	2.25	2.375	2.125	2	1.75	1.25
4	7	3.25	2	2.5	2.75	2.5	2	2.25	1
5	6.25	3.5	2.25	2.625	2.875	2.5	2.125	2.25	1.875
6	7.25	4	2.875	3	3.125	3	2.625	2.5	1.75
7	7	3.75	2.5	2.5	2.875	2.375	1.875	2.375	1.75
8	6.5	3.5	2.125	2.5	2.75	2.375	2	2.125	1.5
Maximum	7.75	4	2.875	3.25	3.75	3.375	2.75	2.5	1.875
Minimum	5.5	3	2	2.25	2.375	2.125	1.875	1.75	1
Range	2.25	1	0.875	1	1.375	1.25	0.875	0.75	0.875
Median	6.875	3.5625	2.3125	2.5625	2.875	2.5	2.0625	2.1875	1.4375
Average	6.75	3.546875	2.328125	2.703125	2.984375	2.65625	2.203125	2.171875	1.4375

Appendix E: Drop-out Figures

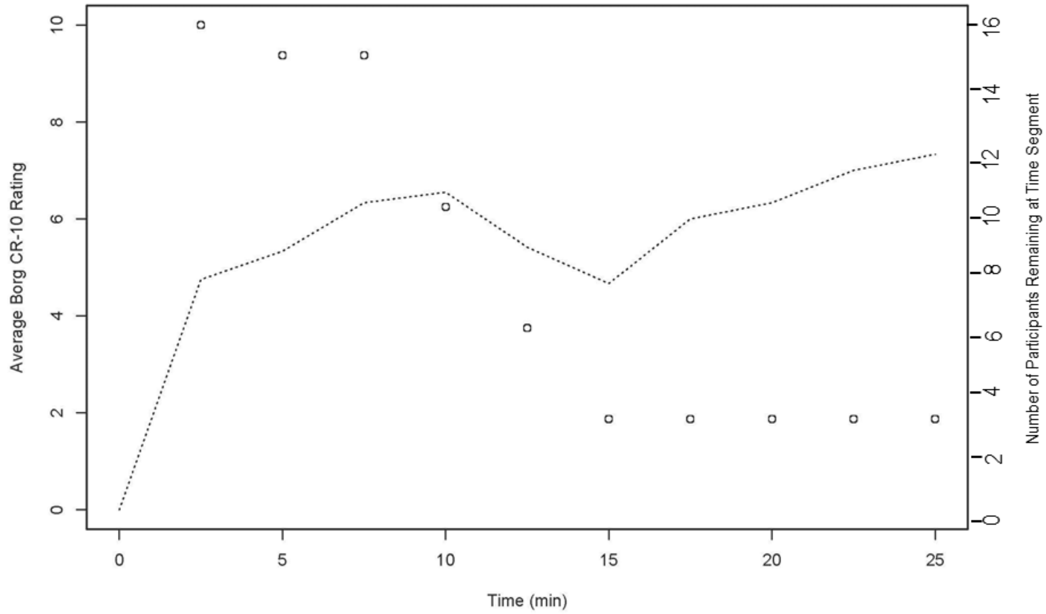

Figure 13 Drop-outs for combination 40% MVC, 7 seconds, 75% DC

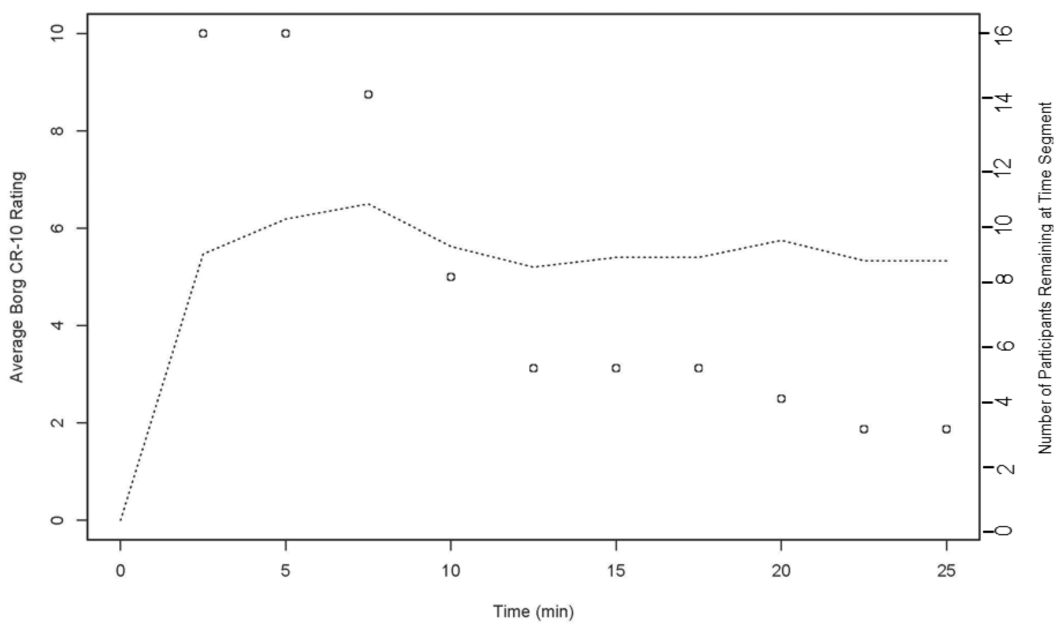

Figure 14 Drop-outs for combination 40% MVC, 4 seconds, 75% DC

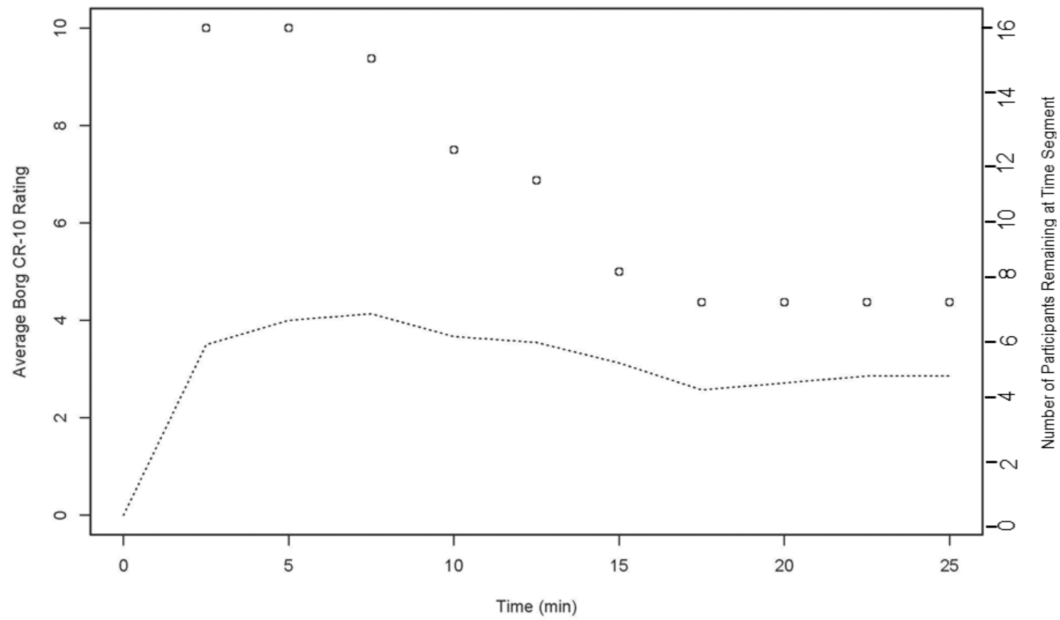

Figure 15 Drop-outs for combination 25% MVC, 1 second, 75% DC

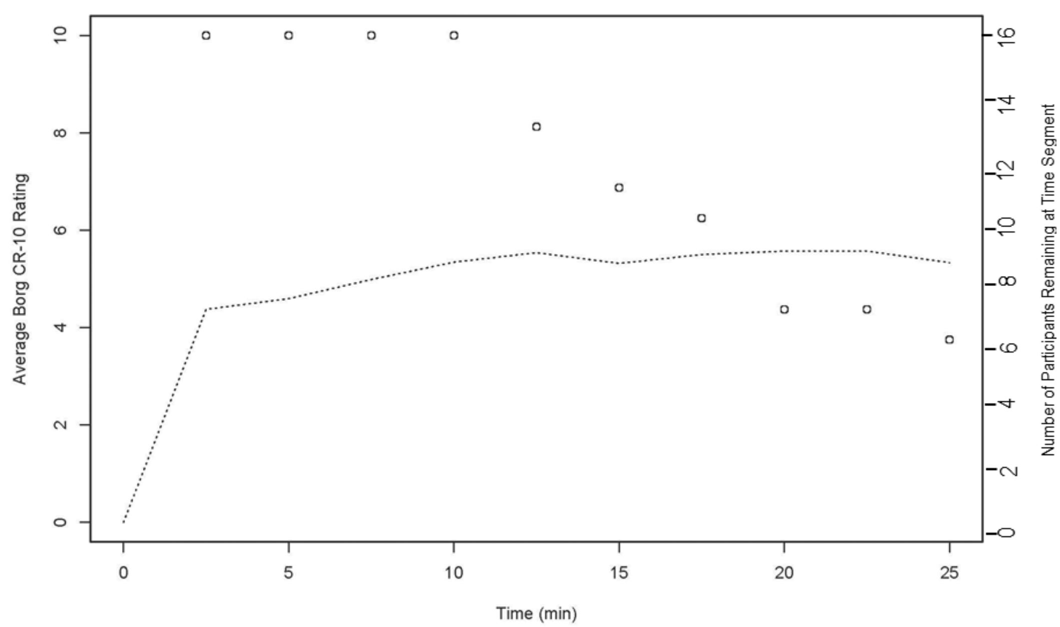

Figure 16 Drop-outs for combination 40% MVC, 1 second, 50% DC

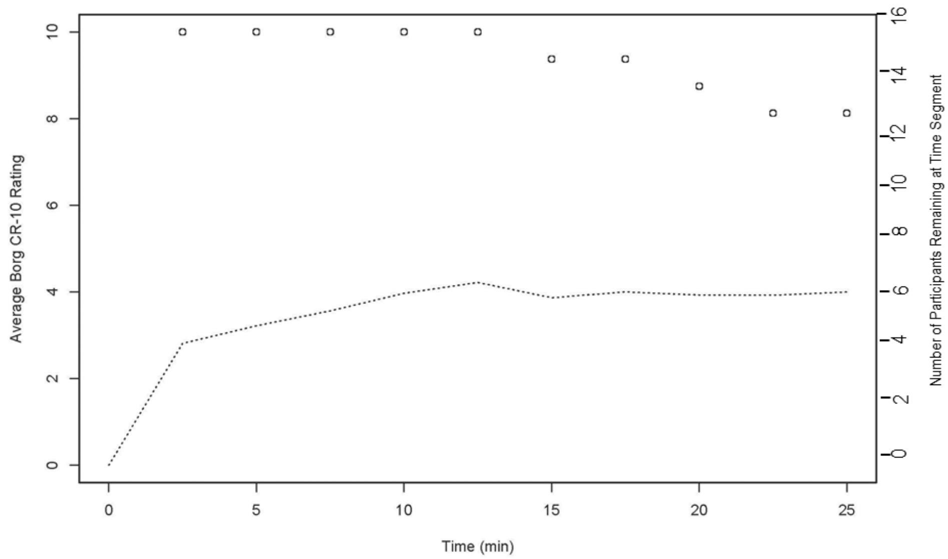

Figure 17 Drop-outs for combination 25% MVC, 4 seconds, 75% DC

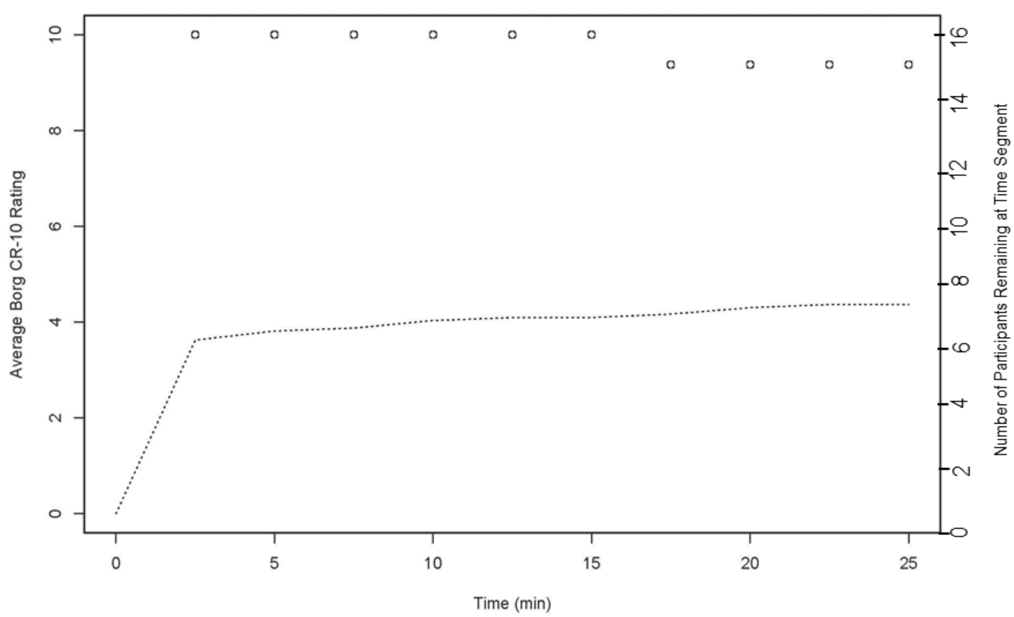

Figure 18 Drop-outs for combination 40% MVC, 7 seconds, 25% DC

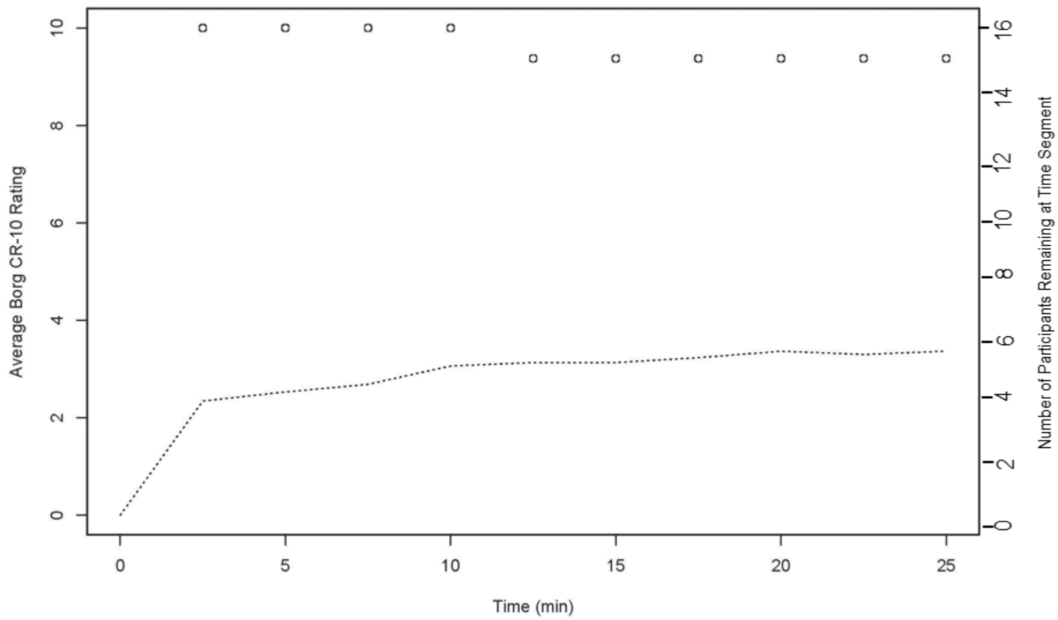

Figure 19 Drop-outs for combination 25% MVC, 1 second, 50% DC

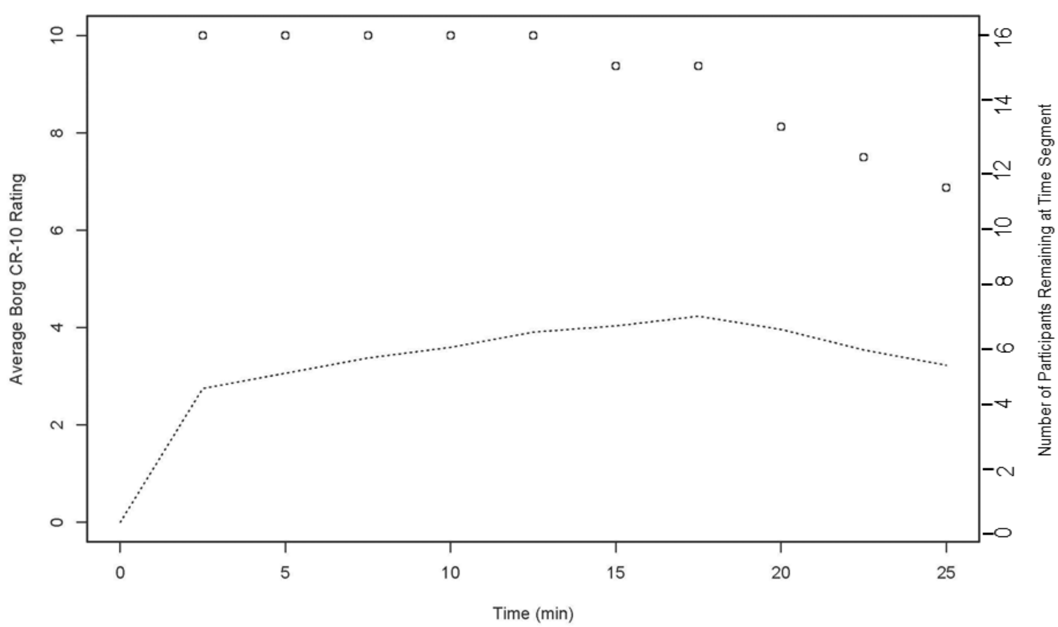

Figure 20 Drop-outs for combination 25% MVC, 7 seconds, 75% DC

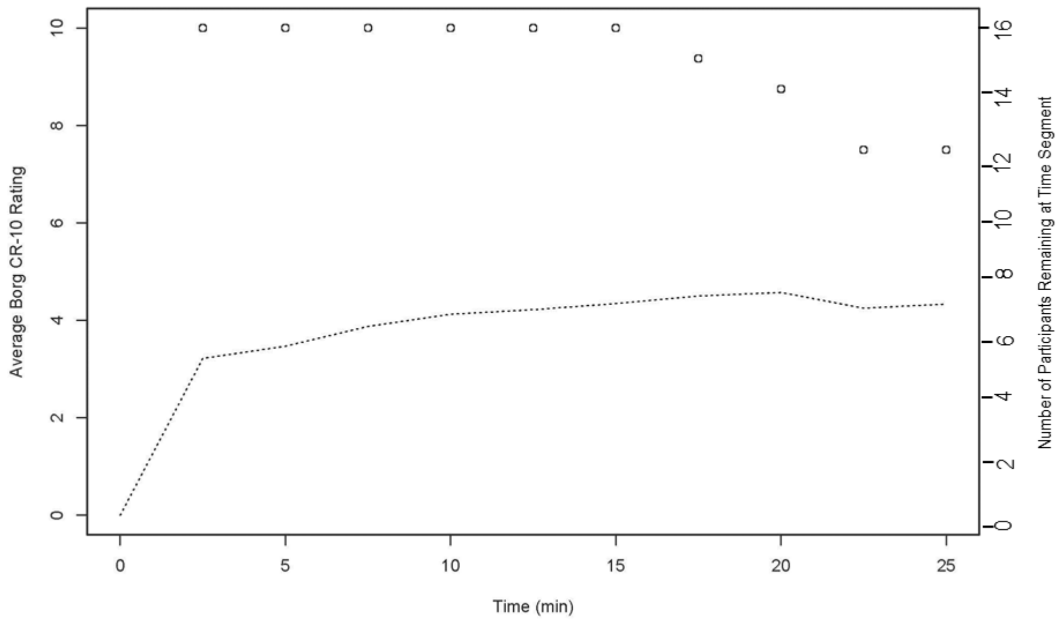

Figure 21 Drop-outs for combination 40% MVC, 4 seconds, 50% DC

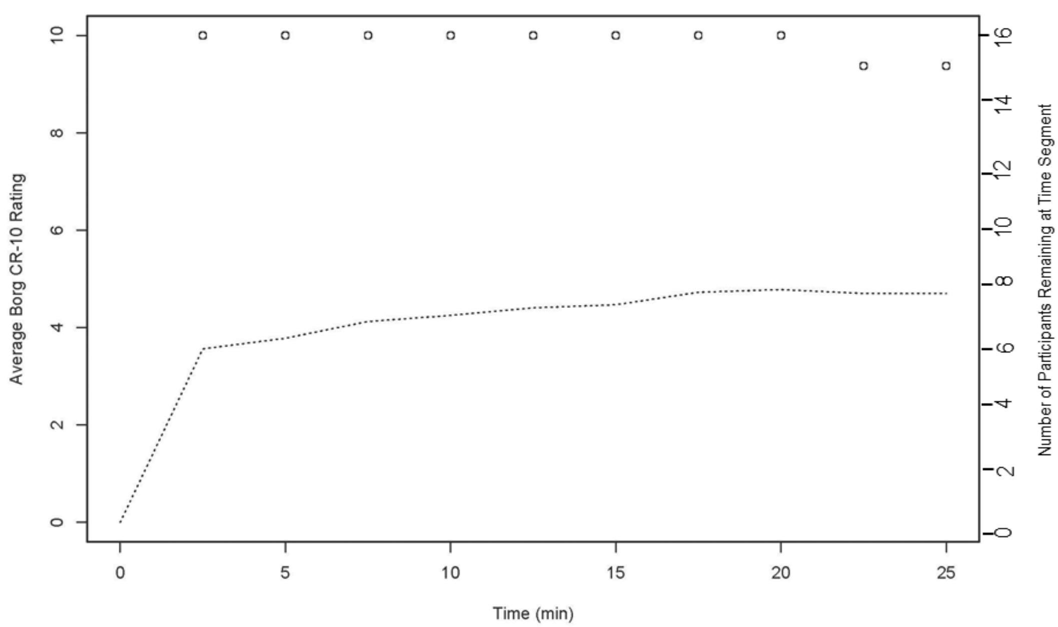

Figure 22 Drop-outs for combination 40% MVC, 7 seconds, 50% DC

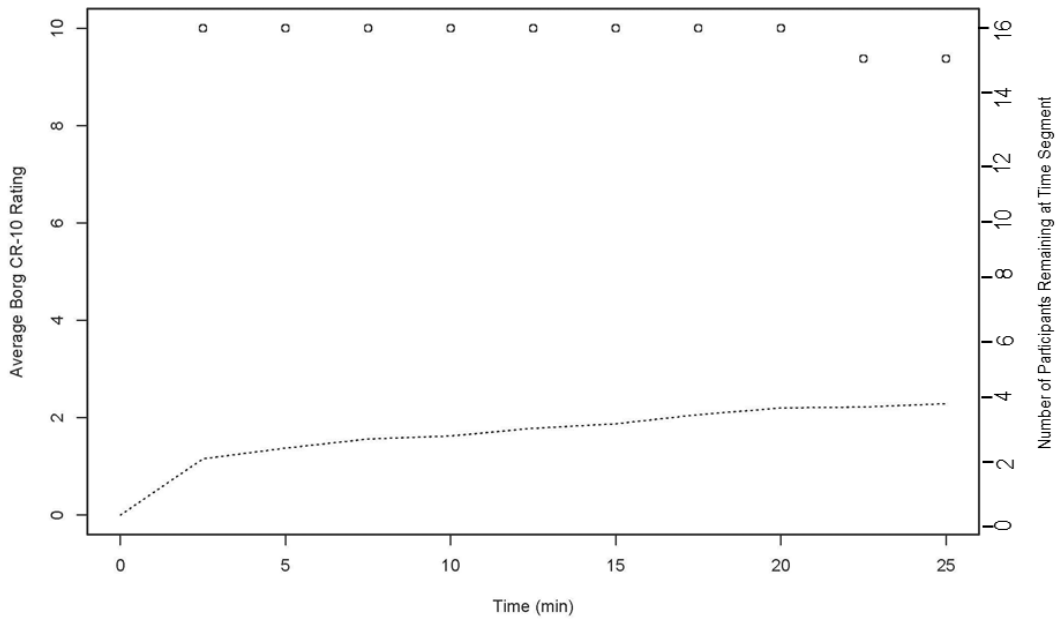

Figure 23 Drop-outs for combination 10% MVC, 1 second, 75% DC

Appendix F: IRB Protocol Form

IRBManager Protocol Form

NOTE: If you are unsure if your study requires IRB approval, please review the UWM IRB Determination Form.

Instructions: Each Section must be completed unless directed otherwise. Incomplete forms will delay the IRB review process and may be returned to you. Enter your information in the **colored boxes** or place an **"X"** in front of the appropriate response(s). If the question does not apply, write **"N/A."**

SECTION A: Title

A1. Full Study Title: The effects of applied grip force on ratings of perceived exertion for frequencies and durations of exertions that result in the same duty cycles.

SECTION B: Study Duration

B1. What is the expected start date? *Data collection, screening, recruitment, enrollment, or consenting activities may not begin until IRB approval has been granted. Format: 07/05/2011*

02/01/2015

B2. What is the expected end date? *Expected end date should take into account data analysis, queries, and paper write-up. Format: 07/05/2014*

01/31/2022

SECTION C: Summary

C1. Write a brief descriptive summary of this study in Layman Terms (non-technical language):

This study will assess subjects' perceptions of exertion when applying grip force to a dynamic grip device. Subjects will undergo 27 total combinations of various grip intensities, durations and frequencies. In this study, there will be 3 tested durations of exertion: 1, 4, and 7 seconds. There will also be 3 tested duty cycles (ie, percent duration of exertion): 25%, 50%, and 75%. Frequencies of exertion will be set based on duration of exertion in order to achieve the prescribed duty cycles. Force levels will be set to 10%, 25%, and 40% of each subject's maximum strength. All 27 combinations will be randomized and repeated by all subjects, resulting in 54 total trials for each subject. Each trial will last 25 minutes. Every 2.5 minutes subjects will be asked to rate their level of exertion on the "Borg CR10" scale, a 100-point verbal anchor fatigue scale, and a 100-point verbal anchor pain scale.

Subjects will participate in eighteen two-hour sessions and two one-hour sessions. Sessions will be held on different days, with a minimum of 12 hours between sessions, to allow subjects adequate recovery time. The first session (one hour) will be an introduction to the study, to obtain informed consent, and to determine the subject's maximum hand-grip strength. The second session (one hour) will be a practice session to confirm maximum grip strength, and allow the subject to become familiar with the study design. Each subject will perform four pre-determined combinations during the practice session. Each practice combination will last 7 minutes, with 5-minutes of rest between tests. Ratings of exertion, pain and fatigue will be taken every minute. Sessions three through eighteen (two hour sessions) will be randomized; each session will contain three 25-minute trials. Ratings of perceived exertion, pain, and fatigue will be taken every 2.5 minutes, with a 12-minute rest break between each trial.

C2. Describe the purpose/objective and the significance of the research:

The purpose of this study is to determine whether handgrip duration and/or frequency result in different sensations of difficulty for the subject, despite having the same duty cycle. This information is important because contemporary literature suggests that duty cycle is the most important of these three variables (force, frequency, and duration of exertion) and this implication could have a strong effect on work/job design. Unlike prior studies that have relied on a psychophysical approach (typically leaving subjects to determine their own maximum acceptable frequency), this study will parameterize force, duration, and duty cycle, allowing these three to be compared as independent factors. The results of this study should help to clarify the relative effects of force, duration of force, and duty cycle on ratings of perceived exertion, fatigue, and pain.

C3. Cite the most relevant literature pertaining to the proposed research:

Abu-Ali, M., Purswell, J. L., & Schlegel, R. E. (1996). Psychophysically determined work-cycle parameters for repetitive hand gripping. International Journal of Industrial Ergonomics, 17(1), 35-42.

A Grant, K., J Habes, D., & Putz-Anderson, V. (1994). Psychophysical and EMG correlates of force exertion in manual work. *International Journal of Industrial Ergonomics, 13(1)*, 31-39.

Byström, S. E. G., & Kilbom, Å. (1990). Physiological response in the forearm during and after isometric intermittent handgrip. European journal of applied physiology and occupational physiology, 60(6), 457-466.

Dahalan, J. B., & Fernandez, J. E. (1993). Psychophysical frequency for a gripping task. International Journal of Industrial Ergonomics, 12(3), 219-230.

Fernandez, J. E., & Marley, R. J. (2012). The development and application of psychophysical methods in upper-extremity work tasks and task elements. International Journal of Industrial Ergonomics.

Finneran, A., & O'Sullivan, L. (2014). Self-selected duty cycle times for grip force, wrist flexion postures and three grip types. Ergonomics, 57(4), 589-601.

Garg, A., & Kapellusch, J. M. (2011). Job analysis techniques for distal upper extremity disorders. *Reviews of Human Factors and Ergonomics*, *7*(1), 149-196.

Harber, P., Hsu, P., & Peña, L. (1994). Subject-based rating of hand-wrist stressors. *Journal of Occupational and Environmental Medicine*, *36*(1), 84-89.

Klein, M. G., & Fernandez, J. E. (1997). The effects of posture, duration, and force on pinching frequency. International Journal of Industrial Ergonomics, 20(4), 267-275.

Moore, A., & Wells, R. (2005). Effect of cycle time and duty cycle on psychophysically determined acceptable levels in a highly repetitive task. *Ergonomics*, *48*(7), 859-873.

Potvin, J. R. (2012). Predicting Maximum Acceptable Efforts for Repetitive Tasks An Equation Based on Duty Cycle. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *54*(2), 175-188.

SECTION D: Subject Population

Section Notes…

- D1. If this study involves analysis of de-identified data only (i.e., no human subject interaction), IRB submission/review may not be necessary. **Please review the UWM IRB Determination Form for more details.**

D1. Identify any population(s) that you will be specifically targeting for the study. Check all that apply: (Place an "X" in the column next to the name of the special population.)

	Existing Dataset(s)		Institutionalized/ Nursing home residents recruited in the nursing home
	UWM Students of PI or study staff		Diagnosable Psychological Disorder/Psychiatrically impaired
x	UWM Students (but not of PI or study staff)		Decisionally/Cognitively Impaired
	Non-UWM students to be recruited in their educational setting, i.e. in class or at school		Economically/Educationally Disadvantaged
	UWM Staff or Faculty		Prisoners
	Pregnant Women/Neonates		International Subjects (residing outside of the US)
	Minors under 18 and ARE NOT wards of the State		Non-English Speaking
	Minors under 18 and ARE wards of the State		Terminally ill
	Other (Please identify):		

D2. Describe the subject group and enter the total number to be enrolled for each group. For example: teachers-50, students-200, parents-25, student control-30, student experimental-30, medical charts-500, dataset of 1500, etc. Then enter the total number of subjects below. Be sure to account for expected drop outs. For example, if you need 100 subjects to complete the entire study, but you expect 5 people will enroll but "drop out" of the study, please enter 105 (not 100).

Describe subject group:	Number:
Adult Females (18 to 35 years of age)	15
TOTAL # OF SUBJECTS:	15
TOTAL # OF SUBJECTS (If UWM is a collaborating site for a multi institutional project):	N/A

D3. For each subject group, list any major inclusion and exclusion criteria (e.g., age, gender, health status/condition, ethnicity, location, English speaking, etc.) and state the justification for the inclusion and exclusion criteria:

We will exclude minors, those with disabilities (or reduced function) in their dominant arm, physician's orders to not exert force with their dominant arm and those who are unable to provide written consent. Subjects will be required to speak/understand English, as well as hear auditory cues. Inclusion criteria include females aged 18-35 years to limit gender and age biases in the statistical analysis. Inclusion/exclusion criteria will be confirmed via self-report in the first informational session.

SECTION E: Study Activities: Recruitment, Informed Consent, and Data Collection

Section Notes…

- Reminder, all recruitment materials, consent forms, data collection instruments, etc. should be attached for IRB review.
- The IRB welcomes the use of flowcharts and tables in the consent form for complex/ multiple study activities.

In the table below, chronologically describe all study activities where human subjects are involved.

- In **column A**, give the activity a short name. Please note that Recruitment, Screening, and consenting will be activities for almost all studies. Other activities may include: Obtaining Dataset, Records Review, Interview, Online Survey, Lab Visit 1, 4 Week Follow-Up, Debriefing, etc.
- In **column B**, describe who will be conducting the study activity and his/her training and/or qualifications to complete the activity. You may use a title (i.e. Research Assistant) rather than a specific name, but training/qualifications must still be described.
- In **column C**, describe in greater detail the activities (recruitment, screening, consent, surveys, audiotaped interviews, tasks, etc.) research participants will be engaged in. Address **where**, **how long**, and **when** each activity takes place.
- In **column D,** describe any possible risks (e.g., physical, psychological, social, economic, legal, etc.) the subject may ***reasonably*** encounter. Describe the **safeguards** that will be put into place to minimize possible risks (e.g., interviews are in a private location, data is anonymous, assigning pseudonyms, where data is stored, coded data, etc.) and what happens if the participant gets hurt or upset (e.g., referred to Norris Health Center, PI will stop the interview and assess, given referral, etc.).

A. Activity Name:	B. Person(s)	C. Activity Description (Please describe any	D. Activity Risks and Safeguards:

	Conducting Activity	forms used):	
Recruitment	Student Investigator (UWM Occupational Therapy (OT) graduate student) & Research Assistants (UWM undergraduate students with prior research experience)	Researchers will initially recruit subjects be by word of mouth. A flyer will be used if necessary, and will be displayed in EMS and Enderis Hall.	None
Session 1: Screening	Same as above	Subjects will be asked if they have a disability (or reduced function) in their dominant arm or physician's orders to not exert force with their dominant arm. It will also be confirmed that all other inclusion/exclusion criteria (listed above) are met.	Subjects may feel uncomfortable sharing personal information. Researchers will explain that this information is essential to the subject's safety and will be kept confidential. No screening materials will be maintained; subject will offer only verbal confirmation of any exclusionary characteristics.
Obtaining Consent	Same as above	The study will be explained and required activities briefly demonstrated. The consent form will be reviewed and verbally described. Potential subjects will be given as much time as they require to review the consent form.	Subjects may decide they do not want to participate after being informed about the study. Subjects will be reminded that they may withdraw at any time without penalty and that, upon request, their data will be destroyed and not used for any analyses or publication. Subjects will be given a copy of the consent form to keep. Signed Informed Consent Forms will be kept in a separate study folder in the PI's office (END 953) that will include payment information and they study's subject key. This study folder will not contain other subject data.

			Subjects will be assigned a unique identifying code. Their name will not be used on any forms other than the consent form (which will not contain their subject code), and temporary subject key. The subject key will NOT be stored electronically; it will be stored in a separate, locked file cabinet with consent forms and will be destroyed upon completion of all data collection.
Baseline Measurements	Same as above	Hand/arm dimensions will be measured using a standard anthropometer. Functional neutral will be measured using a manual goniometer. Subjects will squeeze a Jamar grip dynamometer to obtain a maximum static grip force. Anthropometric Measurement Form attached.	There are no foreseeable risks with this activity. Hard copies of the Anthropometric Measurement Forms will be coded and kept in separate, subject-coded folders in a locked drawer in END 980. All electronically coded files will be stored on a password-protected computer.
Estimating Maximum Dynamic Grip Force	Same as above	After obtaining the maximum voluntary contraction (MVC) grip force from the dynamometer, dynamic grip force will be determined. Researchers will begin by loading the dynamic grip device with 85% of the subject's static MVC. Subjects will be asked to squeeze the device for as long as possible. Weight will be loaded/unloaded accordingly until the mass can be squeezed for at least 3 but not more than 5 seconds. Testing will continue until the same mass is identified by three consecutive exertions. A 5 minute rest break will be given between exertions, subjects will be allowed to take longer rest breaks if desired. 100% dynamic and 100%	Subject's hand and/or forearm will likely become temporarily fatigued during this process. Protocol is designed such that there should be adequate rest time between exertions to recover from this fatigue. Subjects will be allowed more recovery time if needed. Localized fatigue is not expected to last more than 1-2 hours following the trial.

		static MVCs will be recorded on the Anthropometric Form.	
Scheduling	Same as above	Subjects will be asked to schedule subsequent sessions for the study. Scheduling Sheet attached.	There are no foreseeable risks with this activity. Hard copies of the Scheduling Sheets will be kept in separate, subject-coded folders in a locked drawer in END 980.
Session 2: Retest MVC	Same as above	Maximum dynamic grip force that was obtained from session 1 will be retested. The same iterative procedure will be used to identify 100% as was described above in "Estimating Maximum Dynamic Grip Force". In the unlikely event that 100% MVC values for session 1 and session 2 differ by more than 5%, an additional MVC determination session will be added on a separate day and subjects will be compensated for this extra testing session.	See "Estimating Maximum Dynamic Grip Force" (above).
Session 2: Practice MVC Dynamic Grip Trials	Same as above	Subjects will practice using the dynamic grip device and providing ratings. An audio metronome cues the subject to grip, and remains in effect for the required grip duration, and continues to cycle for 7 minutes. There will be a 5-minute rest between each 7-minute combination. Subjects will perform 4 experimental combinations in the following order: 1) MVC 15%,duty cycle (DC) 25%, duration 4 seconds 2) MVC 32%, DC 25%, duration 4 seconds	There is potential for subjects to become fatigued in the hand or forearm during this practice session. Protocol is designed such that there should be adequate rest time; subjects will be allowed more recovery time if needed (no additional compensation will be given for exceeding testing time). Hard copies of the Practice MVC Trial Forms will be kept in separate, subject-coded folders in a locked drawer in END 980.

		3) MVC 15%, DC 75%, duration 1 second 4) MVC 32%, DC 75%, duration 1 second. Subjects will also be asked to give exertion, pain, and fatigue ratings every minute throughout each 7-minute practice trial. Practice MVC Trial Form attached.	
Sessions 2-20: Exertion Ratings (Borg CR10 Scale)	Same as above	Subjects will be asked to rate their perceived exertion based on the question: "How hard were your muscles working during the most recent exertion?" Researchers will then show them the Borg CR10 scale to numerically rate their exertion. Borg CR10 attached. Ratings will be recorded on the Practice MVC Trial Form (session 2) or MVC Trial Form (sessions 3-20).	There are no foreseeable risks with this activity. However, if subjects say their exertion is too high to proceed, researchers will stop the trial, note the time, and allow the subject to rest as long as needed before continuing with the next trial (this would extend total testing time, subjects will not receive additional compensation if this occurs).
Sessions 2-20: Pain Scale	Same as above	Subjects will be asked to rate their perceived pain based on the question: "What is your pain level currently?" Researchers will then show them the Pain Scale to numerically rate their pain level. Pain Scale attached. Ratings will be recorded in the Practice MVC Trial Form (session 2) or MVC Trial Form (sessions 3-20).	There are no foreseeable risks with this activity. However, if subjects say their pain is too high to proceed, researchers will stop the trial, note the time, and allow the subject to rest as long as needed before continuing with the next trial (this would extend total testing time, subjects will not receive additional compensation if this occurs).
Sessions 2-20: Hand/Arm Pain Diagram	Same as above	Subjects will also be asked to indicate where their pain is, based on the question: "Where do you feel your pain currently?" Researchers will then show them the Hand Pain Diagram to indicate the region in which they feel pain. Hand	There are no foreseeable risks with this activity. However, if subjects say their pain is too high to proceed, researchers will stop the trial, note the time, and allow the subject to rest as long as needed before continuing with the next trial (this

		Pain Diagram attached. Ratings will be recorded in the Practice MVC Trial Form (session 2) or MVC Trial Form (sessions 3-20).	would extend total testing time, subjects will not receive additional compensation if this occurs).
<u>Sessions 2-20:</u> Fatigue Scale	Same as above	Subjects will be asked to rate their perceived fatigue based on the question: "How tired do you feel after the most recent exertion?" Researchers will then show them the Fatigue Scale to numerically rate their fatigue. Fatigue Scale attached. Ratings will be recorded in the Practice MVC Trial Form (session 2) or MVC Trial Form (sessions 3-20).	There are no foreseeable risks with this activity. However, if subjects say their fatigue is too high to proceed, researchers will stop the trial, note the time, and allow the subject to rest as long as needed before continuing with the next trial (this would extend total testing time, subjects will not receive additional compensation if this occurs).
<u>Sessions 3-20:</u> MVC Dynamic Grip Trials	Same as above	Subjects will use the dynamic grip device to perform 27 unique combinations twice, resulting in 54 total trials. Trials will be performed in an orthogonal randomized order. An audio metronome cues the subject to grip and remains in effect for the required grip duration. The audio cue repeats for the test cycle of 25 minutes. There will be a minimum of 12 minutes rest between each 25-minute trial. Subjects will also be asked to give exertion, pain, and fatigue ratings every 2.5 minutes throughout each 25-minute trial.MVC Trial Form attached.	Subjects are expected to suffer some temporary, localized muscle fatigue during this testing. Protocol is designed such that there should be adequate rest time between trials to recover from this fatigue and subjects will be allowed more recovery time if needed Sessions have a 30 minute time cushion built into the 2 hour duration to accommodate extra rest. No additional compensation will be given for sessions exceeding 2 hours of testing time. It is expected that subjects will not be physically able to complete 25 minutes of certain test combinations (e.g, 40% MVC, 1 second duration, 75% duty cycle). In the event that subjects choose to stop a trial short, they will be given the remaining test time as additional recovery time. Subjects might feel substantial localized muscle

			fatigue following the two-hour session. This fatigue is expected to last for up to 2-3 hours following the test. This localized fatigue is expected to be consistent with a physically intensive workout in a gym and in extreme circumstances might interfere with activities such as writing with a pen continuously for 20-30 minutes. No lasting effects or damage to hand/arm tissue is expected. Subjects are expected to experience temporary muscular pain in the hand/arm while performing exertions. This pain is expected to resolve immediately after the test concludes (ie, during the rest-period). If pain persists for more than 3 minutes into the rest period, the remainder of the session will be cancelled and an additional session will be scheduled. Subjects that routinely experience lasting pain will be removed from the study and compensated for the trials they completed. Copies of the MVC Trial Forms will be kept in separate, subject-coded folders in a locked drawer in END 980. The data will also be coded and entered into an electronic spreadsheet, which will be stored on a password-protected computer in END 980.

E2. Explain how the data will be analyzed or studied (i.e. quantitatively or qualitatively) and how the data will be reported (i.e. aggregated, anonymously, pseudonyms for participants, etc.):

Data will be temporarily stored on paper forms that will not contain the subject's name. These paper forms will be entered into spreadsheets and stored on a password protected computer after which paper forms will be destroyed. Data will be quantitatively analyzed using statistical software (R and SPSS). Results will be reported in aggregate. No personal identifiers or individual data points will be reported.

SECTION F: Data Security and Confidentiality

Section Notes…

- Please read the IRB Guidance Document on Data Confidentiality for more details and recommendations about data security and confidentiality.

F1. Explain how study data/responses will be stored in relation to any identifying information (name, birthdate, address, IP address, etc.)? Check all that apply.

[_] Identifiable - **Identifiers are collected and stored with study data.**
[X] Coded - **Identifiers are collected and stored separately from study data, but a key exists to link data to identifiable information.**
[X] De-identified - **Identifiers are collected and stored separately from study data without the possibility of linking to data.**
[__] Anonymous - **No identifying information is collected.**

If more than one method is used, explain which method is used for which data.

Data will be coded when collected. Once data collection is complete a new random code will be assigned to each subject's data creating a de-identified dataset. The key linking subject names to subject code and the original coded dataset will be destroyed once the de-identified dataset is created.

F2. Will any recordings (audio/video/photos) be done as part of the study?

[__] **Yes**
[X_] **No [SKIP THIS SECTION]**

If yes, explain what activities will be recorded and what recording method(s) will be used. Will the recordings be used in publications or presentations?

F3. In the table below, describe the data storage and security measures in place to prevent a breach of confidentiality.

- In **column A**, clarify the type of data. Examples may include screening data, paper questionnaires, online survey responses, EMG data, audio recordings, interview transcripts, subject contact information, key linking Study ID to subject identifiers, etc.

- In **<u>column B</u>**, describe the storage location. Examples may include an office in Enderis 750, file cabinet in ENG 270, a laptop computer, desktop computer in GAR 420, Qualtrics servers, etc.
- In **<u>column C</u>**, describe the security measures in place for each storage location to protect against a breach of confidentiality. Examples may include a locked office, encrypted devices, coded data, non-networked computer with password protection, etc.
- In **<u>column D</u>**, clarify who will have access to the data.
- In **<u>column E</u>**, explain when or if data will be discarded.

A. Type of Data	B. Storage Location	C. Security Measures	D. Who will have access	E. Estimated date of disposal
Consent Forms	END 953	Locked private office, stored in file cabinet. Only subject payment information will be stored with these files.	Dr. Kapellusch, Jessica Gall, and Kimberly Dembinski.	January 2022 (6 years after study completion)
Baseline Information	END 980	Locked laboratory, locked file cabinet and password-protected computer.	Research team & Dr. Kapellusch	January 2016
Grip Combinations & Ratings	END 980	Locked laboratory, locked file cabinet and password-protected computer.	Research team & Dr. Kapellusch	January 2016
De-Identified dataset	END 980	Password-protected computer	Dr. Kapellusch & research team.	January 2035 (20 years)

F4. Will data be retained for uses beyond this study? If so, please explain and notify participants in the consent form.

De-identified data will be kept indefinitely (anticipated term of 20 years) for use in future analyses.

SECTION G: Benefits and Risk/Benefit Analysis

Section Notes…

- Do not include Incentives/ Compensations in this section.

G1. Describe any benefits to the individual participants. If there are no anticipated benefits to the subject directly, state so. Describe potential benefits to society (i.e., further knowledge to the area of study) or a specific group of individuals (i.e., teachers, foster children).

There are no direct benefits to the subjects in this study. Participation in this study benefits practitioners and future researchers interested in the independent effects of duration and frequency on hand grip and how those combinations affect perceptions of exertion on the body.

G2. Risks to research participants should be justified by the anticipated benefits to the participants or society. Provide your assessment of how the anticipated risks to participants and steps taken to minimize these risks (as described in Section E), balance against anticipated benefits to the individual or to society.

There is no more than minimal risk posed to study participants. Participants benefit from the study through financial compensation for their time.

SECTION H: Subject Incentives/ Compensations

Section Notes…

- H2 & H3. The IRB recognizes the potential for undue influence and coercion when extra credit is offered. The UWM IRB, as also recommended by OHRP and APA Code of Ethics, agrees when extra credit is offered or required, prospective subjects should be given the choice of an equitable alternative. In instances where the researcher does not know whether extra credit will be accepted and its worth, such information should be conveyed to the subject in the recruitment materials and the consent form. For example, "The awarding of extra credit and its amount is dependent upon your instructor. Please contact your instructor before participating if you have any questions. If extra credit is awarded and you choose to not participate, the instructor will offer an equitable alternative."
- H4. If you intend to submit to the Travel Management Office or Accounts Payable for reimbursement purposes make sure you understand the UWM "Payments to Research Subjects" Procedure 2.4.6 and what each level of payment confidentiality means **(click here for additional information)**.

H1. Does this study involve incentives or compensation to the subjects? For example cash, class extra credit, gift cards, or items.

[_X_] **Yes**
[__] **No [SKIP THIS SECTION]**

H2. Explain what (a) the item is, (b) the amount or approximate value of the item, and (c) when it will be given. For extra credit, state the number of credit hours and/or points. (e.g., $5 after completing each survey, subject will receive [item] even if they do not complete the procedure, extra credit will be award at the end of the semester)**:**

Subjects will receive $10/1-hour session and $20/2-hour session in the form of a UWM check (anticipated $380 total). We will submit payment forms to the University bi-weekly and subjects will be paid for the sessions they have completed.

H3. If extra credit is offered as compensation/incentive, please describe the alternative activity (which can be another research study or class assignment) which will be offered. The alternative activity (either class assignment or another research study) should be similar in the amount of time involved to complete and worth the same extra credit.

H4. If cash or gift cards, select the appropriate confidentiality level for payments (see section notes):

[_X_] **Level 1** indicates that confidentiality of the subjects is not a serious issue, e.g., providing a social security number or other identifying information for payment would not pose a serious risk to subjects.

- For payments over $50, choosing Level 1 requires the researcher to collect and maintain a record of the following: The payee's name, address, and social security number, the amount paid, and signature indicating receipt of payment (for cash or gift cards).
- When Level 1 is selected, a formal notice is not issued by the IRB and the Account Payable assumes Level 1.
- Level 1 payment information will be retained in the extramural account folder at UWM/Research Services and attached to the voucher in Accounts Payable. These are public documents, potentially open to public review.

[ ] **Level 2** indicates that confidentiality is an issue, but is not paramount to the study, e.g., the participant will be involved in a study researching sensitive, yet not illegal issues.

- Choosing a Level 2 requires the researcher to maintain a record of the following: The payee's name, address, and social security number, the amount paid, and signature indicating receipt of payment (for cash or gift cards).
- When Level 2 is selected, a formal notice will be issued by the IRB.
- Level 2 payment information, including the names, are attached to the PIR and become part of the voucher in Accounts Payable. The records retained by Accounts Payable are not considered public record.

[ ] **Level 3** indicates that confidentiality of the subjects must be guaranteed. In this category, identifying information such as a social security number would put a subject at increased risk.

- Choosing a Level 3 requires the researcher to maintain a record of the following: research subject's name and corresponding coded identification. This will be the only record of payee names, and it will stay in the control of the PI.
- Payments are made to the research subjects by either personal check or cash. Gift cards are considered cash.
- If a cash payment is made, the PI must obtain signed receipts.
- If the total payment to an individual subject is over $600 per calendar year, Level 3 cannot be selected.

If Confidentiality Level 2 or 3 is selected, please provide justification.

SECTION I: Deception/ Incomplete Disclosure (INSERT "NA" IF NOT APPLICABLE)

Section Notes…

- If you cannot adequately state the true purpose of the study to the subject in the informed consent, deception/ incomplete disclosure is involved.

I1. Describe (a) what information will be withheld from the subject (b) why such deception/ incomplete disclosure is necessary, and (c) when the subjects will be debriefed about the deception/ incomplete disclosure.

Not applicable.

IMPORTANT – Make sure all sections are complete and attach this document to your IRBManager web submission in the Attachment Page (Y1).

Appendix G: Equivalent Text Descriptions: Figures

Figure 1

Brief Description: Figure 1: Photograph of grip device used for this experiment

Essential Description: Photograph taken looking down at a subject's hand with fingers grasping two cylindrical handles within the palm of the hand. There is a pulley attached to the handles which are attached to weights – which are not visible in the picture.

Figure 2

Brief Description: Figure 2: Borg CR-10 scale

Essential Description: This figure displays a numerical scale from zero to eleven with verbal anchors at certain points along the scale. It is a subjective scale that is used to measure a person's perceived exertion. At zero, the verbal anchors are "nothing at all" and "No P." At ten the verbal anchors are "Extremely strong" and "Max P." At 11 there are no verbal anchors.

Figure 3

Brief Description: Figure 3: Flow chart, session details

Essential Description: This figure is a flow chart which displays the timeline and what occurred for each of the sessions that subjects participated in. There are 3 major sections to the figure: 1) session 1 (1 hour) 2) Session 2 (1 hour) and 3) Sessions 3-20 (2 hours). The figure shows that Session 1 was used for screening for DUE dysfunction, obtaining consent, getting baseline static MVC, estimating MVC for the dynamic grip force, and scheduling future sessions. Session 2 (1 hour) included retesting MVC, practice trials (all subjects performed the same combinations), and subjects rated their exertion levels on the Borg CR-10 scale every 2.5 minutes. Sessions 3-20 (2 hours) included testing all of the dynamic grip trials (each session contained 3 trials of 25 minutes, with rest between); every 2.5 minutes subjects rated their perceived exertion on the Borg CR-10 scale.

Figure 4

Brief Description: Figure 4: Line graph, relation between % Maximum Voluntary Contraction and average Borg CR-10 ratings

Essential Description: This figure is a line graph which displays % Maximum Voluntary Contraction (0-100%) on the X-axis and Borg CR-10 ratings (0-10) on the Y-axis. A fairly steep slope is drawn which connects the last reported average Borg CR-10 ratings at each given MVC. At each tested MVC (10%, 25%, and 40%), there is a vertical line with horizontal whiskers" on the top and bottom of the line which represent the minimum to maximum range of the last given Borg CR-10 ratings for that MVC.

Figure 5

Brief Description: Figure 5: Line graph, relation between Duty Cycle and average Borg CR-10 ratings

Essential Description: This figure is a line graph which displays % Duty Cycle (0-100%) on the X-axis and Borg CR-10 ratings (0-10) on the Y-axis. A moderate slope is drawn which connects the last reported average Borg CR-10 ratings at each given Duty Cycle. At each tested DC (25%, 50%, and 75%), there is a vertical line with horizontal whiskers" on the top and bottom of the line which represent the minimum to maximum range of the last given Borg CR-10 ratings for that DC.

Figure 6

Brief Description: Figure 6: Line graph, relation between Duration of Exertion and average Borg CR-10 ratings

Essential Description: This figure is a line graph which displays Duration of Exertion (0-10 seconds) on the X-axis and Borg CR-10 ratings (0-10) on the Y-axis. An almost straight horizontal line represents the slope and connects the last reported average Borg CR-10 ratings at each given Duration of Exertion (1 second, 4 seconds, and 7 seconds). At each tested Duration of Exertion there is a vertical line with horizontal whiskers" on the top and bottom of the line which represent the minimum to maximum range of the last given Borg CR-10 ratings for that Duration of exertion.

Figure 7

Brief Description: Figure 7: Line graph at 10% Maximum Voluntary Contraction; plotting time in minutes against Borg CR-10 ratings (full scale)

Essential Description: This figure is a line graph with time (0-25 minutes) on the X-axis, and Borg CR-10 ratings (0-10) on the Y-axis. The graphs shows temporal patterns at 2.5 minute increments throughout the full 25 minute trials for each of the combinations tested at 10% MVC. There are nine lines, with three different line types representing each duty cycle, and three different colors representing duration of exertion. Solid lines are 25% DC, dashed lines are 50% DC, and dotted lines are 75% DC. Red lines represent 1 second durations, blue lines represent 4 second durations, and green lines represent 7 second durations. At the 25 minute mark, the red dotted line is the top line (at about a Borg CR-10 of 2) and the blue solid line is the lowest (at about a Borg CR-10 of 1). All of the lines become slightly steeper over time.

Figure 8

Brief Description: Figure 8: Line graph at 10% Maximum Voluntary Contraction; plotting time in minutes against Borg CR-10 ratings (partial scale)

Essential Description: This figure is a line graph with time (0-25 minutes) on the X-axis, and Borg CR-10 ratings (0-3) on the Y-axis (this is the same graph as Figure 8, but with an expanded Y-axis to show more detail on the graph). The graphs shows temporal patterns at 2.5 minute increments throughout the full 25 minute trials for each of the combinations tested at 10% MVC. There are nine lines, with three different line types representing each duty cycle, and three different colors representing duration of exertion. Solid lines are 25% DC, dashed lines are 50% DC, and dotted lines are 75% DC. Red lines represent 1 second durations, blue lines represent 4 second durations, and green lines represent 7 second durations. At the 25 minute mark, the red dotted line is the top line (at about a Borg CR-10 of 2) and the blue solid line is the lowest (at about a Borg CR-10 of 1). All of the lines become slightly steeper over time.

Figure 9

Brief Description: Figure 9: Line graph at 25% Maximum Voluntary Contraction; plotting time in minutes against Borg CR-10 ratings (full scale)

Essential Description: This figure is a line graph with time (0-25 minutes) on the X-axis, and Borg CR-10 ratings (0-10) on the Y-axis. The graphs shows temporal patterns at 2.5 minute increments throughout the full 25 minute trials for each of the combinations tested at 25% MVC. There are nine lines, with three different line types representing each duty cycle, and three different colors representing duration of exertion. Solid lines are 25% DC, dashed lines are 50% DC, and dotted lines are 75% DC. Red lines represent 1 second durations, blue lines represent 4 second durations, and green lines represent 7 second durations. At the 25 minute mark, the blue dotted line is the top line (at about a Borg CR-10 of 3.5) and the blue solid line is the lowest (at about a Borg CR-10 of 2). All three of the dotted lines have dips in their lines.

Figure 10

Brief Description: Figure 10: Line graph at 25% Maximum Voluntary Contraction; plotting time in minutes against Borg CR-10 ratings (partial scale)

Essential Description: This figure is a line graph with time (0-25 minutes) on the X-axis, and Borg CR-10 ratings (0-7) on the Y-axis (this is the same graph as Figure 9, but with an expanded Y-axis to show more detail on the graph). The graphs shows temporal patterns at 2.5 minute increments throughout the full 25 minute trials for each of the combinations tested at 25% MVC. There are nine lines, with three different line types representing each duty cycle, and three different colors representing duration of exertion. Solid lines are 25% DC, dashed lines are 50% DC, and dotted lines are 75% DC. Red lines represent 1 second durations, blue lines represent 4 second durations, and green lines represent 7 second durations. At the 25 minute mark, the blue dotted line is the top line (at about a Borg CR-10 of 3.5) and the blue solid line is the lowest (at about a Borg CR-10 of 2). All three of the dotted lines have dips in their lines.

Figure 11

Brief Description: Figure 11: Line graph at 40% Maximum Voluntary Contraction; plotting time in minutes against Borg CR-10 ratings (full scale)

Essential Description: This figure is a line graph with time (0-25 minutes) on the X-axis, and Borg CR-10 ratings (0-10) on the Y-axis. The graphs shows temporal patterns at 2.5 minute increments throughout the full 25 minute trials for each of the combinations tested at 40% MVC. There are nine lines, with three different line types representing each duty cycle, and three different colors representing duration of exertion. Solid lines are 25% DC, dashed lines are 50% DC, and dotted lines are 75% DC. Red lines represent 1 second durations, blue lines represent 4 second durations, and green lines represent 7 second durations. At the 25 minute mark, the green dotted line is the top line (at about a Borg CR-10 of 7) and the blue solid line is the lowest (at about a Borg CR-10 of 3.5). All three of the dotted lines as well as the red and blue lines have dips in their lines.

Figure 12

Brief Description: Figure 12: Line graph showing an example of the drop-out phenomena at 40% MVC, 1 second, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 1 second, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 2.5 minutes, 11 participants at 5 minutes, 8 participants at 7.5 minutes, 6 participants at 10 minutes, 5 participants at 12.5 minutes, 4 participants at 15 (and 17.5) minutes, and 3 participants for the remainder of the trial.

Figure 13

Brief Description: Figure 13: Line graph showing drop-outs at 40% MVC, 7 seconds, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 7 seconds, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 2.5 minutes, 15 participants at 5 (and 7.5 minutes), 10 participants at 10 minutes, 6 participants at 12.5 minutes, and 3.5 participants for the remainder of the trial.

Figure 14

Brief Description: Figure 14: Line graph showing drop-outs at 40% MVC, 4 seconds, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 4 seconds, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining through 5 minutes, 14 participants at 7.5 minutes, 8 participants at 10 minutes, 5 participants at 12.5 through 17.5 minutes, 4 participants at 20 minutes, and 3 participants for the remainder of the trial.

Figure 15

Brief Description: Figure 15: Line graph showing drop-outs at 25% MVC, 1 second, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (25% MVC, 1 second, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 5 minutes, 15 participants at 7.5 minutes, 12 participants at 10 minutes, 11 participants at 12.5 minutes, 8 participants at 15 minutes, and 7 participants for the remainder of the trial.

Figure 16

Brief Description: Figure 16: Line graph showing drop-outs at 40% MVC, 1 second, 50% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 1 second, 50% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining through 10 minutes, 14 participants at 12.5 minutes, 11 participants at 15 minutes, 10 participants at 17.5 minutes, 7 participants at 20 minutes (and 22.5 minutes),and 6 participants for the remainder of the trial.

Figure 17

Brief Description: Figure 17: Line graph showing drop-outs at 25% MVC, 4 seconds, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (25% MVC, 4 seconds, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 10 minutes, 15 participants at 12.5 minutes, 14 participants at 15 minutes, 13 participants at 20 minutes, 12 participants at 22.5 minutes and for the remainder of the trial.

Figure 18

Brief Description: Figure 18: Line graph showing drop-outs at 40% MVC, 7 seconds, 25% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 7 seconds, 25% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 10 minutes, 15 participants at 12.5 minutes, 14 participants at 15 minutes, and 13 participants at 17.5 minutes (and for the remainder of the trial).

Figure 19

Brief Description: Figure 19: Line graph showing drop-outs at 25% MVC, 1 second, 50% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (25% MVC, 1 second, 50% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 10 minutes and 15 participants at 12.5 minutes (through the remainder of the trial).

Figure 20

Brief Description: Figure 20: Line graph showing drop-outs at 25% MVC, 7 seconds, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (25% MVC, 7 seconds, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 12.5 minutes, 15 participants at 15 minutes (through 17.5 minutes), 13 participants at 20 minutes, 12 participants at 22.5 minutes, and 11 for the remainder of the trial.

Figure 21

Brief Description: Figure 21: Line graph showing drop-outs at 40% MVC, 4 seconds, 50% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 4 seconds, 50% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 15 minutes, 15 participants at 17.5 minutes, 14 participants at 20 minutes, and 12 participants from 22.5 minutes through the remainder of the trial.

Figure 22

Brief Description: Figure 22: Line graph showing drop-outs at 40% MVC, 7 seconds, 50% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (40% MVC, 7 seconds, 50% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 20 minutes and 15 participants remaining from 22.5 minutes through the remainder of the trial.

Figure 23

Brief Description: Figure 23: Line graph showing drop-outs at 10% MVC, 1 second, 75% DC

Essential Description: This figure shows time (0-25 minutes) on the X-axis, and Average Borg CR-10 ratings (0-10) on the left Y-axis. On the right Y-axis, the "number of participants remaining at time segment" is shown. The figure shows what occurs with a line as subjects drop-out. There is one line which shows what occurred over time for the given combination (10% MVC, 1 second, 75% DC). The line dips as people drop out. There is also one circle at every 2.5 minute increment, representing the number of participants remaining at that point in time. This figure shows 16 participants remaining at 20 minutes and 15 participants remaining from 22.5 minutes through the remainder of the trial.

Appendix H: Equivalent Text Descriptions: Tables

Table 1

Brief Description: Table 1: A table showing the results of analysis of five studies' parameters/results, sorted by duty cycle and including Borg CR-10 ratings. Highest/lowest Duty cycle and Borg CR-10 ratings are highlighted

Essential Description: This table compares the results and parameters of research from previous studies. The table has 6 columns: 1) % MVC 2) Duration (in seconds) 3) Frequency (grips/minute) 4) Duty cycle 5) Borg CR-10 ratings 6) study name. The table is organized from lowest to highest duty cycle. The highest and lowest duty cycles are highlighted (100 and 8.8, respectively). The highest and lowest Borg CR-10 ratings are also highlighted (0.6 and 7.5, respectively).

Table 2

Brief Description: Table 2: A table showing the study's experimental combinations

Essential Description: This table shows the 27 combinations that were tested in this experiment. There are four rows of information: 1) Combination number 2) Duty cycle (given in percentages) 3) Force (given in percent MVC) 4) Duration (given in seconds). The design is 3x3x3 in design, with the 27 combinations being a result of 3 duty cycles (25%, 50%, 75%), 3 levels of force (10%, 25%, 40%), duration (1,4,7 seconds). The table is organized from lowest to highest by duty cycle, then force, then by duration.

Table 3

Brief Description: Table 3: A table showing the effective frequencies resulting from duty cycle and duration combinations

Essential Description: This table shows the nine resulting frequencies that are derived from the combination of duty cycles and durations tested in this study. There are 3 columns of information: 1) Duty cycle (given in percentage) 2) Duration (given in seconds) and 3) Frequency (given in grips/minute).

Table 4

Brief Description: Table 4: A table showing population data from the subjects who participated in the study

Essential Description: This table provides information on the eight subjects who participated in this study. Age (in years), Stature (in inches), and 100% MVC (in kilograms) are listed in separate columns. The maximums, minimums, averages, and standard deviations are also included for all of the data.

Table 5

Brief Description: Table 5: A table showing N values at 2.5 minute time segments for twelve combinations with subject drop-outs

Essential Description: This table shows the N values at 2.5 minute time segments for twelve combinations with subject drop-outs. Each subject is equivalent to "n" (n = 8 subjects times 2 trials = 16 total without drop-outs). The table has four major columns: 1) MVC, 2) Duration, 3) DC 4) Minutes. There is a sub-heading under minutes with each 2.5 minute time segment from 2.5 through 25 minutes. The rows are organized by combinations resulting in the most drop-outs at the top to the combination with the least number of drop-outs at the bottom. The time segments resulting in less than 16 participants (drop-outs) are highlighted.

Table 6

Brief Description: Table 6: A table showing the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 10% MVC

Essential Description: This table shows the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 10% MVC. All ratings (including ranges) are based on the last Borg CR-10 rating provided for the combination by subjects. There are two major column headings: 1) Duration and 2) Duty Cycle. There are three sub-headings under duty cycle, broken down into 25%, 50% and 75% duty cycles. Within each duration there are two rows: 1) Borg CR-10 mean (plus or minus standard deviation) and 2) Minimum to maximum range (of the Borg CR-10 rating).

Table 7

Brief Description: Table 7: A table showing the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 25% MVC

Essential Description: This table shows the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 25% MVC. All ratings (including ranges) are based on the last Borg CR-10 rating provided for the combination by subjects. There are two major column headings: 1) Duration and 2) Duty Cycle. There are three sub-headings under duty cycle, broken down into 25%, 50% and 75% duty cycles. Within each duration there are two rows: 1) Borg CR-10 mean (plus or minus standard deviation) and 2) Minimum to maximum range (of the Borg CR-10 rating).

Table 8

Brief Description: Table 8: A table showing the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 40% MVC

Essential Description: This table shows the Borg CR-10 means, standard deviations, and ranges (minimum to maximum) for all combinations at 40% MVC. All ratings (including ranges) are based on the last Borg CR-10 rating provided for the combination by subjects. There are two major column headings: 1) Duration and 2) Duty Cycle. There are three sub-headings under duty cycle, broken down into 25%, 50% and 75% duty cycles. Within each duration there are two rows: 1) Borg CR-10 mean (plus or minus standard deviation) and 2) Minimum to maximum range (of the Borg CR-10 rating).

Table 9

Brief Description: Table 9: A table showing the difference in Borg CR-10 ratings as force increases from 10 to 25% MVC

Essential Description: This table shows the difference in Borg CR-10 ratings as force increases from 10 to 25%. It is derived from data contained in Tables 6 and 7. There are 5 column headings: 1) Duration, 2) 25% DC, 3) 50% DC, 4) 75% DC, 5) Means. The duration column is ordered from lowest to highest duration. Seven resulting means are shown (across durations, and across duty cycles, as well as a grand mean). The grand mean is 1.9.

Table 10

Brief Description: Table 10: A table showing the difference in Borg CR-10 ratings as force increases from 25 to 40% MVC

Essential Description: This table shows the difference in Borg CR-10 ratings as force increases from 25 to 40%. It is derived from data contained in Tables 7 and 8. There are 5 column headings: 1) Duration, 2) 25% DC, 3) 50% DC, 4) 75% DC, 5) Means. The duration column is ordered from lowest to highest duration. Seven resulting means are shown (across durations, and across duty cycles, as well as a grand mean). The grand mean is 2.2.

Table 11

Brief Description: Table 11: A table showing the difference in Borg CR-10 ratings as duty cycle increases from 25 to 50%

Essential Description: This table shows the difference in Borg CR-10 ratings as duty cycle increases from 25 to 50%. It is derived from data contained in Tables 6 through 8. There are 5 columns: 1) Duration 2) 10% MVC, 3) 25% MVC, 4) 40% MVC, and 5) Means. The duration column is ordered from lowest to highest duration. Seven resulting means are shown (across durations, and across forces, as well as a grand mean). The grand mean is 1.4.

Table 12

Brief Description: Table 12: A table showing the difference in Borg CR-10 ratings as duty cycle increases from 50 to 75%

Essential Description: This table shows the difference in Borg CR-10 ratings as duty cycle increases from 50 to 75%. It is derived from data contained in Tables 6 through 8. There are 5 columns: 1) Duration, 2) 10% MVC, 3) 25% MVC, 4) 40% MVC, and 5) Means. The duration column is ordered from lowest to highest duration. Seven resulting means are shown (across durations, and across forces, as well as a grand mean). The grand mean is 1.4.

Table 13

Brief Description: Table 13: A table showing the difference in Borg CR-10 ratings as duration increases from 1 to 4 seconds

Essential Description: This table shows the difference in Borg CR-10 ratings as duration increases from 1 to 4 seconds. It is derived from data contained in Tables 6 through 8. There are 5 columns: 1) Force (in % MVC), 2) 25% DC, 3) 50% DC, 4) 75% DC, and 5) Means. The force column is ordered from lowest to highest MVC. Seven resulting means are shown (across forces, and across duty cycles, as well as a grand mean). The grand mean is -0.6.

Table 14

Brief Description: Table 14: A table showing the difference in Borg CR-10 ratings as duration increases from 4 to 7 seconds

Essential Description: This table shows the difference in Borg CR-10 ratings as duration increases from 4 to 7 seconds. It is derived from data contained in Tables 6 through 8. There are 5 columns: 1) Force (in % MVC), 2) 25% DC, 3) 50% DC, 4) 75% DC, and 5) Means. The force column is ordered from lowest to highest MVC. Seven resulting means are shown (across forces, and across duty cycles, as well as a grand mean). The grand mean is 0.1.

Table 15

Brief Description: Table 15: A table showing the P-values, AIC scores, and adjusted R-squared values for linear regression models with final Borg CR-10 rating as the dependent variable

Essential Description: This table shows the P-values, AIC scores, and adjusted R-squared values for linear regression models with final Borg CR-10 rating as the dependent variable. There are 3 columns: 1) Parameter, 2) Model 1, and 3) Model 2. The parameters which resulted in statistically significant data are highlighted. Highlighted values within Model 1 are: 1) %MVC, 2) % MVC * DC, and 3) Subject. Highlighted values within Model 2 are: 1) % MVC * F*D, and 2) Subject. There is a note at the bottom of the table stating that "subjects were treated as a random effect in each model."