# The Influence of Multiple Risk Factors on WMSD Risk and Evaluation of Measurement Methods Used to Assess Risks

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(Abstract)

Despite high prevalence rates of work-related musculoskeletal disorders (WMSDs), the causes and pathways of WMSD development are not fully understood. Multiple factors (physical, psychosocial, and individual) have been associated with WMSD development, but causal inferences are not available due to lack of experimental designs. Because the responses, validity, and reliability of measured outcomes under multiple-exposure environments are not known, the current work analyzed the effects of multiple WMSD risk factors on several measurement methods.

Forty-eight participants completed four trials of simulated manufacturing work at different levels of physical and psychosocial exposure for one psychosocial dimension (job control, job demands, time pressure, or social support). The three independent variables significantly affected outcomes, including muscle activity, heart rate, task performance, discomfort and workload ratings, and psychosocial environment perceptions. Social interaction should take priority over working in isolation, and pressure to achieve high performance should be minimized to reduce WMSD risk.

A secondary data analysis determined measurements that could estimate WMSD risk efficiently. Convergent and discriminant validity was assessed to retain methods that provided unique information and minimized overlap between similar methods. For the given manufacturing environment, one muscle activity measure, heart rate mean and variability, one set of workload and discomfort ratings, and a psychosocial questionnaire were the best WMSD risk measurement methods.

The third study assessed the test-retest reliability of the outcome measures of an additional trial involving 24 participants. Workload and discomfort appeared reliable under high levels of physical exposure but not under psychosocial manipulations. Physiological measures were

reliable for <50% of parameters. The psychosocial questionnaire was reliable under favorable social support but not high physical exposure and favorable job control.

The final study determined the number of psychosocial factors experienced through factor analysis on psychosocial questionnaire responses from the main experiment. Participants could distinguish psychosocial dimensions in the work environment, and this questionnaire may be used in experimental settings to measure perceptions of the psychosocial environment.

The current research provided a basis for measuring physical and psychosocial exposure simultaneously in occupational settings. Using this knowledge may allow practitioners to focus on interventions and designs that reduce WMSD risk exposure.

## Table of Contents

## Table of Figures

## Table of Tables

## ***Dedication***

*To those who lost their lives on April 16, 2007 on the campus of Virginia Tech*
*Your spirit lives on in every Hokie*

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## Chapter 1: Introduction

A major goal of occupational ergonomics, preventing work-related musculoskeletal disorders (WMSDs), can be approached by addressing potential causes from multiple risk factors. While traditional ergonomics alone has a history of reducing reported WMSDs by 10-25% (Hendrick & Kleiner, 2001), additional investigations into other classes of potential risk factors (e.g., psychosocial risk factors) may allow researchers and practitioners to successfully lower WMSD rates further by applying interventions to address multiple factor exposures. A first step in researching other risk factors is to determine which potential factors to measure and how to measure them. Epidemiological evidence suggests a significant role of psychosocial factors, which are factors in the work environment outside of physical requirements. For instance, Bildt Thorbjornsson, Michelson, and Kilbom (1999) collected 24 years' worth of questionnaire and interview data regarding WMSD prevalence and causes for workers and concluded that there were two influential factors related to the psychosocial environment: poor social relations at work and low influence over work conditions. Other epidemiological studies suggest that factors such as job demands, time pressure, and stimulus from work activities are also significantly associated with WMSD development (Ariëns, van Mechelen, Bongers, Bouter, & van der Wal, 2001; Bongers, de Winter, Kompier, & Hildebrandt, 1993; Buckle, 1997; National Institute of Occupational and Safety Health, 2001). However, measuring psychosocial factors simultaneously with physical and individual risk factors continues to challenge researchers.

The National Research Council (1999) gives several general areas of research that need to be addressed concerning the role of psychosocial factors in WMSD development. The first is to develop models and describe mechanisms that underlie the relationships between psychosocial factors and WMSD outcomes. The second is to improve measurement methods, and the last is to consider multiple factors in designing and analyzing experiments and data. A simplified model (Figure 1) of WMSD development based on ecological and biopsychosocial models of WMSD development (Melin & Lundberg, 1997; Sauter & Swanson, 1996) is used to guide the current research, which will address the first area. The position taken towards improving measurement methods (the second suggested research area) is that many measurement methods that have adequate reliability and validity already exist, but choosing the best methods to measure all aspects of the work environment remains to be determined.

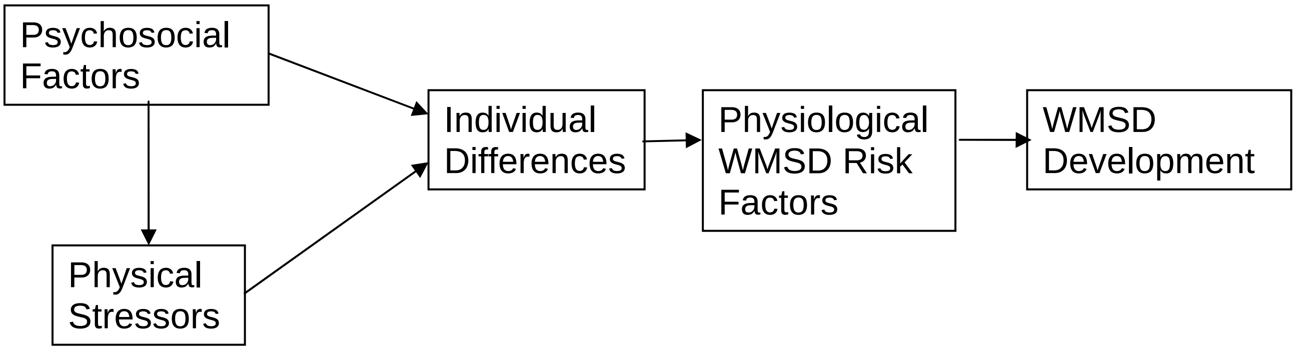


Figure 1. Proposed model of WMSD development

The final issue, considering multiple factors in experimental design, has been ignored or not fully explored in previous work. Measuring multiple factors simultaneously and then separating the influence of physical demands from psychosocial demands remains a major research challenge to address. Several problems arise in the process of measuring multiple factors. The main problem is the quality and depth of data collection. In general, many studies attempting to quantify the effects of psychosocial factors have not thoroughly investigated the physical characteristics of occupations being studied. Likewise, many studies focus on physical workloads and do not consider psychosocial factors. In studies that do address both physical and psychosocial factors, high correlations between physical load and psychosocial factors make separating the relative contributions of risk factors difficult (Bongers et al., 1993). More recently, MacDonald, Karasek, Punnett, and Scharf (2001) also found that covariation between physical and psychosocial risk factors is particularly an issue among blue-collar and low-status white-collar workers in their study of 410 workers and suggest some of this covariation may be the result of similar work organization patterns. Therefore occupation type is another variable to consider in determining relative risks.

### *Objectives*

The current research addressed gaps in research on the effects of multiple risk factors in WMSD development in occupational settings. The two overarching objectives were to investigate the effects of multiple WMSD risk factors in experimental settings and to determine a valid and easily accessible set of measurement tools to quantify multiple risk factor exposures in occupational settings. To address these research objectives, a large laboratory study was conducted to evaluate a proposed comprehensive measurement method under different levels of physical (2 levels) and psychosocial (4 types at 2 levels) risk factor exposures. The experimental task was a simulated automotive assembly operation. Physical, psychosocial, and individual risk factors were measured through questionnaires, rating scales, performance assessments, and physiological measures. Several contributions resulted from the proposed research:

1. The design of the laboratory experiment compared four different psychosocial factors under the same physical demands and work tasks. This allowed comparisons of the effects of different psychosocial dimensions and interactions between physical and psychosocial exposure on WMSD risk factors. Psychosocial dimensions were narrowly defined so as not to create an overlap with physical demands whenever possible.
2. Several measurement issues concerning the methods chosen were evaluated including
    a. Convergent and discriminant validity of proposed measurement methods
    b. Test-retest reliability of subjective and physiological measurement methods
    c. Factor analysis of a psychosocial questionnaire
    d. Minimum sample size needed to estimate outcomes measures under multiple risk factors.

### *Scope and Limitations*

The experiment took place in a laboratory setting and exposed study participants to different combinations of physical and psychosocial exposure. Physical exposure was limited to changes in tool weight. Each participant experienced one of four psychosocial dimensions: social support, job demands, job control, or time pressure.

One limitation of the study design was the use of a laboratory setting rather than an occupational setting, which may have limited external validity. In particular, physical and psychosocial exposures may be interpreted differently when they occur on a daily basis over the course of years instead of a few hours during an experiment. The laboratory simulation of a work environment was limited to a manufacturing task. Other occupational settings such as an office or construction environment may have different levels of exposure to various risk factors, but the methods developed in this study are applicable to other occupations.

Not all possible risk factors could be included in the study. Instead, the factors that can be adjusted within an occupational setting and that have the highest hypothesized effect on WMSD risk were chosen. Psychosocial dimensions were based on epidemiological findings (Ariëns et al., 2001; Bildt Thorbjörnsson et al., 2000; Bongers et al., 1993; Buckle, 1997; National Institute of Occupational and Safety Health, 2001), and force was used to induce physical exposure. Research is fairly well-developed in supporting the role of physical exposure in WMSD development, so a detailed analysis of physical risk factors was not included here. Also, several physical risk factors such as vibration and number of joint movements were excluded due to the task chosen. Risk factors were limited to those that occur in the workplace and that could eventually be altered through work design.

Finally, the use of students as participants in the study presented several limitations. Demographic characteristics such as average age, average education level, and ethnic distribution were not fully representative of the general working population. Therefore no conclusions were drawn regarding the effects of these individual factors on WMSD risk.

### *Summary*

The research explored the effects of physical and psychosocial exposure in occupational settings and the methods that can be used to measure the effects. One large laboratory study consisting of four smaller parts was conducted in which participants completed a simulated automotive assembly task under various levels of physical and psychosocial exposures. Measurement methods included questionnaires, rating scales, performance measures, and physiological data to assess perceptions and physiological reactions to the work environment. The research provided insight into effects of physical and psychosocial exposure on WMSD risk factors and into the measurement methods that can be used to gain an accurate estimate of risk exposure levels in occupational settings. The recommendations for the types of measurement methods and the sample size needed to collect accurate data can be used in occupational settings to determine risk levels and areas of focus for intervention and redesign efforts.

# Chapter 2: The influence of physical and psychosocial exposures on physiological and subjective responses to the work environment


## Abstract

**Objective:** This study tested the effects of select psychosocial factors on physiological and subjective outcomes in an experimental setting.

**Methods:** Forty-eight participants were exposed to favorable and unfavorable levels of one psychosocial manipulation (job demands, job control, social support, or time pressure) at high and low levels of physical exposure using a simulated manufacturing task. Muscle activity, heart rate, discomfort, workload, and perceptions of the psychosocial environment were recorded.

**Results:** Physical and psychosocial factors influenced all potential risk factors. Namely, social support manipulation participants had the lowest muscle activity, and job demands manipulation participants had the highest shoulder discomfort ratings along with the lowest heart rate variability, a potential indicator of high mental workload.

**Conclusions:** The experimental data show that workplace evaluation should consider both psychosocial and physical exposure in determining WMSD risk.



***Keywords*:** psychosocial factors, WMSD risk factors, manufacturing, workload, EMG, heart rate

## Introduction

Epidemiological studies have shown an increased risk of WMSD development when unfavorable psychosocial characteristics are present in the workplace. There is strong evidence that physical factors (repetitive motion, exertion, range of joint motion, vibration, and combinations of these factors) are linked to WMSDs (National Institute of Occupational and Safety Health, 2001), but establishing such a link for psychosocial factors is more difficult because of potentially complex interactions (Aptel, Aublet-Cuvelier, & Cnockaert, 2002). Bildt Thorbjornsson et al. (1999) collected 24 years of questionnaire and interview data from 484 people in the Swedish general working population regarding WMSD risk factors. They concluded that there were two influential factors related to the psychosocial environment: poor social relations at work and low influence over work conditions. A 10-year follow up study of 902 blue and white collar employees in the metal industry showed that psychosocial factors were associated with physical problems regardless of physical workload, even after controlling for age, gender, and socioeconomic status (Leino & Hänninen, 1995). Other epidemiological studies suggest factors such as job demands, time pressure, and stimulus from work activities are also significantly associated with WMSD development (Ariëns et al., 2001; Bongers et al., 1993; Buckle, 1997; National Institute of Occupational and Safety Health, 2001). While these studies provide evidence of association between psychosocial factors and WMSD outcomes, little is known on how these factors increase risk or more generally what pathophysiological pathways exist.

Experimental study designs have the potential to increase knowledge regarding how psychosocial factors contribute to WMSD development, yet such studies remains sparse. Previous experimental studies have been limited mainly to the influence of one work environment factor (generally defined as mental demands or psychosocial stressors) on activities such as typing or manual materials handling. For instance, increased mental demands have been associated with increased trunk muscle forces during manual materials handling (Davis, Marras, Heaney, Waters, & Gupta, 2002), in trapezius muscle activity during laboratory-based mental activities and physical exercises (Lundberg et al., 2002), and in cervicobrachial muscle activity during typing (Leyman, Mirka, Kaber, & Sommerich, 2004). In a study of psychological stressors (polite and supportive versus impolite and unsupportive experimenters), women had higher muscle activity under stressful conditions than men, and personality (Myers-Briggs type) had differential effects on muscle activity (Marras, Davis, Heaney, Maronitis, & Allread, 2000).

In the current study, four dimensions of the psychosocial environment (social support, job control, time pressure, and job demands) were included that have been identified in epidemiological studies as being significantly associated with WMSD development. Social support can be divided into support from supervisors and support from coworkers. In this experiment coworker support was manipulated so that the role of the supervisor (experimenter) would be equivalent across all psychosocial dimensions. Job control refers to the level of decision authority given to workers about different aspects of their work, and job demands refer to characteristics of the work environment that can lead to psychological stress (Karasek, Brisson, Kawakami, Houtman, & Bongers, 1998). Perceptions of time pressure can be manipulated by increasing task requirements within a set task completion time (Hughes, Babski-Reeves, & Smith-Jackson, 2007). These factors were experimentally manipulated within the same work task to allow for direct comparisons. Measured outcomes were perceptions of the work environment, workload, and discomfort along with physiological changes in muscle activity and heart rate. Less favorable psychosocial conditions were hypothesized to be linked with higher perceived workload, discomfort, muscle activity and heart rate.

## Methods

Participants performed four trials consisting of a simulated manufacturing job with two tasks under different levels of exposure to physical and psychosocial factors. Physiological and subjective responses to the experiment conditions were recorded through EMG, heart rate, workload ratings, discomfort ratings, and perceptions of the psychosocial environment. Prior to the trials, an orientation session was used to gather basic demographic, personality type, and resting heart rate data.

### *Experiment Design*

Three independent variables, physical exposure, psychosocial exposure, and psychosocial dimension, were included in a 2x2x4 full factorial experiment. A mixed-factors design was used in which physical and psychosocial exposure levels were manipulated as within-subjects factors. Four psychosocial dimensions were varied between participants: job control, job demands, social support, and time pressure. Psychosocial dimension was manipulated between-subjects factor to limit the number of trials for each participant. Each participant completed four trials under each level of psychosocial and physical exposure for one psychosocial dimension in addition to an orientation session on a separate day to explain procedures and provide familiarization with the task and recording methods. Presentation order was balanced using a Latin square design. A total of 48 participants completed the experiment with 12 experiencing each psychosocial dimension (Table 1).

Table 1. Mixed-factors experimental design

| Demand Levels | Time Pressure | | Social Support | | Job Demands | | Job Control | |
|---|---|---|---|---|---|---|---|---|
| | favorable | unfavorable | favorable | unfavorable | favorable | unfavorable | favorable | unfavorable |
| low physical<br>high physical | 1-12 | | 13-24 | | 25-36 | | 37-48 | |

### *Participants*

There were 31 males and 17 females involved, with a mean (SD) age of 23.1 years (4.7 years) (Table 2). Potential participants were required to either perform arm-strengthening exercise on a regular basis or have manual labor experience, in addition to being free of any medical condition that could affect arm strength or mobility to qualify for the experiment. All participants involved were exercising regularly at the time of the experiment, and 25 reported they had manual labor experience. All but one participant was a current university student. Pairs of participants were used in the social support dimension. To this end, approximately half of the participants were given the option to recruit a partner or to work individually when they initially joined the experiment.

Table 2. Participant demographics.

| | Job demands (n) | Time pressure (n) | Job control (n) | Social support (n) | Mean Age (SD) | Jenkins[1] Type A | Bortner[2] Type A |
|---|---|---|---|---|---|---|---|
| Males | 9 | 8 | 9 | 5 | 24.0 (5.1) | 8 | 21 |
| Females | 3 | 4 | 3 | 7 | 21.4 (3.3) | 10 | 13 |
| Total | 12 | 12 | 12 | 12 | 23.1 (4.7) | 18 | 34 |

[1] (Yarnold & Bryant, 1994)
[2] (Johnston & Shaper, 1983)

### *Simulated Work*

The job consisted of two tasks that simulated work on an assembly line in an automotive facility: repetitive overhead efforts from nut and bolt tightening on the underbody of a chassis and simple small parts assembly. All task parameters were based on task analyses of actual work tasks and are the same as that described in Sood et al. (2007). The simulated overhead efforts (Figure 2) involved repetitive tapping on an inverted computer keyboard. The keyboard was adjustable in height, and participants tapped four specifically numbered keys on the keyboard (Figure 2) using non-powered drills of different weights (0.5 kg or 1.25 kg) with their dominant arm at a constant pace (80 beats per minute, indicated by a digital metronome). Task height was adjusted for each participant to be 40% of the difference between having the upper arm parallel to the ground and elbow bent at 90° and having the arm extended completely overhead. Wires were strung across the keyboard forcing participants to perform obstacle avoidance as well as vertical and horizontal drill movement to complete the task. The assembly task involved screwing and unscrewing nuts and bolts at a work height that kept the arms in a more neutral position (slightly below elbow height). No set requirements were given for the small parts assemblies other than to perform the task continuously.

Figure 2. Representation of overhead tapping task.

Tapping and assembly tasks were alternated within each cycle, which was 54 s, to match the cycle time used in an automotive manufacturing plant (Sood et al., 2007). The tapping task was considered the “work” portion of the cycle while the assembly task was considered the “rest” part. Participants spent either 33% or 66% of every cycle on each task. An auditory signal directed when to switch activities. Participants switched between 33% and 66% lengths for each task every 15 minutes, except during trials conducted at high social support and high job control levels which had variable durations at each length. Each trial lasted one hour. An example sequence of the task and data measurement (described in Dependent Variables) is provided in Figure 3. Participants had additional work requirements depending on the psychosocial factor manipulation to which they were exposed (details provided in Independent Variables). Key taps were recorded through a laptop connected to the keyboard, and performance was measured as the percentage of accurate key taps.

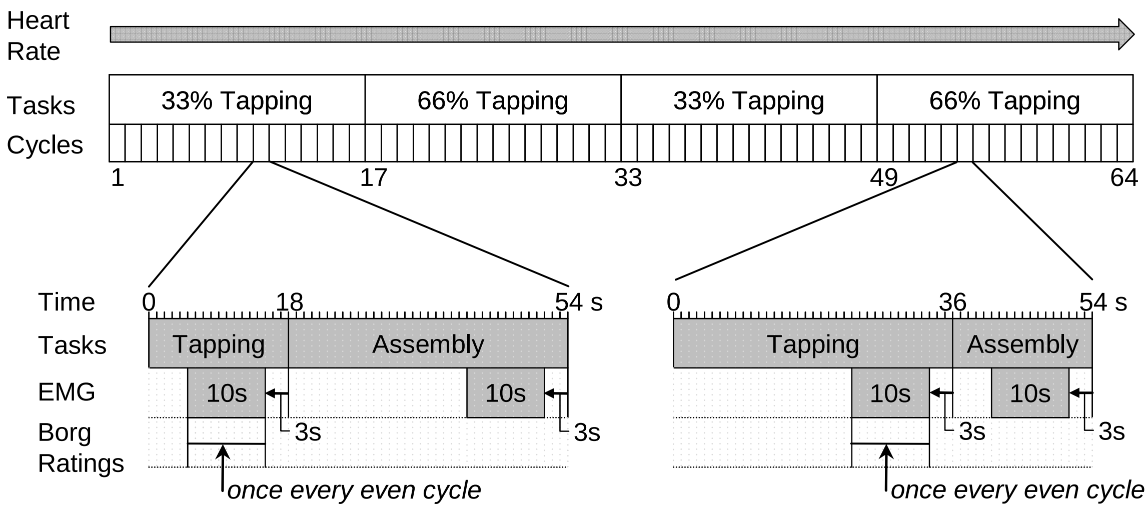


Figure 3. Task sequence and data recording for a trial with task length changes every 15 min.

### *Independent Variables*

Physical exposure was manipulated at two levels by using a lightweight tool (0.5 kg) for low exposure and a heavier tool (1.25 kg) for high exposure. Previous use of these weights has led to differences in perceived demands, discomfort, and endurance times (Nussbaum, Sood, & Hager, 2002). Other potential physical exposure risk factors such as repetition level and posture were kept constant to avoid confounding effects with psychosocial exposure manipulations.

Psychosocial exposure was manipulated at two levels and differed according to the psychosocial factor dimension to which each participant was assigned. These exposures were created to minimize possible direct influences on physical exposure level. If assigned to the job control, job demands, or time pressure dimensions, participants completed the experiment individually. Participants completed the experiment in self-selected pairs in the social support dimension.

*Job Control:* In the unfavorable level of job control, duty cycle (33 or 66%) alternated every 15 minutes. In the favorable job control condition participants determined when to switch between the 33% and 66% duty cycles, provided that half of the trial was completed using each duty cycle. Participants verbally notified the experimenter when they wanted to change duty cycle (from 33% to 66% or vice versa), and the number and duration of duty cycle changes were recorded. Verbal reminders of trial time for each duty cycle were provided at each change.

*Time Pressure*: Time pressure was manipulated by introducing a concurrent mental task as an unfavorable psychosocial condition, while the favorable time pressure level did not include the mental task. The additional task consisted of answering math questions (two per cycle) while continuing the main tasks (overhead tapping and assembly). The math questions were a random mix of multiplication of a single digit excluding 0 and 1 with a two digit number between 11 and 50, and subtraction of two numbers between 11 and 99, and these were intended to provide a medium to high level of perceived mental workload (DiDomenico & Nussbaum, 2005). The math questions were framed in the context of a realistic work calculation, such as ordering parts (e.g. "Compute the cost of ordering 6 parts that cost $0.35 each"), and were presented orally. Performance on these additional activities was recorded through responses classified as correct, incorrect, skip, repeat, or no response. If a participant did not provide the correct answer, the next question was presented. Participants were instructed to give the tapping tasks, assemblies and math questions equal attention and importance. Assigning equal importance to the math task was anticipated to improve motivation to complete problems rather than concentrating solely on the tapping or assembly tasks.

*Social Support:* Social support was manipulated by varying the level of interaction between pairs of participants completing the tasks. Participants shared this task, meaning that while one participant was performing the key tapping, the other participant was performing the nut and bolt assembly. A result of this design was that one participant initially performed their task under the long duty cycle while the other completed their task under the short duty cycle. Participants switched tasks based on a computer generated auditory signal. In the unfavorable social support condition, participants were prohibited from talking or otherwise interacting during the trial. As with the other conditions, duty cycle switched every 15 minutes. In the favorable social support condition, participants were able to switch duty cycle (from 33% to 66% or vice versa) as desired (as long as each person completed half of the trial at each duty cycle), and were permitted to talk while working. It was noted that topics of conversation should be pleasant rather than potentially controversial or uncomfortable.

*Job Demands:* Job demands were manipulated by changing the level of prompting regarding performance. In the favorable job demands condition, no feedback was provided regarding task performance. In the unfavorable job demands condition, participants were periodically reminded to maintain the highest performance possible by keeping tapping accuracy as high as possible and by maintaining an exact tapping pace as set by the metronome. Reminders were provided every fourth cycle so that participants received the same number of reminders regardless of actual performance level.

### *Dependent Variables*

Muscle activity and heart rate were measured as physiological responses to the work environment. Muscle activity has been linked with fatigue and pain (Hägg & Åström, 1997; Hansson et al., 2000; Veiersted, Westgaard, & Andersen, 1990), so any differences in muscle activity from the independent variables may indicate increased WMSD risk. Heart rate (HR) can be used as a measure of overall workload and energy expenditure (Åstrand & Rodahl, 1986; Spurr et al., 1988). While HR is highly reproducible within individuals performing the same work (Åstrand & Rodahl, 1986), it does not discriminate well between different levels of workload in mentally demanding tasks (Backs, 1998). Heart rate variability (HRV), however, can be used to discriminate different levels of mental workload (Backs, 1998). Therefore, both heart rate mean and variability were obtained.

*Muscle Activity:* Surface electromyography (EMG) was used to estimate the activity of the middle deltoid, anterior deltoid, and upper trapezius on the dominant side, using 10 mm, rectangular Ag/AgCl pre-gelled bipolar disposable electrodes (placed as described in Perotto, 1994). These muscles were selected as they are active in this type of overhead work (Nussbaum, 2001). The trapezius is also active in hand work similar to the small parts assembly task (typing) and may be affected by psychosocial conditions (McLean & Urquhart, 2002). The skin was prepared for electrode application by shaving, slightly abrading, and cleaning the skin with alcohol to minimize impedance.

Signals were transmitted through short (less than 30 cm) leads to preamplifiers (100 gain), amplified, band-pass filtered (10-500 Hz), RMS converted (110 ms time constant), and A/D converted by hardware. The gain was set such that RMS signals did not exceed 2-3 volts, and input impedance was less than 10 kΩ as measured after a 15-minute stabilization period. EMG data were collected for 10-seconds at a sampling rate of 1000 Hz during the last portion of the two tasks in each work cycle (see Figure 3), which resulted in 128 windows of data (64 from the tapping task and 64 from the small parts assembly) for each one-hour trial. Mean and maximum values within each window were computed and averaged by task (T: tapping or A: small parts assembly) for each trial. These values are denoted as $EMG\text{-}mean_T$, $EMG\text{-}mean_A$, $EMG\text{-}max_T$, and $EMG\text{-}max_A$.

EMG were normalized using values obtained from maximum voluntary contractions (MVC) for each muscle. Before every trial, MVCs were conducted by having participants perform a separate exercise to elicit a maximum isometric contraction for each muscle, similar to previously used methods (Nussbaum, Clark, Lanza, & Rice, 2001). Two chains with handlebar grips were attached to a floor plate. Participants grasped one handlebar with their dominant hand and lifted their arm forward for the anterior deltoid, and they abducted their shoulder for the middle deltoid. To obtain the MVC for the trapezius, participants grasped a handlebar in each hand and pulled up as if they were shrugging. The procedure for each exercise had the participant exert as hard as possible for 5 seconds in a ramp-up, ramp-down pattern. A series of three MVCs were performed, with 45 seconds of rest between each. The highest value of each trial was recorded, but if the highest reading occurred in the last trial, further trials were conducted until a non-maximum value was observed.

*Heart Rate:* A second measure of physiological response, heart rate (HR), was collected using a heart rate monitor (Polar S810: Polar Electro Inc., Lake Success, NY). HR data were recorded continuously as beat-to-beat (R-R) intervals over the entire trial. HRV was calculated as the standard deviation in HR over a trial (Kamath & Fallen, 1993). HR data were normalized using each participant's measured resting and estimated maximum HR (220 - age, from Eastman Kodak Company, 2004). Resting heart rate was obtained by recording heart rate for 5 minutes during the orientation session and determining the lowest 15-second average. While there are no standard procedures for measuring heart rate, some have recommended resting for at least five minutes before measuring heart rate (Jouven et al., 2006). This was accomplished in the current experiment by having participants sit quietly while reading informed consent forms and completing a demographic questionnaire prior to recording heart rate, which took 5-10 minutes.

*Workload Ratings:* Participants rated their perceptions of workload using two workload measurement tools: the NASA task load index (NASA-TLX: Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT: Reid & Nygren, 1988) which can be found in Appendices G and H. The NASA-TLX was originally designed as a multidimensional subjective mental workload assessment tool. Users rate their levels of mental demand, physical demand, temporal demand, performance, effort, and frustration level on visual-analog scales (VAS), and these ratings are averaged using weights from a pair-wise comparison of demands. These pair-wise comparisons were completed prior to every trial after an explanation of the specific trial conditions. The comparisons were an estimation of which demands the participants felt would be greatest during the trial, and the ratings provided on the VAS after the trial reflected the workload experienced by the participant. The mark on each VAS was measured from 0 to 12.75cm and multiplied by the corresponding weighting factor before being added to the total weighted workload and dividing by 15 (the total number of paired choices). Unweighted workload was also calculated by adding the ratings and dividing by six. Unweighted and weighted measures of total workload from the NASA-TLX sub-scales have been shown to be equivalent in a previous study (Moroney, Biers, Eggemeier, & Mitchell, 1992) and could save the step of completing the pair-wise comparisons in the future. In the current study the NASA-TLX was interpreted as an overall perceived workload measure because physical exposure level could influence certain components of the scale such as physical demand and effort.

SWAT is a set of three ratings on perceived mental effort load, time load, and stress load that can be combined for an overall mental workload measure. A modified version of these scales using three visual-analog scales (VAS) with the original anchor descriptions was used here as a subjective measure of mental workload. The VAS version of SWAT has been shown to be more sensitive in measuring moderate levels of mental workload (Luximon & Goonetilleke, 2001), and it was found in a previous study to discriminate perceived workload levels under different psychosocial conditions (Hughes et al., 2007). Each VAS is 20cm in length, and each mark on the three scales is measured and added for a total workload score.

*Perceived Discomfort:* Participants rated their discomfort using two scales. Shoulder discomfort was assessed every other cycle during the tapping task using the Borg-CR10 scale (Borg, 1982), modified to assess discomfort rather than exertion as originally developed (Appendix E). The Borg-CR10 scale provides a way for participants to rate perceived exertion or discomfort during a task. The scale is a category-ratio scale with a range from “0, nothing at all”, to “10, extremely strong (almost max)”. This type of rating scale is easy to administer and has been used successfully in occupational settings (e.g. Andersen et al., 2002). A display of the rating scale was provided near the work surface. To ensure participants were not overly fatigued, any participant reaching a rating of 7 or higher was reminded of their option to terminate the experiment. Participants were encouraged to notify the experimenter if they experienced discomfort in other areas of the body. For each trial, the maximum rating, difference between the maximum and minimum rating (difference), overall mean rating, and means for 33% and 66% duty cycles were all obtained as dependent measures.

The body discomfort map (BDM: J. L. Visser & Straker, 1994) was presented at the end of the experimental trial as an overall assessment of physical discomfort (Appendix F). Participants checked areas of the body in which they experienced discomfort and provided a rating using the same 0 to 10 scale to indicate the maximum level of discomfort experienced during the trial.

*Psychosocial Questionnaire:* Perceptions of the psychosocial environment were assessed using a 30-item questionnaire consisting of items drawn from the Job Content Questionnaire (JCQ: Karasek et al., 1998). Only questions from categories that were relevant to the current task were included (e.g. questions on job security and customer relations were omitted). All questions from the following scales were retained (Appendix I): skill discretion (6 items), decision authority (3 items), psychological work demands (8 items), physical job demands (sub-divided into exertion

(3 items) and isometric loads (2 items)), supervisor support (4 items), and coworker support (4 items). Participants that were not in the social support dimension were instructed to leave questions blank that involved ratings of coworkers. Scoring was conducted using methods provided in the JCQ User's Guide (Karasek, 1985).

### *Procedures*

Participants attended one orientation session and completed four experimental trials on separate days. Participants were asked to avoid alcohol, smoking, excessive caffeine, and heavy lifting for 24 hours prior to each trial to ensure the quality of EMG and heart rate data. Trials took place at approximately the same time of day to avoid changes due to circadian rhythms, and between one day and two weeks of rest were given between trials to avoid potential residual muscle fatigue, physiological changes, and poor retention of trial procedures.

During an orientation session, participants completed informed consent forms (Appendix A) and a demographic questionnaire (Appendix B). Type A personality tendencies are hypothesized to directly influence muscle activity (Glasscock, Turville, Joines, & Mirka, 1999) and psychosocial outcomes including perceived stress and job satisfaction (Day & Jreige, 2002). Both the Jenkins student activity survey (Appendix C: Yarnold & Bryant, 1994) and the Bortner questionnaire (Appendix D: Johnston & Shaper, 1983) were administered to determine Type A personality tendencies (summary results in Table 2). After obtaining resting heart rate and determining the appropriate work height, each participant was guided through the use of the Borg scale (Appendix E) and was allowed to practice the tapping task for 5 minutes using the heavier drill. At the end of the orientation, participants were shown pictures from the automotive assembly lines, which were the basis for the experimental task, to provide context for the application of the research.

In each experimental session, setup procedures started with electrode and heart rate monitor placement. After reviewing the task parameters for the trial, participants completed NASA-TLX pair-wise comparisons (Appendix G) followed by MVC testing. Participants performed the trials (simulated job) for one hour and then completed the BDM (Appendix F), NASA-TLX rating scale (Appendix G), SWAT rating scale (Appendix H), and psychosocial questionnaire

(Appendix I) at the conclusion of the trial. When answering the psychosocial questionnaire, participants were instructed to envision that the task was their full-time job, just as in the pictures of the overhead assembly line they viewed prior to the trials, and to consider the experimenter to be their supervisor and any partner as a co-worker. Post-trial ratings and questionnaires were always presented in the same order to provide consistency between trials and avoid potential confusion of procedures. Participants were compensated $8/hour for their time.

### *Analysis*

All dependent variables were first assessed for normality using the Shapiro-Wilk's statistic and by inspecting histograms for symmetry. From this, task accuracy was adjusted using a square root transformation to reduce skewness. Out of nine areas of the body included in the BDM, only neck, low back, and dominant shoulder ratings were retained, as the other body area ratings were essentially zero and showed little variance. All other variables were considered to be from a normal distribution and were included in parametric analysis. A MANCOVA ($\alpha = .05$) was conducted to look for overall differences among all outcome variables for the main effects and their interactions. Gender was included as a blocking variable, and scores from the two personality tests (Bortner and Jenkins Type A tendencies tests) were entered as covariates. Gender and the two Type A tendencies scores all showed significant effects on the dependent variables, but they were not analyzed further in the current study. ANOVAs were run for each dependent variable given significance of the MANCOVA. Tukey HSD post hoc tests (Appendix L) were conducted for variables showing significant effects of psychosocial dimension. Post-hoc tests were not necessary for physical and psychosocial exposure since these had two levels.

All participants experienced two trials that were identical: no psychosocial manipulations at high and low physical exposure levels. The exception to this was the social support condition in which participants performed the same task but in the presence of their experiment partner. To test whether the groups exposed to the 4 different dimensions of psychosocial demands were similar, a MANOVA was run with only the data from the identical trials. The only clear difference observed was for muscle activity in the social support dimension compared to the other three conditions, which is explored in the discussion section. Because no other patterns of differences between dimensions were found, comparisons across all dimensions were made.

The psychometric properties of the JCQ have not been thoroughly investigated (Vagg & Spielberger, 1998), so the current study did not assume ratio or interval properties of the psychosocial questionnaire scores. Although Gillen et al. (2002) used ANOVA to compare JCQ ratings across union and non-union construction workers, previous studies using the JCQ have been mainly epidemiological in design and have been concerned with calculating odds ratios (e.g. Punnett, Gold, Katz, Gore, & Wegman, 2004; e.g. Wahlström, Hagberg, Toomingas, & Wigaeus Tornqvist, 2004). In one study of the Maastricht Cohort, scales from the JCQ were analyzed by dividing responses at the median in 'high' and 'low' levels and using these categories in a logistic regression (Bültmann, Kant, Schröer, & Kasl, 2002). A non-parametric approach was used in the current study. Specifically, the Kruskal-Wallis test was used to compare psychosocial dimensions since this is a test for factors having more than two levels, and the Mann-Whitney test was used for physical exposure level and psychosocial exposure level because this test is designed to test two levels of a single factor (Siegel & Castellan, 1988). All effects were considered significant at $\alpha = .05$.

The number of participants needed to detect differences ($\alpha = .05$) with sufficient power ($1- \beta = 0.80$) was estimated using results from a similar study (Hughes et al., 2007). Participants in that study were exposed to time pressure and job demand manipulations, and muscle activity and workload ratings were collected. Many of the significant effect sizes were considered "large" (e.g. SWAT total workload means ranged from 22 to 44). Using this information and degrees of freedom of 15 (4 psychosocial dimensions x 2 psychosocial exposure levels x 2 physical exposure levels – 1 = 15), a sample size of 63 to 69 was needed (Murphy & Myors, 2004). To use a balanced Latin Square to distribute trial orders, 64 participants were originally proposed. However, after completing 48 participants, analysis revealed that several effects were significant, and data collection was halted. Based on the results of a retrospective power analysis, all main effects had adequate power as they detected significant differences, and non-significant interaction effects had observed power of at least 0.4374 (Table 3).

Table 3. Retrospective power analysis for main effects and interactions

| Effect | Significance (*p*-value) | Observed Power |
|---|---|---|
| Psychosocial dimension | 0.0000 | 1.0000 |
| Physical exposure level | 0.0000 | 1.0000 |
| Psychosocial exposure level | 0.0036 | 0.9970 |
| Psychosocial dimension * Physical exposure level | 0.9339 | 0.9782 |
| Psychosocial dimension * Psychosocial exposure level | 0.3625 | 0.9987 |
| Physical exposure level * Psychosocial exposure level | 0.9878 | 0.4374 |
| Psychosocial dimension * Physical exposure level * Psychosocial exposure level | 0.9761 | 0.4811 |

## Results

The MANCOVA showed that psychosocial dimension, psychosocial exposure level, physical exposure level and one interaction effect between psychosocial dimension and psychosocial exposure level had significant effects on at least one measured outcome. In a small number of trials heart rate data (six trials) or EMG data (one trial) were not recorded successfully due to excessive noise in the data, equipment malfunction, or experimenter error. These instances appeared to be randomly distributed across conditions, and account for the differing numbers of observations (n) in each table provided in Appendix J and Appendix K. Furthermore, not all participants answered every question in the psychosocial questionnaire, since they were instructed to leave blank any items that did not pertain to their trial.

Trial order was significant for 20 of the 37 dependent variables. No discernable pattern was detected, so order effects are expected to be minimal. However, an exception occurred in workload ratings using the SWAT scale where the order in which the first trial had low physical exposure and no psychosocial manipulation had significantly lower time load, mental load, and total workload ratings. The magnitude of the difference was between three and five points out of 20 total points for time load and mental load ratings and approximately eight points out of 60 total points for total workload ratings.

### *Physiological Outcomes*

### Muscle Activity

All means and standard deviations for physiological outcomes can be found in Appendix J. Muscle activity was found to be significantly different between psychosocial dimensions. Mean muscle activity levels for social support participants were significantly lower for all muscles during the overhead tapping task (Figure 4) and significantly higher during assemblies than participants in the other psychosocial dimensions (Figure 5). Job control dimension participants exhibited higher mean muscle activity during the tapping portion of each cycle in the trapezius and anterior deltoid than the other dimensions (trapezius approached significance when comparing job control to time pressure at $p = .059$). Additionally, the maximum muscle activity for the trapezius and anterior deltoid was significantly higher during assemblies for the social support dimension when compared to the job demands and time pressure dimensions.

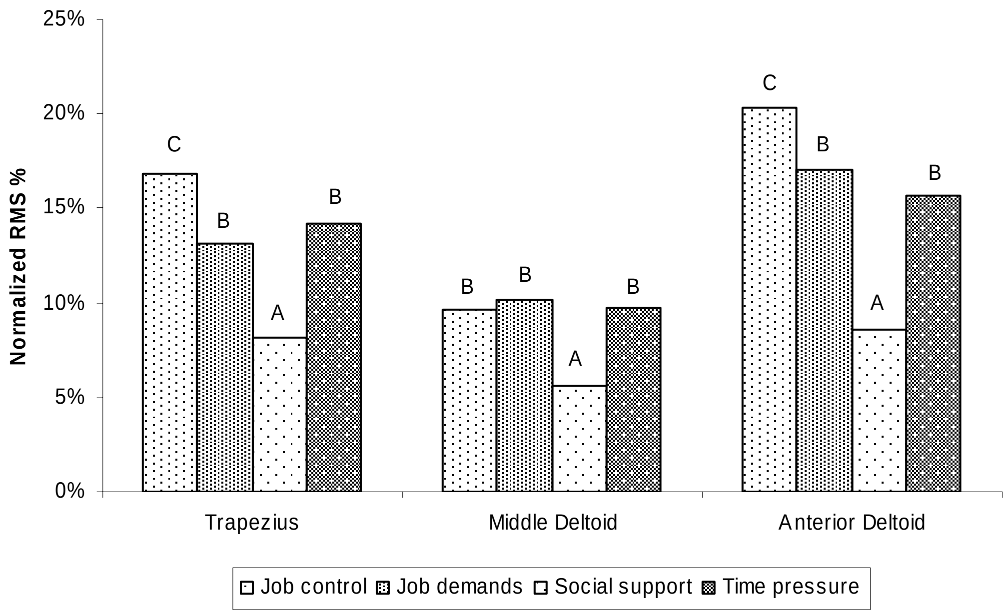


Figure 4. Mean muscle activity during overhead tapping. (Letters indicate equivalent groups per muscle.)

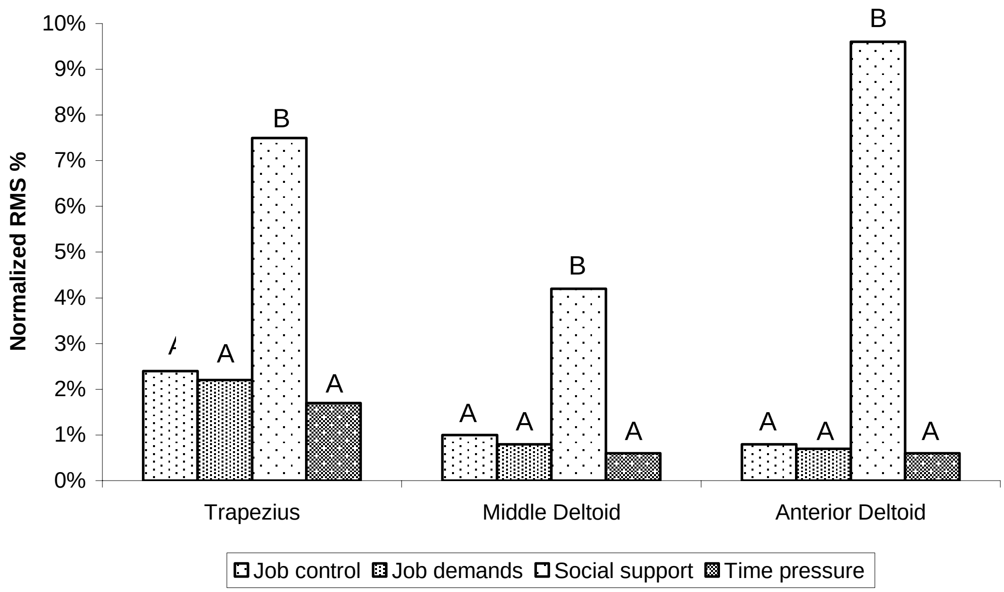


Figure 5. Mean muscle activity during small parts assembly. (Letters indicate equivalent groups per muscle.)

Under high physical exposure, middle deltoid EMG-mean$_T$ and anterior deltoid EMG-mean$_T$ was higher than in low physical exposure. Muscle activity levels were found to be similar regardless of physical exposure level during small parts assembly (*p*-values ranged from .362 to .683). Muscle activity was not significantly different between psychosocial exposure levels (*p*-values range from .108 to .894).

## Heart Rate

Time pressure participants had a higher normalized mean heart rate (with standard deviations in parentheses) of 96.2 (17.4) bpm than those in the job control dimension at 90.2 (8.70) bpm. The job demands dimension had significantly lower normalized heart rate variability (7.43 (1.61) bpm) than the other three dimensions (> 9.0 bpm). Mean heart rate, normalized mean heart rate, and normalized heart rate variation approached significance for high levels of physical exposure (all were higher than low levels of exposure; $p$ = .078, .085, and .087 respectively). No differences were found between psychosocial exposure levels (*p*-values range from .340 to .889).

## Performance

Job demands participants had significantly higher performance (94.9% (3.07%) tapping accuracy) than any other dimension (< 90%), and time pressure participants had significantly higher performance at 89.9% (9.74%) than those in the social support dimension at 85.5% (8.63%). Performance was significantly lower under higher physical exposure (87.1% (10.5%) versus 91.1% (8.55%) under low physical exposure), but no difference was observed for psychosocial exposure levels ($p$ = .970)

### *Subjective Outcomes*

### Perceived Workload

All means and standard deviations for subjective outcomes can be found in Appendix K. There were few differences in workload ratings between psychosocial dimensions. From the NASA-TLX ratings, only the social support dimension had significantly higher ratings of mental demand (6.18 (3.13)) than the job control dimension (3.71 (3.11)). SWAT ratings showed no differences between psychosocial dimensions ($p \geq .138$).

Mental demand, temporal demand, frustration, and total NASA-TLX ratings were all higher at less favorable psychosocial exposure levels. Other components of the NASA-TLX scale (physical demand, performance, and effort) did not show any differences across psychosocial exposure levels (Figure 6). Mental load (9.12 (4.88) versus 6.95 (4.56)), stress load (7.82 (5.07) versus 6.44 (4.68)) and total SWAT workload ratings (29.4 (10.5) versus 25.0 (10.8)) were higher under less favorable psychosocial exposure. The third component of the SWAT scale, time load, was not significantly different across psychosocial dimensions ($p$ = .227). High physical exposure level resulted in higher perceived physical demand, temporal demand and effort (Figure 7), and overall NASA-TLX scores (7.15 (1.71) versus 6.16 (1.81) for unweighted workload and 7.24 (1.84) versus 6.27 (2.00) for weighted workload) as well as stress load (8.13 (5.13) versus 6.12 (4.44)) and total workload (29.5 (10.6) versus 24.7 (11.0)) from the SWAT scale.

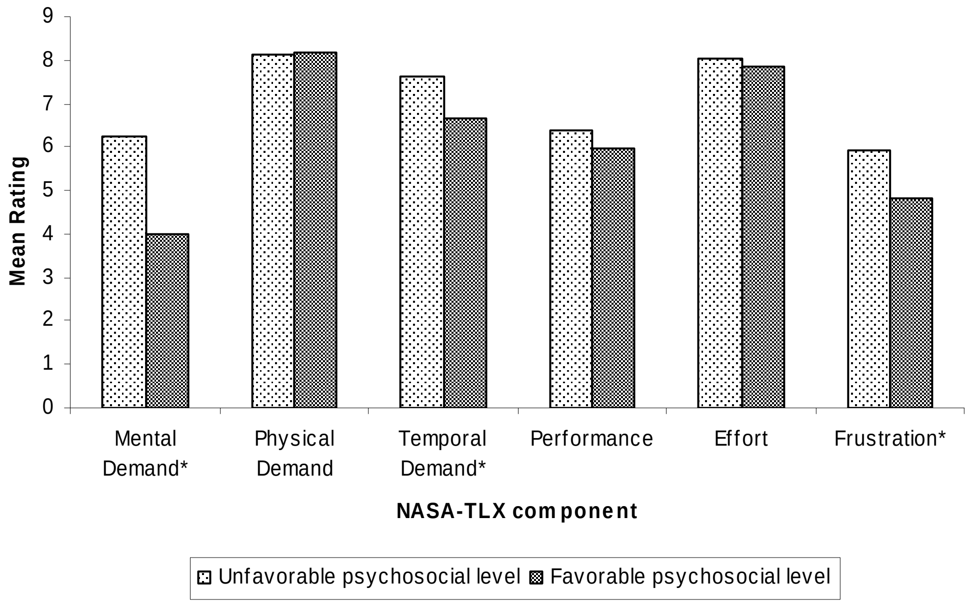


Figure 6. NASA-TLX workload ratings for psychosocial exposure levels. (* significant difference between levels)

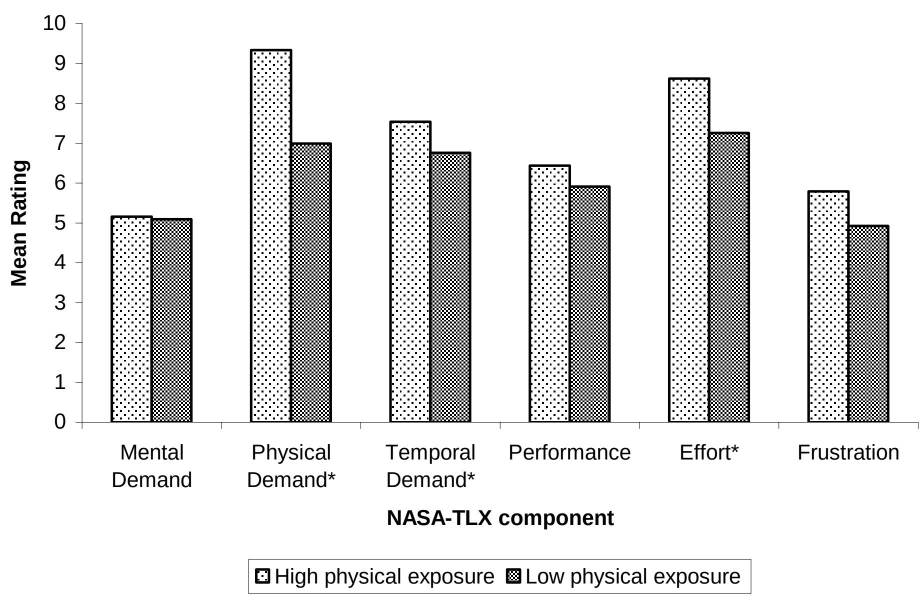


Figure 7. NASA-TLX workload ratings for physical exposure levels. (* significant difference between levels)

## Ratings of Discomfort

No single psychosocial dimension had consistent differences in BDM ratings. Participants in the social support dimension had significantly higher ratings of neck discomfort than the job demands and time pressure dimensions. Job demands dimension participants had significantly lower shoulder discomfort ratings than the other three dimensions, and time pressure dimension participants had significantly higher ratings of low back discomfort than the job control dimension (Figure 8).

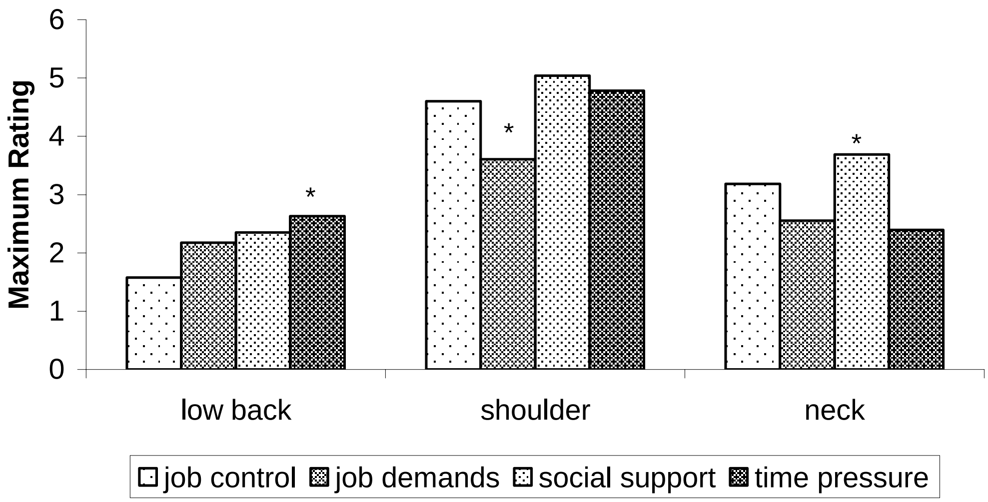


Figure 8. Body discomfort map (BDM) ratings for psychosocial dimensions. (* significant differences)

Time pressure and job demands dimensions yielded significantly larger differences between participants' highest and lowest Borg ratings over the course of each trial than the social support and job control dimensions (3.95 (1.64) and 3.92 (1.68) versus 4.80 (1.79) and 4.87 (1.87)). Job demands participants also had significantly lower average ratings during the 33% duty cycles than job control and social support participants (1.23 (0.99) versus 2.00 (1.49) and 2.00 (1.28)). The social support dimension tended to have higher overall average Borg ratings than the job demands dimension ($p$ = .054). BDM and Borg shoulder ratings were significantly higher for high levels of physical exposure. No differences were found for any discomfort ratings between the psychosocial exposure levels.

### *Psychosocial Questionnaire*

Higher levels of decision authority were perceived by participants in the job control (26.6 (9.00)) and social support (25.5 (7.36)) dimensions when compared to the time pressure dimension (20.7 (7.22)). Those in the job control dimension perceived higher psychological work demands (2.38

(1.80)) than the social support dimension (3.50 (1.79)) and higher physical loads (2.92 (1.07)) than the job demands dimension (3.73 (1.41)). Note that lower scores indicate less favorable conditions.

Levels of co-worker and supervisor support were analyzed for differences between psychosocial exposure and physical exposure for the social support dimension only using ANOVA. While the high psychosocial exposure level resulted in higher ratings of coworker and supervisor support, these differences were not statistically significant ($p$ = .536 for coworker support and .373 for supervisor support). Physical exposure did not appear to influence ratings of support ($p$ = .943 for coworker support and .308 for supervisor support).

High levels of physical exposure resulted in significantly higher levels of physical exertion (5.86 (1.49) versus 6.66 (1.49) where lower numbers indicate unfavorable levels), but no other variables in the psychosocial environment were perceived differently when physical exposure changed ($p \geq .189$). No differences were observed between psychosocial exposure levels ($p$ = .054 for decision authority, all other $p \geq .209$).

### *Interactions*

The interaction between psychosocial exposure level and psychosocial dimension showed significant differences for mental load (SWAT), SWAT total workload (Figure 9), and NASA-TLX mental demand (Figure 10). The interaction effect also approached significance for weighted NASA-TLX workload ($p$ = .069). Under low psychosocial exposure level, the time pressure dimension had the lowest levels of all four of these workload dimensions, but time pressure had the highest levels of the workload dimensions under high psychosocial exposure levels. No other significant interaction effects were found ($p \geq .250$).

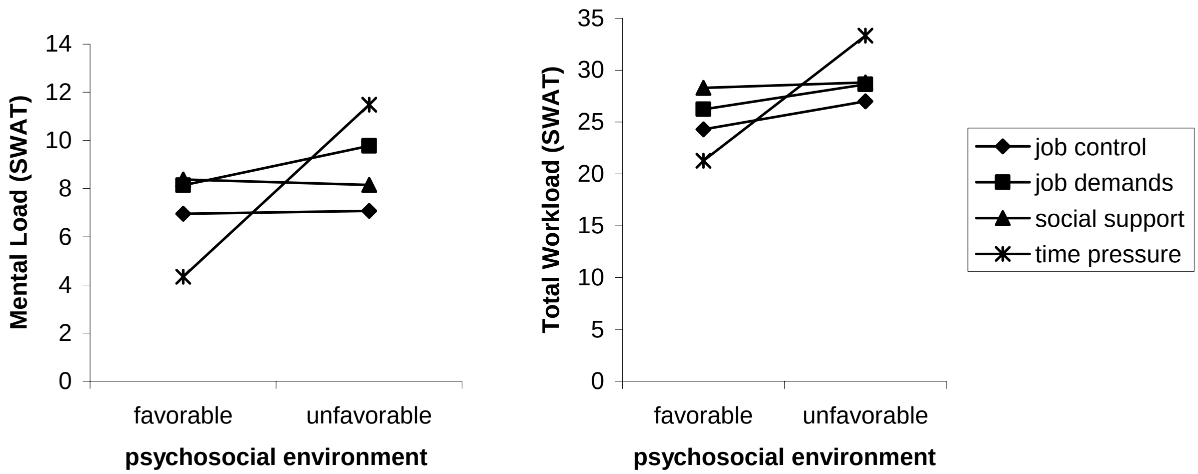


Figure 9. Interaction effect between psychosocial dimension and psychosocial exposure on mental load and total workload ratings (SWAT).

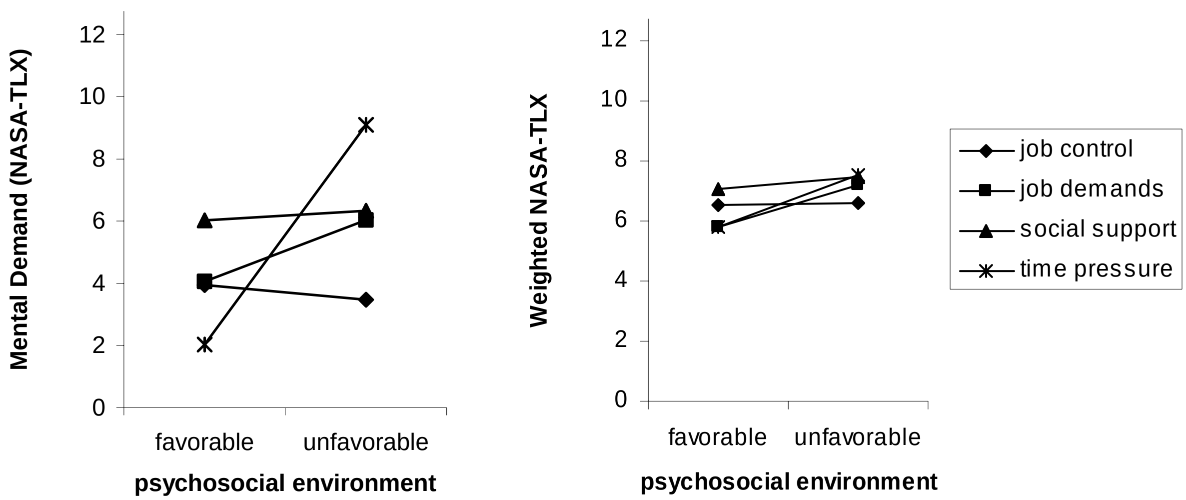


Figure 10. Interaction effect between psychosocial dimension and psychosocial exposure on mental demand and weighted workload (NASA-TLX).

## Discussion

This experiment manipulated four psychosocial conditions for identical tasks that simulated overhead manufacturing. By using the same tasks for all psychosocial manipulations, comparisons could be made between the dimensions on physiological and subjective outcomes.

### *Efficacy of Manipulations*

The social support and job control manipulations were designed to have higher participant control over experiment parameters, and the psychosocial questionnaire verified this manipulation by showing higher levels of decision authority for these two groups. The ability to change duty cycle was also expected to reduce physical loads, but this was only partially supported by the decrease in muscle activity in the social support dimension. The finding of lower muscle activity with higher levels of support agrees with epidemiological evidence, which suggests that social support from either coworkers or supervisors decreases the risk of neck and shoulder disorders (Ariëns et al., 2001; Bongers et al., 1993).

The job control dimension actually had higher muscle activity and reported higher physical loads than the job demands dimension on the psychosocial questionnaire. This result was surprising because the job control dimension was hypothesized to be a favorable psychosocial manipulation associated with decreased risk for neck and shoulder disorders, whereas increases in job demands are associated with higher risk for neck/shoulder disorders (Ariëns et al., 2001; Bongers et al., 1993). However, differences in perceptions of whether the favorable job control was indeed positive or negative may have influenced muscle activity. Several participants in the job control dimension mentioned that they preferred the unfavorable job control condition where they were told when to switch between 33% and 66% duty cycle because they "didn't have to think as much." These participants may have had increased muscle activity as a result of the added pressure of thinking about when to change cycles. Others expressed appreciation at being able to change to the 33% duty cycle whenever they got tired from the 66% duty cycle under the favorable level of job control, and these participants may have had results that agreed with the original hypothesis.

Unfavorable time pressure conditions were expected to result in higher temporal demand, mental demand (due to the math questions task), and psychological work demands. Those participants in the time pressure manipulation had marginally higher ratings of mental demands (NASA-TLX) than participants in the job control manipulation and showed no differences for the other subjective ratings. However, the difference between favorable and unfavorable psychosocial exposure level (absence vs. presence of math questions) resulted in much larger differences in mental load ratings and overall SWAT workload than for other psychosocial dimensions.

Finally, the job demands manipulation was expected to result in higher psychological work demands, but no matching trend was found. Instead, heart rate variability was lower and task performance was higher, both of which may indicate higher levels of mental workload. Ratings of shoulder discomfort was highest for participants in the job demands condition, which agrees with other research that has found that unfavorable levels of job demands are associated with higher risk of neck and shoulder disorders (Ariëns et al., 2001; Bongers et al., 1993). The combination of low heart rate variability, high levels of performance, and high ratings of shoulder discomfort may provide insight into the pathway between high job demands and WMSD development. Unfavorable levels of demands that require higher performance and higher levels of mental workload may lead to higher levels of musculoskeletal discomfort, which can be a precursor to injury/illness.

Physical exposure levels largely provided expected results by showing higher muscle activity and higher mean heart rate (nearly significant) along with higher Borg ratings and shoulder discomfort ratings on the BDM. Physical demands were rated higher on the NASA-TLX, and physical exertion was higher on the psychosocial questionnaire for high levels of physical exposure. High levels of physical demands have been associated with increased WMSD risk (Buckle, 1997; Punnett et al., 2004; Werner, Franzblau, Gell, Ulin, & Armstrong, 2005b), so these responses may be included as potential contributors in the pathway of WMSD development.

Psychosocial exposure level manipulations resulted in differences in outcomes only in workload ratings. No other measures, including the psychosocial questionnaire, showed any differences. This suggests that participants may have been aware of the manipulation but not to the extent that it affected physiological measures or opinions of the work environment during the final psychosocial questionnaire.

### *Sensitivity of Outcome Measures*

*Workload ratings:* The two workload rating scales both showed changes when psychosocial and physical exposure levels changed and appeared to be sensitive to the type of exposure. While the NASA-TLX component of temporal demand increased for both high physical exposure and unfavorable psychosocial conditions, physical demand and effort increased only with higher physical exposure whereas mental demand and frustration increased only with unfavorable psychosocial exposure. Mental load, stress load, and total workload from SWAT ratings increased under unfavorable psychosocial conditions, and stress load and total workload of the SWAT scale increased under high physical exposure. Stress load increased with both types of exposure, indicating that in this type of work setting, psychological stress results from both physical and psychosocial demands.

No differences were observed in workload ratings between the psychosocial manipulations, perhaps because participants did not have the same range of experiences across psychosocial dimensions. All participants experienced two trials with no psychosocial manipulation (with low and high physical demands). The two trials introducing the psychosocial manipulations were more favorable for those in the job control and social support dimensions and less favorable for those in the time pressure and job demands dimensions. Therefore the relative interpretations of high and low workload may have been the same regardless of dimension since each participant was only exposed to one psychosocial dimension. Previous research has suggested that participants be given examples of a full range of workload to control for context effects and increase validity of subjective ratings (Colle, 1998). In the future, providing examples of the full range of potential workload levels may help distinguish workload between different psychosocial manipulations.

*Discomfort ratings:* Higher discomfort ratings were expected under higher physical exposure, and this hypothesis was supported for all of the Borg rating measures. However, only dominant shoulder discomfort ratings on the BDM showed this trend. No differences were found for psychosocial exposure level for the BDM and Borg ratings.

Both methods of discomfort rating showed sensitivity to psychosocial dimension even though total physical exposure remained constant across trials regardless of psychosocial manipulation. Trials in which participants were allowed to switch between long and short duty cycle times as desired (job control and social support) had the potential to reduce discomfort by allowing for breaks from the long duty cycle time as needed. The difference in Borg ratings was lower for these two dimensions, which suggests that participants did take advantage of the ability to switch duty cycle when discomfort reached a certain point even though the social support dimension had higher overall mean Borg ratings and higher neck discomfort. Participants in the job demands dimension had lower discomfort ratings which did not match previous epidemiological evidence linking high job demands with higher neck and shoulder discomfort (Andersen et al., 2002). The participants in this unfavorable psychosocial condition may have become accustomed to their work conditions and not rated discomfort as highly, which has been observed also in actual automotive manufacturing environments (Zetterberg et al., 1997).

The possibility that participants in the social support condition may be influenced in their discomfort ratings by their partner was investigated by comparing BDM scores, which were completed away from their partner, with Borg ratings, which were stated aloud. The dominant shoulder rating was approximately equal to the maximum Borg rating (5.042 vs. 5.084), so peer pressure does not appear to have been an influence.

*Muscle Activity:* Muscle activity and discomfort ratings were expected to show similar trends, and this was the case for physical exposure level. However, job control participants showed higher muscle activity while having lower ratings of low back discomfort and a smaller difference in Borg ratings than other dimensions. Inconsistencies such as these have been found in a field study of 564 car assembly workers in which subjective complaints about the neck, shoulders and feet related to job satisfaction but not to physical signs of WMSD development (Zetterberg et al., 1997).

*Heart rate:* Mean normalized heart rate was expected to indicate physical workload. Physical exposure level did reflect this trend but only approached significance according to the set criterion ($\alpha = .05$). Time pressure participants exhibited higher heart rate averages, but the only indication that they experienced higher physical workload was a significantly higher rating of low back discomfort on the BDM. This result matches those found in a study of manufacturing workers in which workers in a flexible configuration (similar to the job control and social support manipulations in the current study) had consistent heart rates throughout the workday whereas those workers on a line assembly had a significant increase in heart rate over the day (Melin, Lundberg, Söderlund, & Granqvist, 1999). Although participants were asked to avoid certain activities prior to the experiment that are known to affect heart rate, there are still many variables affecting heart rate that were difficult to account for, such as sinus arrhythmia from breathing patterns and physical fitness level (Kamath & Fallen, 1993).

This study showed a weak relationship between heart rate variability and mental workload levels. Participants in the job demands manipulation had significantly lower normalized heart rate variability than the other three dimensions. Lower heart rate variability has been linked to higher levels of mental demand in some previous studies while other studies have found no relationship (Meshkati, 1988; Tsang & Wilson, 1997). In this study, the job demands dimension did have the highest average mental load and time load ratings from the SWAT scale (although not statistically significant), but NASA-TLX measures of mental demand and overall workload did not follow the same pattern. The psychosocial questionnaire also showed no pattern of higher perceived psychological work demands for job demands dimension participants. One possible explanation for the lower heart rate variability is that the authoritarian-style management of constant pressure to achieve high performance actually placed participants under higher demands, but participants did not acknowledge the demands in their workload and psychosocial environment ratings.

*Psychosocial Questionnaire:* Skill discretion was not significantly different between any conditions, but this is most likely due to performing the same task in every trial. Differences were found for the other categories common to all conditions: psychological work demands, decision authority, physical loads, and physical exertion. Co-worker and supervisor support was higher when the social support dimension was allowed to chat and determine work distribution, but the difference between that level and the baseline condition was not significant. As demonstrated by the lower muscle activity levels in the social support dimension participants, the presence of having a companion at work may make more difference in the work environment than the level of interaction between participants. Alternatively, the experimental design may not have offered enough opportunity for participants to truly work together given that the task was set and each participant had to meet the same work requirements.

### *Implications for WMSD risk and work design*

Muscle activity was lowest during the duty portion of the cycle and highest during the rest portion of the cycle for social support dimension participants. However, there was no difference in muscle activity between psychosocial and physical exposure levels within this dimension. It seems that merely the presence of another person influences muscle activity regardless of the level of interaction between the two people. Interestingly, participants in the social support dimension reported higher levels of discomfort in the neck (BDM) and in the overall mean Borg rating. This suggests that subjective and physiological measurements are needed to obtain a complete picture of employee reactions to the work environment and task demands.

The pathways between social support and WMSD development are not clear, but previous research has found associations between social support and factors such as fatigue, absenteeism, musculoskeletal pain. Woods' (2005) review of the effects of social support on WMSD risk concluded that poor social support, whether from coworkers or supervisors, is linked with higher prevalence of WMSDs. In epidemiological studies of general working populations, low social support has been linked with increased fatigue (Bültmann et al., 2002) and elbow/hand/wrist disorders (van den Heuvel, van der Beek, Blatter, Hoogendoorn, & Bongers, 2005). Associations between low levels of support and increased musculoskeletal pain and disabilities have been found in several specific occupations as well. In one study, low management support predicted low back pain and total musculoskeletal pain in auto repair garage workers (Torp, Riise, & Moen, 2001). Low social support has been associated with more severe hand and arm numbness among VDU workers (Faucett & Rempel, 1994) and with disability in nurses (Camerino et al., 2001). There is also limited evidence that poor social support contributes to higher musculoskeletal sickness absence, restricted activity, and lower return-to-work rates after musculoskeletal problems (Woods, 2005). A study of 1,919 Danish employees across 52 workplaces concluded that 12% of work absences were due to low social support (Nielsen, Rugulies, Smith-Hansen, Christensen, & Kristensen, 2006).

Inquiry into teamwork's association with WMSD risk indicators may provide further explanations of how social support relates to WMSDs. The quality of teamwork has been shown to affect absenteeism and musculoskeletal discomfort. In one study of manufacturing teams, higher absenteeism was related to larger team sizes, lower collectivism, and lower procedural justice climate and strength (Colquitt, Noe, & Jackson, 2002). While no hypotheses were presented for the reasons of absences, a certain percentage of these absences may be related to musculoskeletal problems considering the results of Nielson et al.'s study (2006) mentioned previously. In another study of an organization undergoing several stages of work organization interventions, low open group process levels and low group cohesiveness were associated with higher musculoskeletal discomfort (Carayon, Haims, Hoonakker, & Swanson, 2006). Therefore, improving the quality of teamwork may reduce absenteeism and musculoskeletal discomfort.

Favorable levels of social support may have a protective effect by helping workers cope and by preventing WMSDs (Woods, 2005). Allowing interactions among employees may be helpful in reducing loads on the muscles in situations where physical demand levels cannot be reduced reasonably, which could potentially lower WMSD risk.

Although physiological responses may be more closely associated with the development of pain and WMSD symptoms, perceived tension and high job strain may also increase risk for developing pain. A previous study investigating the development of neck pain through a questionnaire showed that high job strain and perceived muscular tension significantly increased the risk of neck pain development (Wahlström et al., 2004). Unfavorable levels of mental demand have been shown to result in constant muscle activity of the trapezius, which can increase risk of WMSD development (Lundberg et al., 1994). These previous studies support the current results, given that both high physical and psychosocial exposure levels were associated with either higher workload ratings, higher muscle activity, or higher discomfort ratings. Therefore, work designers should try to minimize poor psychosocial conditions along with high physical exposure.

### *Limitations and Future Directions*

The manipulation of psychosocial dimension as a between-subjects factor rather than a within-subjects factor weakened the ability to compare differences between the dimensions of psychosocial factors on physiological responses. Ideally, each participant would experience each psychosocial dimension separately to gain insight into the relative effects of each factor type. Furthermore, psychosocial factors are rarely experienced in isolation in the work environment. Future studies may attempt to combine psychosocial factor dimensions which will allow for studies on potential interactions. Since no differences other than workload ratings were found for the different psychosocial exposure levels in this study, future studies may omit this factor and simply have ‘presence’ or ‘absence’ of the desired factors.

The presence of a trial order effect could indicate that participants adapted to the conditions over the course of the experiment. The only clear pattern of the order effect occurred for SWAT ratings for participants that experienced low physical exposure and no psychosocial manipulation in the first trial. These participants had lower time load and mental load ratings over the course of the experiment, perhaps because they adapted to the conditions before experiencing more demanding combinations such as high physical exposure or unfavorable psychosocial conditions. Because of the ability to become accustomed to job stressors over time, others have suggested that the presence of stressors be measured in terms of frequency, duration, and intensity rather than perceptions of stress (Landsbergis, Theorell, Schwartz, Greiner, & Krause, 2000), which was used in this study.

The effects of gender and personality type should also be investigated more thoroughly for their potential influence on physiological and subjective responses to the work environment. In the current study gender and Type A tendencies were evaluated as covariates and were found to be significant. Gender, age, and occupational status can bias responses to psychosocial questionnaires (Ørhede & Kreiner, 2000), and males and females may interpret the psychosocial environment differently (Feveile, Jensen, & Burr, 2002; Hooftman, van der Beek, Bongers, & van Mechelen, 2005; Josephson et al., 1999). Females with Type A tendencies have shown higher levels of perceived workload than females with Type B tendencies, mainly due to increased frustration levels (Sato et al., 1999). Certain personality traits such as Type A tendencies and certain Myers-Briggs types have been associated with higher muscle activity (Glasscock et al., 1999; Marras et al., 2000) and perceived stress (Day & Jreige, 2002).

The potential interactions between pairs of participants in the social support manipulation may need to be considered in depth for future research. Pairs may have had different levels of competitiveness or cooperation depending on gender, personality type (Type A tendencies), and the type of relationship for each pair. This could affect all of the outcome measures due to this difference in the construction of the work environment.

## Conclusions

This study supports findings on the relationships between psychosocial factors and WMSD risk. By using an experimental design, different psychosocial factors were shown to increase WMSD risk factors such as muscle activity, perceived discomfort, and perceived workload. The following recommendations can be made to potentially improve workplaces by reducing exposure to WMSD risk factors:

- Both physical and psychosocial exposures should be measured in work environments to detect potentially harmful levels of exposure.
- Opportunities for social interaction should be part of workplace design to potentially reduce muscle activity rather than having individuals work in isolation.
- Excessive pressure from management to achieve high performance should be minimized to reduce WMSD risk.

## Chapter 3: Comparison of measurement methods for assessing WMSD risk under different psychosocial and physical conditions


### Abstract

*Objective:* The purpose of this study was to determine an efficient set of measurements from several widely-used methods to assess physical and psychosocial exposures simultaneously in a simulated work environment.

*Methods:* Forty-eight participants (31 males and 17 females) completed an experiment involving simulated overhead work under different combinations of physical and psychosocial exposure (job demands, job control, social support, and time pressure). Measured responses were muscle activity, heart rate, and perceptions of workload, discomfort, and the psychosocial environment. These responses were analyzed using a multitrait-multimethod (MTMM) matrix to assess convergent and discriminant validity. Measures with high convergent validity were considered redundant, and only those measures most sensitive to the experimental manipulations were retained. Measures with high discriminant validity were assumed to be measuring different aspects of the work environment, and these were included in the final set of methods.

*Results:* The two measures of workload (NASA-TLX and SWAT) were highly convergent as were the two measures of discomfort (Borg-CR10 and Body Discomfort Map ratings) and the electromyography (EMG) from three shoulder muscles. Heart rate measures were significantly related to discomfort and perceptions of the psychosocial environment, though the correlations were moderate. The psychosocial questionnaire showed discriminant validity and appeared to be sensitive to different types of workload.

*Conclusion:* After removing measures that provided redundant information, the final set of measurements were: EMG from the trapezius, NASA-TLX as a measure of workload, discomfort ratings using the Borg-CR10 scale, heart rate mean and variability, and the psychosocial questionnaire that includes categories relevant to the work environment. All of these measurements are non-intrusive and relatively easy to obtain. Hence, use of these is recommended for efficient assessment of physical and psychosocial exposures for comparable tasks (i.e. involving repetitive intermittent efforts at low-moderate levels of physical and mental demands).

*Keywords:* Psychosocial factors, convergent validity, discriminant validity, EMG, heart rate, workload, perceived discomfort

## Introduction

Academic and government groups have emphasized the need to incorporate personal, psychological, and social factors into research on work-related musculoskeletal disorders (WMSDs: Department of Health and Human Services, 2001), but measurement criteria for evaluating these factors in conjunction with more traditional physical risk factors have not been thoroughly developed. Differences between longitudinal, cross-sectional, and experimental designs, along with differences in defining and measuring factors of interest, have contributed to a wide variety of results and conclusions on the importance of various WMSD risk factors. Many researchers opt for questionnaires and subjective rating scales to evaluate physical and psychosocial factors, but there are several drawbacks to using these techniques, such as lack of external validity and the potential differences between subjective and objective assessments of exposure (Punnett & Wegman, 2004). Others promote the use of objective measures such as heart rate, heart rate variability, motion capture, goniometry, muscle activity, stress hormone levels, etc. to quantify exposure (Lundberg & Johansson, 2000). However, there are numerous questions regarding practicality in occupational settings, responsiveness to exposure, and degree of intra- and inter-person variability (Hurrell, Nelson, & Simmons, 1998).

A blend of individual, physical, and psychosocial factors should be measured to obtain a comprehensive assessment of all potential risk factors. There are a number of specific factors within each of these three broad categories of risk factors, and researchers typically narrow the list to a manageable size according to the purpose of the study or the tasks being evaluated (Hurrell et al., 1998). Physical, psychosocial, and individual factors should be measured simultaneously to compare accurately exposure levels and eventually to determine the relative contribution of each factor to WMSD development. The benefits and limitations of subjective self-report questionnaires and objective physiological measures must be considered in developing measurement methods appropriate for collecting data from different exposures.

## Questionnaires and Self-reports

Self-report measures derived from questionnaire responses can be used for subjective estimates of physical and psychosocial exposure as well as WMSD symptoms. Researchers are inclined to measure psychosocial factors through questionnaires for ease of administration and lower cost and time requirements. Information about past exposure can be acquired easily, although recall could be inaccurate. Self-reports are also a convenient method of getting general demographic information and other personal characteristics, such as work schedules. Self-reports often have high correlations with observer ratings of workplace conditions despite the possibility of bias from individual interpretations of the work environment (Benavides, Benach, & Muntaner, 2002). Therefore, self-reports may be a valid proxy to direct measurements of physical and psychosocial factors.

Aside from the influence of personal perceptions, developing questionnaires that provide meaningful data is another challenge when using self-reports (Punnett & Wegman, 2004). Often measures are too general to establish differences between jobs (Hurrell et al., 1998); although items that are too specific to certain jobs limit the external validity of questionnaires. For instance, a study of females in nursing and retailing attributed the lack of significant findings of psychosocial factors to questionnaires that were designed for manufacturing and which did not have measures that were specific to these service occupations (Vasseljen, Holte, & Westgaard, 2001). Hurrell et al. (1998) also noted that many questionnaires need to be updated to reflect changes in technology, increased diversification of the workforce, workplace violence, and the increase in service occupations.

### Physiological Measurements

Physiological measurements may provide a crucial link between physical and psychosocial exposure and WMSD development by explaining how perceived strain translates to increases in WMSD risk. Heart rate activity, blood pressure, muscle activity, stress hormone levels, and other measures provide an objective measure of individual strain (Lundberg & Johansson, 2000). Blood pressure, cortisol and catecholamine levels, muscle activity, and heart rate may be higher during work periods than during rest periods (Evans & Steptoe, 2001; Rissén, Melin, Sandsjö, Dohns, & Lundberg, 2000), which indicate WMSD risk. Hormone levels have been associated with low-back pain and long-term disability (Theorell, Hasselhorn, & MUSIC-Norrtälje Study Group, 2002), and muscle activity has been associated with pain (Hägg & Åström, 1997; Hansson et al., 2000; Veiersted et al., 1990). Although a direct relationship between heart rate measures and WMSD outcomes is not clear, heart rate measures and blood pressure may be related to WMSD risk indirectly as an indication of energy expenditure (Spurr et al., 1988), psychosocial stress (Nater et al., 2005), and mental demands (Meshkati, 1988). The main disadvantage of using physiological measures is that data collection is considerably more complex and invasive to workers during the workday than questionnaires or observations. Also, researchers are still in the preliminary stages of understanding the relationships between specific exposure factors and physiological outcomes and in validating these physiological reactions. The responsiveness of each variable to different exposures is largely unknown, and individual differences constitute a large amount of variance in these measures (Hurrell et al., 1998). Still, the objectivity of these measures along with the potential to provide more explanation of the pathways of WMSD development makes them appealing to the scientific community for further investigation.

A comprehensive method of assessing physical and psychosocial risk factor exposure in the work environment would provide a starting point for determining the relative contributions of different risk factors in WMSD development. Information is available regarding the effects of many proposed WMSD risk factors individually, but previous research has failed to combine these factors simultaneously to determine which risk factors are most significant in predicting WMSD development. Given the advantages and disadvantages of questionnaires and physiological measurement, both types of data collection should be combined to provide information that can be used to verify and validate proposed effects of physical and psychosocial risk factor exposure through triangulation.

This study evaluated convergent and discriminant validity using a multitrait-multimethod matrix (MTMM: Campbell & Fiske, 1959) among several methods used to measure physical and psychosocial factors in work environments. The MTMM matrix correlated various methods of measurement of the same constructs, which for the current study included questionnaires and physiological measurements. These measurements are intended to be used simultaneously to evaluate both physical and psychosocial factors. Physiological and subjective measures were hypothesized to be highly correlated because they both capture the effects of adverse conditions in the workplace. Highly redundant measures were removed from the final set of measurement methods to create an efficient set of tools that can measure exposure to potential WMSD risk factors.

## Methods

The current study was a secondary analysis of data from an experiment presented in Chapter 2. The methods are presented in summary form below.

### *Experiment Design*

A 2x2x4 mixed factors experiment was conducted in which participants completed simulated automotive assembly tasks under two levels of physical exposure and two levels of psychosocial exposure. The four psychosocial dimensions were defined as social support, time pressure, job demands, and job control; and each participant experienced one of the four psychosocial dimensions. Forty-eight participants each completed four experimental sessions under one psychosocial dimension and four combinations of physical and psychosocial exposure level.

### *Participants*

Forty-eight participants, that had no history of WMSDs or other potentially confounding conditions that may have caused extra pain or fatigue during the task, were recruited from a university community. Mean age of participants was 23.1 (4.7) years, and 31 males and 17 females completed the experiment. Participants were required to have either manual work experience (in the past five years for at least one month duration) or perform upper-body strengthening exercise regularly (minimum of 2-3 hours per week for two months) to ensure adequate strength capabilities to minimize muscle discomfort.

### *Simulated Work*

Two tasks that simulated automotive assembly, overhead tapping (simulating nut and bolt tightening on the underbody of a chassis) and small parts assembly (screwing and unscrewing nuts from bolts), were used in the study. Overhead tapping was simulated by attaching a computer keyboard to an adjustable-height overhead tapping surface and having participants tap specifically numbered keys on the keyboard using non-powered drills of different weights (Figure 2). The tapping height was adjusted to be the 40% difference between the participant's overhead reach and the height of having the upper arm parallel to the ground with the elbow bent at 90°. Tapping speed was dictated by a metronome set to 80 beats per minute. The duration of the tasks was either 33% or 66% of a 54-second cycle, and an auditory signal was used to indicate when to switch between tasks. Participants changed between the 33% and 66% duty cycles every 15 minutes (with the exception of favorable job control and social support conditions), and each trial lasted one hour. All task parameters aside from the times to switch duty cycles were based on analysis of actual work tasks (Nussbaum et al., 2002).

Figure 11. Representation of overhead tapping task.

### *Independent Variables*

Physical exposure level was manipulated through the use of a heavy tool (non-powered drill weighing 1.25 kg) in the high exposure condition and a light tool (non-powered drill weighing 0.50 kg) in the low exposure condition. Psychosocial exposure level had a favorable and unfavorable level depending on whether the presence or absence of the chosen psychosocial dimension was considered a negative or positive influence on the work environment.

Participants were subjected to one of the four psychosocial dimensions: social support, time pressure, job demands, or job control. Psychosocial exposures were carefully chosen to minimize overlap with physical exposures. Social support was manipulated by level of interaction allowed (talking or silence) between pairs of participants and by level of cooperation allowed (determining when to switch between 33% and 66% duty cycles). During the favorable social support condition, participants could chat during the task and could determine when to switch between duty cycles as long as each participant completed half of the total trial at 33% duty and half at 66% duty. High time pressure introduced an additional math task that was completed simultaneously with the manufacturing tasks. The math task involved answering either 2-digit by 2-digit subtraction (excluding 10) or 2-digit (numbers 2 – 50) by 1-digit (excluding 0 and 1) multiplication questions at a rate of two per cycle. Responses were recorded, but no feedback was provided by the experimenter on performance. High job demands imposed additional verbal prompting from the experimenter for the participant to maintain high standards of job performance at a rate of once every four cycles. Finally, high job control was characterized by allowing participants to determine when to change between 33% and 66% duty cycles while maintaining equivalent work requirements by requiring that half of each trial be spent at each duty cycle.

### *Dependent Factors*

Each category of outcomes used two measurement methods (except the psychosocial questionnaire) to allow comparisons of which measurement method has the highest validity and sensitivity to the experimental manipulations.

### Physiological outcomes

Muscle activity and heart rate data were used as indicators of physiological reactions to the experimental conditions.

*Muscle activity:* Muscle activity of the middle deltoid, anterior deltoid, and trapezius on the dominant side was collected using electromyography (EMG). Muscle activity has been related to physical and psychosocial factors in several experimental studies (e.g. Leyman et al., 2004; e.g. Marras et al., 2000). These three muscles are active in overhead work (Nussbaum, 2001). The trapezius is active in hand work similar to the small parts assembly, and it may be affected by psychosocial conditions (McLean & Urquhart, 2002). To prepare for electrode application, the skin was shaved, slightly abraded, and cleansed with alcohol to minimize impedance. The electrodes (10 mm, rectangular Ag/AgCl pre-gelled bipolar disposable) were placed according to clinical procedures (Perotto, 1994). In order to continue the trial, input impedance had to be less than 10 kΩ as measured after a 15-minute stabilization period using a voltmeter; otherwise the electrode application was repeated.

Signals were transmitted through short (less than 30 cm) leads to preamplifiers (100 gain), amplified, band-pass filtered (10-500 Hz), RMS converted (110 ms time constant), and A/D converted by hardware. The gain was set such that RMS signals did not exceed 2-3 volts, and EMG data was collected continuously at a sampling rate of 1000 Hz for each one-hour session. The final 10 seconds of each tapping and assembly portion of the cycle (minus a 3 s buffer) was used for analysis. Mean and maximum values within each window were computed and averaged by task (T: tapping or A: small parts assembly). These values are denoted as EMG-$mean_T$, EMG-$mean_A$, EMG-$max_T$, and EMG-$max_A$.

MVCs (Maximum Voluntary Contraction) from each participant were used to normalize EMG data. MVCs were collected before every trial by having participants perform a separate exercise to elicit a maximum isometric contraction for each muscle similar to previously used methods (Nussbaum et al., 2001). Two chains with handlebar grips were attached to a floor plate. Participants grasped one handlebar with their dominant hand and lifted their arm forward for the anterior deltoid and abducted their shoulder for the middle deltoid. To obtain the MVE for the trapezius, participants grasped both handlebars (one in each hand) and performed a shrugging motion. Participants contracted his/her muscle as much as possible for 5 s in a ramp-up ramp-down contraction procedure for a series of three trials with 45 s of rest between each trial. The highest voltage of each trial was recorded, and if the highest reading occurred in the last trial, further trials were conducted until a non-maximum voltage reading was obtained.

*Heart rate:* Heart rate data were recorded continuously as beat-to-beat (R-R) data (Polar S810: Polar Electro Inc., Lake Success, NY) for the entire trial. Both heart rate and heart rate variability were assessed because heart rate is hypothesized to indicate physical demands while heart rate variability may measure mental demands (Wickens & Hollands, 2000). Heart rate is an indication of energy expenditure (Åstrand & Rodahl, 1986) and has been linked to workers that are under higher levels of strain and biomechanical exposure (Holte & Westgaard, 2002). Heart rate variability was calculated as the standard deviation in heart rate during each trial (Task

Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). All data were downloaded directly to a personal computer using the Polar software. Recorded data were normalized using each participant's resting heart rate and maximum calculated heart rate (220 - age, Eastman Kodak Company, 2004). Resting heart rate was the lowest 15 s average recorded at any point during a 5 min resting period completed during the orientation session.

### Subjective outcomes

*Workload ratings:* Two methods of workload assessment, the NASA Task Load Index (NASA-TLX: Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT: Reid & Nygren, 1988) were given at the end of each trial. Both scales used a visual analog scale (VAS) allowing participants to indicate their level of perceived workload for each trial. Previous studies support a potential link between perceived workload levels and WMSD risk (Hanse, 2002; Skov, Borg, & Ørhede, 1996). Skov *et al.* (1996) found that in a study of 1306 salespeople, those with high job demands were more likely to report WMSD symptoms of the neck and shoulder; while Hanse (2002) found a high odds ratio for WMSD development for workers using computer displays for prolonged time periods and reporting high perceived workload levels.

The NASA-TLX consists of six scales: mental demand, physical demand, temporal demand, effort, performance, and frustration. Prior to the experiment, participants completed a pair-wise comparison by rating which demand for every possible pairing of the six scales would be greatest during the trial. Participants completed the VAS, which measured 12.75 cm in length with two anchors, at the conclusion of each trial. These ratings were multiplied by the total number of weightings. The final workload score was obtained by adding the weighted ratings and dividing by 15. An unweighted measure of workload was also obtained by adding the VAS measures and dividing by six.

The SWAT consists of three scales: time load, mental load, and stress load, which are presented on VAS of 20 cm length with three anchors. The VAS was used instead of the original method of choosing one of the three anchors because the VAS may be more sensitive to lower levels of workload (Luximon & Goonetilleke, 2001). Participants rated workload using this scale at the conclusion of each trial. The three scales were added for a total perceived workload measure, ranging from 0 to 60.

*Discomfort ratings:* Two methods of collecting subjective discomfort ratings, the Borg-CR10 scale (Borg, 1982) and the Body Discomfort Map (BDM: J. L. Visser & Straker, 1994) were used during each trial. Participants provided ratings of discomfort for the shoulder area at the end of every other cycle using the Borg-CR10 rating scale. This scale ranges from 0 "Nothing at all" to 10 "Extremely strong, almost max". Maximum rating, difference between maximum and minimum ratings (difference), overall mean rating, and means for the short (33%) duty cycle and long (66%) duty cycle were used for analyses. Participants also rated perceived discomfort in other body parts using the BDM at the conclusion of each trial. Each area of the body was given a rating using the same Borg-CR10 scale on the maximum level of discomfort reached during the trial. This scale was originally developed for dentistry and has also been used in manufacturing settings (Straker, Stevenson, & Twomey, 1997).

#### Psychosocial questionnaire

Perceptions of the psychosocial environment were obtained at the end of each trial using a 30-item questionnaire taken from several scales of the Job Content Questionnaire (JCQ: Karasek et al., 1998) including skill discretion (six items), decision authority (three items), psychological work demands (eight items), physical job demands sub-divided into exertion (three items) and isometric loads (two items), supervisor support (four items), and coworker support (four items). Scales for job security, customer relations, etc. which did not pertain to the current task were omitted. The JCQ has been tested successfully in several occupations and countries and found to be reliable (Karasek et al., 1998), and scores from job demands and coworker support have been linked to neck pain (Ariëns et al., 2001). Participants completed the questionnaire at the conclusion of each trial, and scores were calculated using the methods suggested by the JCQ User's Guide (Karasek, 1985).

### *Procedure*

Prior to experimental trials, each participant attended a 30-minute orientation session to complete IRB forms and a demographic questionnaire, to record resting heart rate, to familiarize themselves with the experimental task, and to familiarize themselves with the Borg rating scale.

Each participant then completed four experimental trials at each combination of physical and psychosocial level under one psychosocial dimension. Prior to each task session, participants were instrumented with the heart rate monitor and electrodes, and they completed the NASA-TLX pair-wise comparison sheet. After performing the task for one hour, participants completed the BDM, NASA-TLX ratings, SWAT ratings, and the psychosocial questionnaire. The trials were at least two days apart to minimize residual fatigue but no more than two weeks apart. Each experiment session lasted approximately two hours.

### *Analysis*

All variables except task performance were considered to come from a normal distribution based on analysis from the primary study (Chapter 2), and a square-root transformation on task performance was used to achieve normality. The multitrait-multimethod (MTMM) approach (Campbell & Fiske, 1959) was used to correlate all assessment measures employed in the study. Measures were classified into three areas: physiological measures (heart rate and EMG measures), subjective measures (NASA-TLX, SWAT, Borg ratings, and BDM ratings), and the psychosocial questionnaire. Correlations were computed between components within the same measure and between components of different measures. Pearson product moment correlation coefficients were used because data were normally distributed and had interval scale measurement properties. All reported correlations were significant at $\alpha = .05$ unless otherwise noted.

If two measures assessed the same constructs, they should have significant correlations, which will indicate high convergent validity. This was important for determining whether subjective and physiological measures were recording the same information and were possibly redundant. The MTMM matrix was used to determine discriminant validity of the measures, which is the ability to distinguish different traits. Discriminant validity means the measure of one trait should not be highly correlated with measures of other traits, particularly if the measures are from the same method or questionnaire (Wothke, 1995). If the correlations were high, this could indicate that the test did not have measures that were sensitive to the differences among the manipulations, or it could mean that the manipulations were not truly different. By considering convergent and discriminant validity, measures may be retained or removed to create a more efficient set of measurements.

## Results

The MTMM matrix compared every component of each measurement method employed in the study. Due to the large number of correlations, the results are divided into four major categories:

1. Physiological measurements: muscle activity and heart rate
2. Subjective measurements: SWAT and NASA-TLX perceived workload ratings, Borg discomfort ratings, and BDM ratings
3. Comparisons of physiological and subjective measurements
4. Comparisons of psychosocial questionnaire results with physiological and subjective measurements

### *Physiological measurements*

Figure 12 summarizes the muscle activity and heart rate measurements that were significantly correlated with more than 50% of the items in other measurement categories. All mean EMG (tapping and assembly tasks) were related (n = 191), though the relationship was positive within tapping and assembly measures but negative between tapping and assembly measures (Table 4). Mean and maximum assembly measures increased together (except middle deltoid EMG-$max_A$ with trapezius EMG-$mean_A$ and anterior deltoid EMG-$mean_A$); though mean tapping measures were not related to maximum assembly measures. Maximum activity of each muscle increased with other muscles within both tapping and assembly measures. Trapezius EMG-$max_T$ and middle deltoid EMG-$max_T$ increased with all other maximum tapping and assembly measures, but anterior deltoid EMG-$max_T$ was not related to any maximum assembly measures.

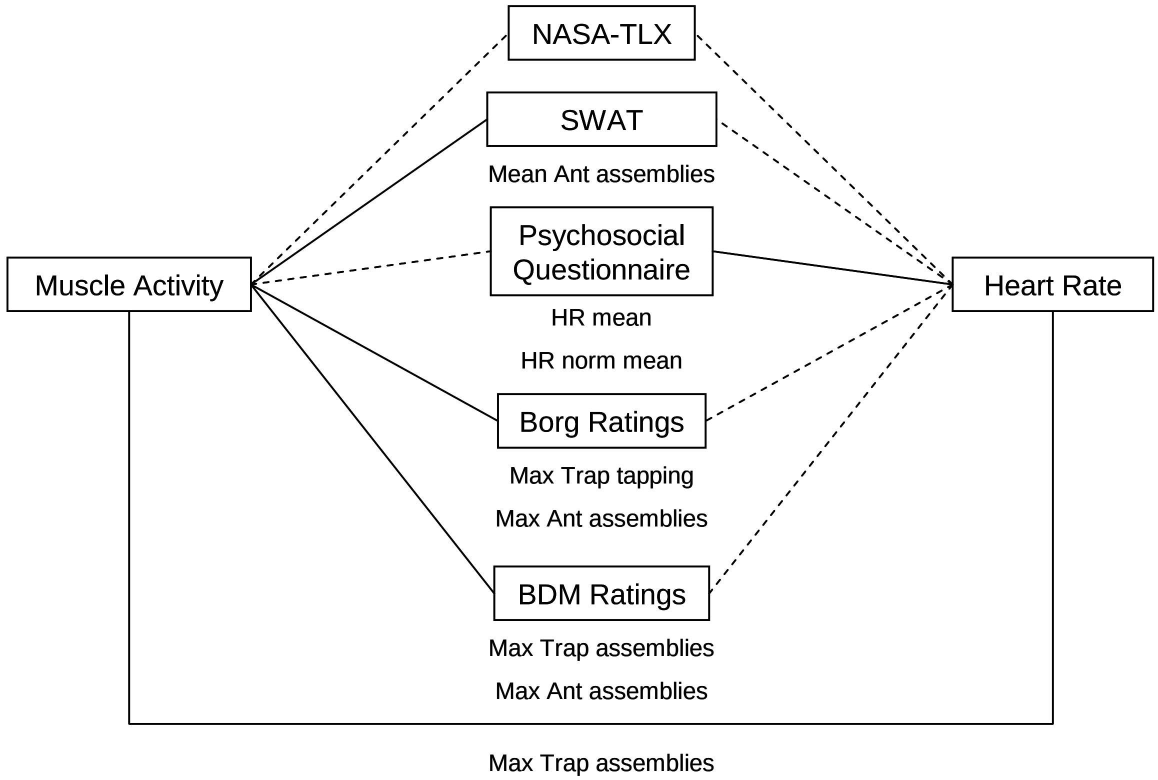


Figure 12. Muscle activity and heart rate measurements significantly correlated with ≥ 50% of other measurements. (Dashed lines indicate < 50% significant correlations. Parameters under each outcome measure were significantly correlated.)

Table 4. Correlations among physiological outcome measures.

| | HR mean | HR stdev | HR norm mean | HR norm stdev | Trap EMG-mean$_T$ | Mid EMG-mean$_T$ | Ant EMG-mean$_T$ | Trap EMG-mean$_A$ | Mid EMG-mean$_A$ | Ant EMG-mean$_A$ | Trap EMG-max$_T$ | Mid EMG-max$_T$ | Ant EMG-max$_T$ | Trap EMG-mean$_A$ | Mid EMG-mean$_A$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HR mean | | | | | | | | | | | | | | | |
| HR stdev | .268*** | | | | | | | | | | | | | | |
| HR norm mean | .750*** | .305*** | | | | | | | | | | | | | |
| HR norm stdev | .328*** | .989*** | .275*** | | | | | | | | | | | | |
| Trap EMG-mean$_T$ | .009 | .095 | .048 | .086 | | | | | | | | | | | |
| Mid EMG-mean$_T$ | .135 | .134 | .187* | .101 | .444*** | | | | | | | | | | |
| Ant EMG-mean$_T$ | .084 | .062 | .183* | .036 | .436*** | .476*** | | | | | | | | | |
| Trap EMG-mean$_A$ | .068 | .169* | -.043 | .188* | -.261*** | -.328*** | -.445*** | | | | | | | | |
| Mid EMG-mean$_A$ | .124 | .092 | -.005 | .122 | -.345*** | -.311*** | -.449*** | .780*** | | | | | | | |
| Ant EMG-mean$_A$ | .085 | .023 | -.072 | .062 | -.472*** | -.473*** | -.544*** | .802*** | .815*** | | | | | | |
| Trap EMG-max$_T$ | .089 | .062 | .037 | .064 | .478*** | .248*** | .175* | .126 | .106 | -.038 | | | | | |
| Mid EMG-max$_T$ | .163* | .102 | .201** | .080 | .093 | .358*** | .089 | .096 | .242*** | .046 | .275*** | | | | |
| Ant EMG-max$_T$ | .059 | -.002 | .104 | -.018 | .125 | .170* | .426*** | -.080 | .058 | -.098 | .180* | .213** | | | |
| Trap EMG-max$_A$ | .131 | .189** | .053 | .195** | .108 | .080 | -.013 | .385*** | .324*** | .249*** | .634*** | .367*** | .120 | | |
| Mid EMG-max$_A$ | 191** | .036 | .116 | .049 | .027 | .095 | .016 | .086 | .268*** | .117 | .308*** | .676*** | .094 | .369*** | |
| Ant EMG-max$_A$ | .120 | -.014 | .002 | .012 | -.117 | -.053 | -.089 | .285*** | .381*** | .392*** | .376*** | .328*** | .117 | .562*** | .570*** |

*** $p < .001$, ** $p < .01$, * $p < .05$

HR = heart rate, Norm = normalized, Stdev = standard deviation

Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid

EMG-max$_T$= maximum EMG during tapping

EMG-max$_A$= maximum EMG during assemblies

EMG-mean$_T$= mean EMG during tapping

EMG-mean$_A$= mean EMG during assemblies

All heart rate measures were positively correlated with each other at $p < .001$ ($r \geq .268$, n = 186). When considering the relationship between these two physiological measures (n = 185), mean heart rate increased as maximum assembly middle deltoid activity increased. Normalized mean heart rate was related positively to middle deltoid EMG-$mean_T$, middle deltoid EMG-$max_T$, and anterior deltoid EMG-$mean_T$. Heart rate variability and normalized heart rate variability had a direct relationship with trapezius EMG-$mean_A$ and trapezius EMG-$max_A$.

### *Subjective measurements*

### Perceived workload

All components of the NASA-TLX scores (n = 192) were related positively to each other strongly with the exception of mental demand and physical demand showing no significant relationship (Table 5). Relationships between performance ratings and mental demand, physical demand, and effort were considerably weaker than the others, though still significant ($p < .05$). Overall SWAT ratings (n = 192) were significantly correlated ($r > .50$) to time load, mental load, and stress load, and stress load was related strongly to mental load. Time load was significantly correlated with mental load and to stress load, although the correlation value was lower.

Table 5. Correlations among subjective outcome measures.

| | Mental Demand | Physical Demand | Temporal Demand | Perform ance | Effort | Frustrat-ion | Total unweight-ed | Total weight-ed | Time Load | Mental Load | Stress Load | Total work-load | Max-imum | Differ-ence | 33% mean | 66% mean | Overall mean | Neck | Shoulder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NASA-TLX ratings | | | | | | | | | | | | | | | | | | | |
| Mental Demand | | | | | | | | | | | | | | | | | | | |
| Physical Demand | -.017 | | | | | | | | | | | | | | | | | | |
| Temporal Demand | .225** | .323*** | | | | | | | | | | | | | | | | | |
| Perform-ance | .161* | .146* | .230** | | | | | | | | | | | | | | | | |
| Effort | .218** | .516*** | .378*** | .184* | | | | | | | | | | | | | | | |
| Frustrat-ion | .235** | .237** | .240** | .331*** | .305*** | | | | | | | | | | | | | | |
| Total un-weighted | .541*** | .582*** | .634*** | .542*** | .685*** | .671*** | | | | | | | | | | | | | |
| Total weighted | .614*** | .442*** | .568*** | .543*** | .613*** | .596*** | .928*** | | | | | | | | | | | | |
| SWAT ratings | | | | | | | | | | | | | | | | | | | |
| Time Load | .104 | .196** | .152* | .020 | .255** | .146* | .237** | .216** | | | | | | | | | | | |
| Mental Load | .702*** | 0.111 | .214** | .170* | .237** | .193** | .470*** | .530*** | .228** | | | | | | | | | | |
| Stress Load | .392*** | .233** | .187** | .310*** | .295*** | .609*** | .576*** | .559*** | .197** | .520*** | | | | | | | | | |
| Total workload | .539*** | .236*** | .257*** | .235** | .359*** | .430*** | .582*** | .595*** | .645*** | .784*** | .773*** | | | | | | | | |
| Borg discomfort ratings | | | | | | | | | | | | | | | | | | | |
| Maximum | -.053 | .571*** | .234** | .145* | .246*** | .303*** | .387*** | .307*** | -.005 | .085 | .363*** | .191** | | | | | | | |
| Difference | -.005 | .487*** | .163* | 0.058 | .194** | .201** | .296*** | .255*** | .009 | .170* | .295*** | .202** | .896*** | | | | | | |
| 33% mean | -.031 | .447*** | .277*** | .269*** | .333*** | .302*** | .422*** | .322*** | -.028 | -.035 | .321*** | .116 | .652*** | .328*** | | | | | |
| 66% mean | -.050 | .552*** | .218** | .185* | .237** | .344*** | .400*** | .312*** | -.030 | .027 | .338*** | .144* | .923*** | .719*** | .739*** | | | | |
| Overall mean | -.045 | .546*** | .259*** | .236** | .300*** | .349*** | .438*** | .338*** | -.030 | .000 | .355*** | .142* | .864*** | .592*** | .910*** | .951*** | | | |
| Body Discomfort Map ratings | | | | | | | | | | | | | | | | | | | |
| Neck | .015 | .289*** | .064 | .155* | .215** | .166* | .241*** | .165* | -.153* | -.060 | .044 | -.076 | .425*** | .230** | .537*** | .548*** | .583*** | | |
| Dominant shoulder | -.097 | .425*** | .229** | .185* | .145 | .302*** | .317*** | .239*** | -.028 | -.066 | .297*** | .094 | .732*** | .522*** | .627*** | .814*** | .786*** | .491*** | |
| Low back | -.080 | .197** | .097 | .082 | -.006 | .129 | .111 | .075 | -.076 | -.143* | .038 | -.074 | .399*** | .296*** | .294*** | .446*** | .408*** | .387*** | .415*** |

*** $p < .001$, ** $p < .01$, * $p < .05$

All relationships between SWAT and NASA-TLX measures were significantly, positively correlated (n = 192) with only three exceptions: time load was not related to mental demands or frustration, and mental load was not related to physical demands. Figure 13 provides a summary of the NASA-TLX and SWAT measures that were significantly correlated with at least 50% of items from other measurement categories.

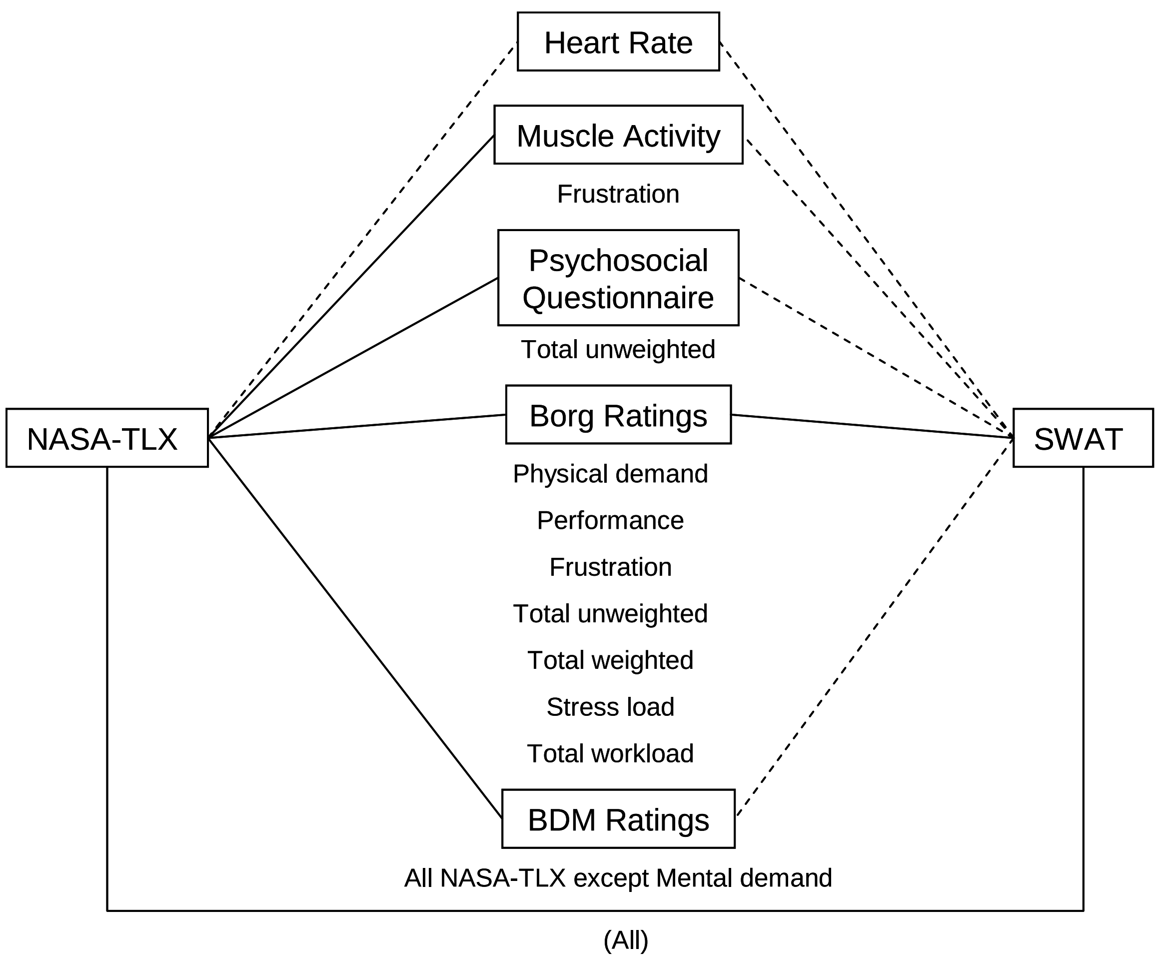


Figure 13. NASA-TLX and SWAT ratings significantly correlated with ≥ 50% of other measurements. (Dashed lines indicate < 50% significant correlations. Parameters under each outcome measure were significantly correlated.)

## Discomfort ratings

All BDM ratings were related with $r \geq .387$, n = 192. All Borg parameters were strongly related at $r \geq .328$, n = 192, and all BDM ratings and Borg parameters were related at $r \geq .230$, n = 192.

Figure 14 provides a summary of the Borg and BDM ratings that were significantly correlated with 50% or more of the items in other measurement categories.

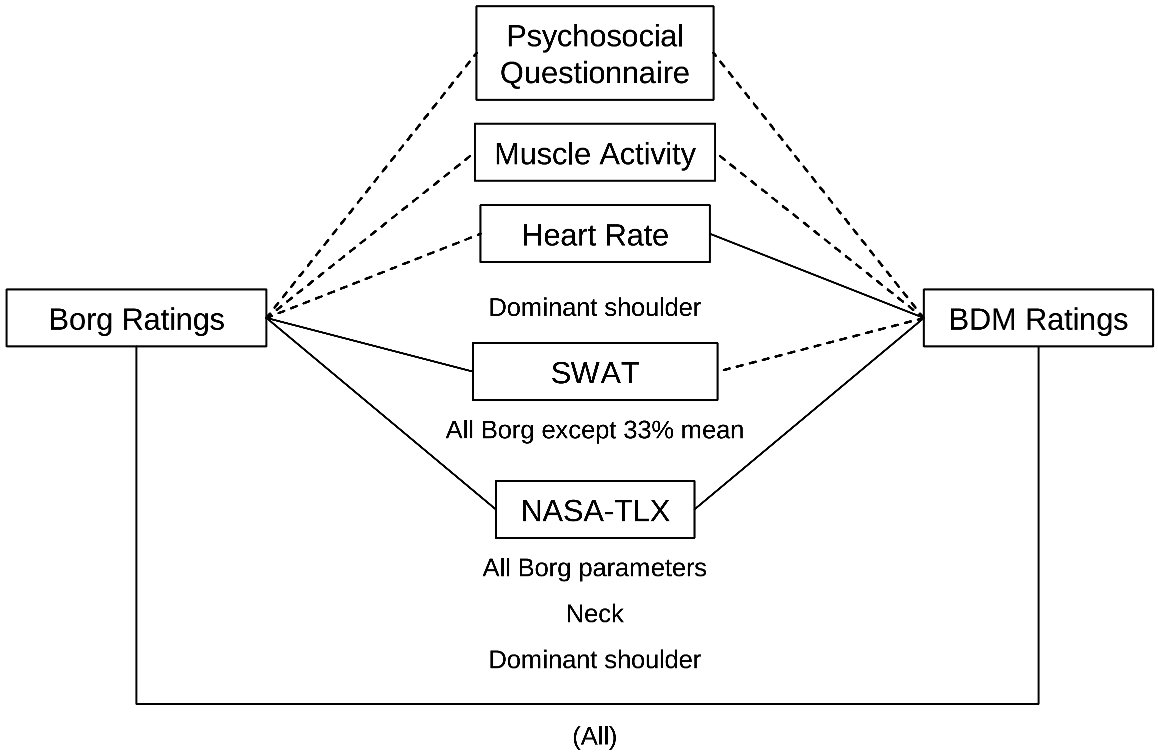


Figure 14. Borg and BDM ratings significantly correlated with ≥ 50% of other measurements. (Dashed lines indicate < 50% significant correlations. Parameters under each outcome measure were significantly correlated.)

## SWAT and discomfort ratings

Three relationships were found between SWAT ratings and BDM ratings (n = 192). Time load increased as neck discomfort decreased, and higher levels of mental load were associated with lower ratings of low back discomfort. However, shoulder discomfort ratings increased as stress load increased.

Borg parameters were not related to time load or mental load, with the exception of Borg difference with mental load ($r = .170$, $p = .018$, n = 192). However, stress load and total SWAT were significantly and positively related to all Borg discomfort measures except SWAT total with 33% mean ratings. Stress load had higher correlations with Borg ratings ($r \geq .295$, n = 192) than overall SWAT scores ($r \geq .142$, n = 192).

### NASA-TLX and discomfort ratings

Shoulder ratings were positively correlated with all NASA-TLX parameters with the exception of mental demand and effort (n = 192). Neck ratings were positively related to all NASA-TLX parameters except for mental demand and temporal demand. Low back ratings increased with physical exposure only.

Mental demand was not related to any Borg measure (n = 192). However, all other NASA-TLX parameters were positively related to all of the Borg measures with the exception of Borg difference and performance. Correlations were highest between physical demand and Borg ratings ($r \geq .447$), while the other significant correlations ranged from .145 (performance and Borg Max) to .438 (unweighted NASA-TLX total and overall mean Borg rating).

## *Physiological and subjective measurement comparison*

### Workload ratings and heart rate activity

Heart rate measures were not related to any NASA-TLX parameters (n = 186, Table 6). The time load component of the SWAT rating scale was inversely related to heart rate mean.

Table 6. Correlations between physiological and subjective outcome measures.

| | HR mean | HR stdev | HR norm mean | HR norm stdev | Trap EMG-mean$_T$ | Mid EMG-mean$_T$ | Ant EMG-mean$_T$ | Trap EMG-mean$_A$ | Mid EMG-mean$_A$ | Ant EMG-mean$_A$ | Trap EMG-max$_T$ | Mid EMG-max$_T$ | Ant EMG-max$_T$ | Trap EMG-max$_A$ | Mid EMG-max$_A$ | Ant EMG-max$_A$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NASA-TLX ratings | | | | | | | | | | | | | | | | |
| Mental Demand | -.078 | -.035 | -.024 | -.060 | -.111 | -.026 | -.071 | .001 | -.021 | .043 | -.066 | .052 | -.010 | -.082 | -.015 | -.043 |
| Physical Demand | .111 | -.015 | -.007 | .010 | .213** | .180* | .125 | -.087 | -.027 | -.002 | .136 | .051 | .018 | .071 | .034 | .021 |
| Temporal Demand | .082 | -.062 | .118 | -.076 | .232** | .142* | .165* | -.145* | -.053 | -.099 | .125 | .157* | .021 | .047 | .067 | .029 |
| Performance | .065 | .039 | -.003 | .036 | .138 | .135 | .124 | .100 | .106 | .017 | .133 | .056 | .082 | .068 | .087 | .061 |
| Effort | .082 | .079 | .042 | .087 | .162* | .101 | .019 | .029 | .047 | .026 | .056 | .114 | -.023 | -.015 | .014 | -.098 |
| Frustration | .084 | -.018 | .018 | -.011 | -.055 | .048 | -.105 | .200** | .300*** | .297*** | .047 | .160* | -.095 | .070 | .184* | .189** |
| Total unweighted | .087 | -.008 | .035 | -.010 | .136 | .148* | .054 | .034 | .104 | .092 | .108 | .161* | -.009 | .040 | .104 | .050 |
| Total weighted | .013 | .017 | -.018 | .006 | .067 | .110 | .007 | .106 | .150* | .144* | .110 | .136 | .012 | .055 | .054 | .033 |
| SWAT ratings | | | | | | | | | | | | | | | | |
| Time Load | -.196** | -.108 | -.128 | -.120 | .031 | -.089 | -.004 | .004 | .003 | .103 | .010 | -.039 | -.077 | -.027 | .012 | .022 |
| Mental Load | -.003 | -.043 | -.009 | -.055 | -.127 | -.041 | -.006 | .009 | -.006 | .073 | -.099 | .029 | -.010 | -.066 | .013 | .043 |
| Stress Load | .091 | -.022 | .018 | -.019 | -.105 | .025 | -.128 | .082 | .156 | .235** | .062 | .075 | -.039 | .095 | .095 | .235** |
| Total Workload | -.048 | -.077 | -.053 | -.086 | -.089 | -.046 | -.057 | .045 | .071 | .187** | -.007 | .033 | -.053 | .007 | .057 | .139 |
| Borg discomfort ratings | | | | | | | | | | | | | | | | |
| Maximum | .190** | .066 | .203 | .062 | .133 | .160* | .021 | -.027 | .051 | .022 | .145* | .112 | .037 | .105 | .118 | .125 |
| Difference | .181 | .055 | .213** | .045 | .134 | .227** | .014 | -.107 | -.017 | -.060 | .094 | .099 | .015 | .033 | .066 | .026 |
| 33% mean | .076 | .039 | .068 | .043 | .141 | -.036 | -.029 | .105 | .144* | .122 | .123 | .123 | .049 | .093 | .138 | .165* |
| 66% mean | .142 | .069 | .132 | .069 | .095 | .097 | .031 | .064 | .120 | .106 | .167* | .120 | .050 | .152* | .145* | .174* |
| Overall mean | .121 | .058 | .110 | .060 | .122 | .041 | .005 | .088 | .142 | .123 | .158* | .129 | .052 | .135 | .153* | .184* |
| Body Discomfort Map ratings | | | | | | | | | | | | | | | | |
| Neck | .141 | .132 | .057 | .146 | .037 | .006 | .030 | .147* | .088 | .084 | .119 | .159* | .031 | .144* | .145* | .170* |
| Dominant shoulder | .150* | .138 | .162* | .135 | .053 | .071 | .100 | .093 | .120 | .129 | .180* | .139 | .090 | .220** | .142 | .156* |
| Low back | .085 | -.098 | .083 | -.107 | -.096 | .170* | .070 | -.011 | .018 | .020 | .071 | .129 | .006 | .013 | .046 | .121 |

*** $p < .001$, ** $p < .01$, * $p < .05$

HR = heart rate, Norm = normalized, Stdev = standard deviation

Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid

EMG-max$_T$= maximum EMG during tapping, EMG-max$_A$= maximum EMG during assemblies

EMG-mean$_T$= mean EMG during tapping, EMG-mean$_A$= mean EMG during assemblies

### Workload ratings and muscle activity

NASA-TLX ratings were related to several components of measured muscle activity (n = 191). Temporal demand increased with all three measures of mean muscle activity during tapping but decreased when trapezius activity increased during the assembly task. Physical demand was related positively to trapezius EMG-$mean_T$ and middle deltoid EMG-$mean_T$ activity. Effort increased with trapezius EMG-$mean_T$, and the unweighted total increased with middle deltoid EMG-$mean_T$. Frustration increased with all three mean activity measures during assemblies. Total weighted workload also increased with mean middle and anterior deltoid in assemblies.

Middle deltoid EMG-$max_T$ was related positively with temporal demands, frustration, and unweighted total workload. Anterior deltoid EMG-$max_A$ increased with frustration.

For the SWAT ratings, stress load was positively correlated with mean activity in all 3 muscles during the assembly portions, and SWAT total was positively correlated with anterior deltoid EMG-$mean_A$ (n = 191).

### Discomfort ratings and heart rate activity

Shoulder discomfort ratings increased with heart rate mean and normalized heart rate mean (n = 186). Heart rate mean and normalized heart rate mean were related positively to the maximum Borg rating and the difference between the highest and lowest Borg ratings (n = 186).

### Discomfort ratings and muscle activity

Ratings of discomfort on the BDM did not correlate with mean muscle activity with the exception of neck discomfort ratings with trapezius EMG-$mean_A$ and low back discomfort ratings with middle deltoid EMG-$mean_T$ (n = 191). However, maximum activity of all three muscles during assemblies had a direct relationship with neck and shoulder discomfort ratings. Neck discomfort ratings were related positively to middle deltoid EMG-$max_T$, and shoulder discomfort ratings were related positively to trapezius EMG-$max_T$.

Maximum Borg ratings and the difference in Borg ratings directly related to middle deltoid EMG-$mean_T$ (n = 191). Middle deltoid EMG-$mean_A$ was related positively to 33% duty mean ratings, and trapezius EMG-max$_T$ was related positively to maximum Borg ratings, 66% duty mean ratings, and overall mean ratings. All three measures of maximum activity during assemblies were directly related to 66% duty mean ratings, anterior deltoid EMG-max$_A$ was related positively to 33% duty mean ratings, and middle deltoid EMG-max$_A$ and anterior deltoid EMG-max$_A$ were related directly to overall mean.

### *Psychosocial questionnaire*

Few significant correlations existed between the different constructs of the psychosocial questionnaire: skill discretion was positively related to decision authority and physical loads, and skill discretion was negatively related to psychological work demands (Table 7). Physical loads were related directly to physical exertion, and perceptions of decision authority increased when the supervisor was perceived as being more supportive. Coworker and supervisor support were directly related. (Note that a high score on the psychosocial questionnaire indicates a more positive environment.) Please refer to Figure 15 for a summary of psychosocial categories that were significantly related with 50% or more of the items in other measurement categories.

Table 7. Correlations between psychosocial environment ratings and subjective and physiological measures. Higher psychosocial ratings indicate a favorable work environment

| | Skill Discretion | n | Decision Authority | n | Work Demands | n | Physical Exertion | n | Physical Loads | n | Supervisor Support | n | Coworker Support | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Skill Discretion | | | | | | | | | | | | | | |
| Decision Authority | .593*** | 177 | | | | | | | | | | | | |
| Work Demands | -.229** | 141 | -.083 | 136 | | | | | | | | | | |
| Physical Exertion | .008 | 185 | -.046 | 175 | .280*** | 139 | | | | | | | | |
| Physical Loads | .306*** | 189 | .130 | 180 | .062 | 142 | .403*** | 186 | | | | | | |
| Supervisor Support | .102 | 99 | .339*** | 97 | .179 | 94 | .121 | 98 | .173 | 99 | | | | |
| Coworker Support | -.066 | 80 | .151 | 80 | .128 | 78 | -.119 | 80 | -.042 | 80 | .705*** | 79 | | |
| NASA-TLX | | | | | | | | | | | | | | |
| Mental Demand | .104 | 189 | -.035 | 180 | -.218** | 142 | -.075 | 186 | .046 | 192 | .109 | 99 | .146 | 80 |
| Physical Demand | .031 | 189 | .075 | 180 | -.103 | 142 | -.387*** | 186 | -.199** | 192 | .174 | 99 | .276* | 80 |
| Temporal Demand | .083 | 189 | .096 | 180 | -.220** | 142 | -.288*** | 186 | -.242*** | 192 | .002 | 99 | .093 | 80 |
| Performance | -.161* | 189 | -.045 | 180 | .000 | 142 | -.107 | 186 | -.139 | 192 | -.021 | 99 | .022 | 80 |
| Effort | .098 | 189 | .083 | 180 | -.107 | 142 | -.307*** | 186 | -.042 | 192 | .309** | 99 | .278* | 80 |
| Frustration | -.034 | 189 | -.127 | 180 | .021 | 142 | -.224** | 186 | -.192** | 192 | -.067 | 99 | .064 | 80 |
| Total unweighted | .036 | 189 | .001 | 180 | -.168* | 142 | -.370*** | 186 | -.205** | 192 | .127 | 99 | .236* | 80 |
| Total weighted | .026 | 189 | -.002 | 180 | -.146 | 142 | -.251*** | 186 | -.172* | 192 | .236 | 99 | .315** | 80 |
| SWAT | | | | | | | | | | | | | | |
| Time Load | .047 | 189 | -.117 | 180 | -.225** | 142 | -.089 | 186 | -.126 | 192 | -.116 | 99 | -.136 | 80 |
| Mental Load | -.042 | 189 | -.054 | 180 | -.219** | 142 | -.159* | 186 | -.050 | 192 | .085 | 99 | .084 | 80 |
| Stress Load | -.084 | 189 | -.111 | 180 | -.114 | 142 | -.275*** | 186 | -.229** | 192 | .013 | 99 | .215 | 80 |
| Total workload | -.031 | 189 | -.129 | 180 | -.251** | 142 | -.228** | 186 | -.180* | 192 | -.008 | 99 | .068 | 80 |
| Borg ratings | | | | | | | | | | | | | | |
| Maximum | -.095 | 189 | -.108 | 180 | -.057 | 142 | -.313*** | 186 | -.246*** | 192 | -.052 | 99 | .159 | 80 |
| Difference | -.125 | 189 | -.178* | 180 | -.081 | 142 | -.240*** | 186 | -.179* | 192 | -.124 | 99 | .028 | 80 |
| 33% mean | .075 | 189 | .125 | 180 | -.086 | 142 | -.229*** | 186 | -.213** | 192 | .145 | 99 | .315** | 80 |
| 66% mean | -.051 | 189 | -.019 | 180 | -.059 | 142 | -.314*** | 186 | -.203** | 192 | .052 | 99 | .253* | 80 |
| Overall mean | .005 | 189 | .046 | 180 | -.075 | 142 | -.329*** | 186 | -.222** | 192 | .096 | 99 | .295** | 80 |
| BDM | | | | | | | | | | | | | | |
| Neck | .046 | 189 | .071 | 180 | .004 | 142 | -.119 | 186 | -.079 | 192 | .229* | 99 | .212 | 80 |
| Dominant shoulder | .024 | 189 | .069 | 180 | -.050 | 142 | -.217** | 186 | -.160* | 192 | -.020 | 99 | .228* | 80 |
| Low Back | -.186* | 189 | -.165* | 180 | -.024 | 142 | -.058 | 186 | -.178* | 192 | -.032 | 99 | -.030 | 80 |
| HR mean | -.310*** | 183 | -.164* | 175 | .074 | 138 | -.228** | 180 | -.162* | 186 | -.115 | 95 | .004 | 77 |
| HR stdev | -.066 | 183 | -.055 | 175 | .194* | 138 | .068 | 180 | .281*** | 186 | .164 | 95 | .280* | 77 |
| HR norm mean | -.356*** | 183 | -.262*** | 175 | .048 | 138 | -.266*** | 180 | -.096 | 186 | -.253* | 95 | -.085 | 77 |
| HR norm stdev | -.056 | 183 | -.036 | 175 | .196* | 138 | .070 | 180 | .277*** | 186 | .176 | 95 | .277* | 77 |
| Trap EMG-mean$_T$ | .100 | 188 | .192* | 179 | -.017 | 141 | -.166* | 185 | -.118 | 191 | -.097 | 98 | -.101 | 79 |
| Mid EMG-mean$_T$ | -.063 | 188 | .016 | 179 | -.061 | 141 | -.150* | 185 | -.089 | 191 | -.020 | 98 | -.116 | 79 |
| Ant EMG-mean$_T$ | -.010 | 188 | .113 | 179 | -.068 | 141 | -.096 | 185 | -.018 | 191 | -.139 | 98 | -.234* | 79 |
| Trap EMG-mean$_A$ | -.064 | 188 | .012 | 179 | .181* | 141 | .066 | 185 | .105 | 191 | .219* | 98 | .359* | 79 |
| Mid EMG-mean$_A$ | -.119 | 188 | -.003 | 179 | .152 | 141 | -.023 | 185 | .009 | 191 | .137 | 98 | .289** | 79 |
| Ant EMG-mean$_A$ | -.090 | 188 | -.033 | 179 | .134 | 141 | -.019 | 185 | -.004 | 191 | .205* | 98 | .377*** | 79 |
| Trap EMG-max$_T$ | -.005 | 188 | .087 | 179 | .089 | 141 | -.124 | 185 | -.139 | 191 | .140 | 98 | .235* | 79 |
| Mid EMG-max$_T$ | -.050 | 188 | .018 | 179 | -.112 | 141 | -.075 | 185 | -.043 | 191 | -.021 | 98 | -.033 | 79 |
| Ant EMG-max$_T$ | -.015 | 188 | .096 | 179 | .022 | 141 | -.065 | 185 | .005 | 191 | -.123 | 98 | -.085 | 79 |
| Trap EMG-max$_A$ | -.028 | 188 | .046 | 179 | .132 | 141 | -.021 | 185 | -.091 | 191 | .182 | 98 | .312** | 79 |
| Mid EMG-max$_A$ | -.048 | 188 | -.021 | 179 | -.133 | 141 | -.054 | 185 | -.099 | 191 | .154 | 98 | .159 | 79 |
| Ant EMG-max$_A$ | -.031 | 188 | .041 | 179 | .015 | 141 | -.092 | 185 | -.133 | 191 | .210* | 98 | .280* | 79 |

*** $p < .001$, ** $p < .01$, * $p < .05$

HR = heart rate, Norm = normalized, Stdev = standard deviation

Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid

EMG-max$_T$= maximum EMG during tapping, EMG-max$_A$= maximum EMG during assemblies

EMG-mean$_T$= mean EMG during tapping, EMG-mean$_A$= mean EMG during assemblies

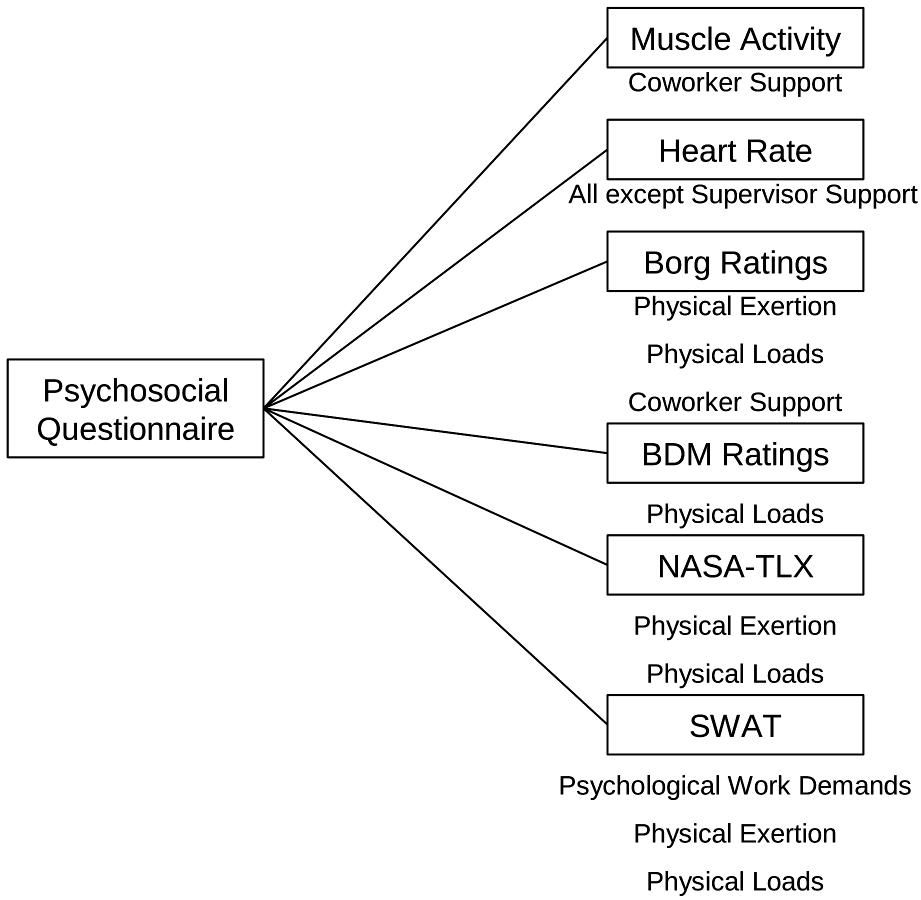


Figure 15. Psychosocial questionnaire categories significantly correlated with ≥ 50% of other measurements. (Dashed lines indicate < 50% significant correlations.)

## Workload ratings

SWAT components of time load, mental load, and total workload were higher when psychological work demands were greater. Mental load increased with physical exertion, and stress load and total workload also increased with physical exertion and physical isometric loads.

Participants rated their performance (on the NASA-TLX) as being higher when skill discretion levels were higher, and decision authority was not associated with any NASA-TLX component. Psychological work demands were higher when mental demand, temporal demand, and unweighted total workload increased. Physical exertion increased with all NASA-TLX components except mental demand and performance, and physical loads increased with all components except mental demand, performance, and effort. Higher supervisor support was related to increased effort and higher weighted total workload, and higher coworker support was correlated with higher physical demands, effort, and unweighted and weighted total workload.

### Discomfort ratings

Higher levels of physical exertion and physical loads were related with higher Borg ratings for all Borg parameters. Lower levels of decision authority were associated with larger differences between minimum and maximum Borg ratings, and higher coworker support was related to higher 33% mean, 66% mean, and overall mean Borg ratings.

Higher ratings of low back discomfort on the BDM were related to lower levels of skill discretion and decision authority, but psychological work demands were not related to any BDM ratings. Higher levels of physical exertion and physical loads were related to higher shoulder discomfort ratings, and higher low back discomfort ratings were related to higher levels of physical loads. Higher levels of coworker support were related to higher shoulder discomfort ratings, high levels of supervisor support were correlated with high neck discomfort ratings.

### Physiological measurements

Mean heart rate and heart rate variability were sensitive to different types of perceived psychosocial conditions. Higher mean heart rate was associated with low levels of skill discretion and decision authority and high levels of physical exertion, and physical loads. Higher normalized mean heart rates were related to low levels of skill discretion, decision authority, and supervisor support and with high levels of physical exertion. Higher heart rate variability (raw and normalized) was related to more favorable levels of psychological work demands, physical loads, and coworker support.

High levels of decision authority were related to higher trapezius EMG-$mean_T$, and lower levels of psychological work demands were related to higher trapezius EMG-$mean_A$. High physical exertion was related to higher trapezius EMG-$mean_T$ and middle deltoid EMG-$mean_T$. High levels of supervisor support were related to higher trapezius EMG-$mean_A$ and anterior deltoid EMG-$mean_A$ and to higher anterior deltoid EMG-$max_A$. Higher levels of coworker support were related to higher muscle activity in all three mean off-duty measures and for trapezius EMG-

$max_A$ and anterior deltoid EMG-$max_A$. Anterior deltoid EMG-$mean_T$ increased when there were lower levels of coworker support.

## Discussion

The correlations between outcome measures were strongest among measures from the same class of measurements, such as NASA-TLX and SWAT ratings or Borg and BDM ratings. Most methods had high correlations within themselves, such as the different components of the NASA-TLX scale. Correlations between different classes of measures were not as strong, which indicates that these different measures captured different aspects of responses to the work environment. Using multiple classes of measurement methods may be necessary to obtain a complete picture of WMSD risk factor exposure in the workplace.

### *Physiological Measures*

Muscle activity for the three muscles was positively related during tapping and assembly tasks, which indicates high levels of muscle coactivation and high convergent validity. It may be possible to measure only one muscle of this group during overhead work although individual differences in work style may influence which shoulder muscle has the highest activity. A previous study has shown that recording exposure data continuously can be used to distinguish high and low risk tasks (Babski-Reeves & Crumpton-Young, 2003), so retaining EMG measurement is needed as part of WMSD risk measurement. Ideally the muscle chosen should be most closely related to the physical demands of the task. For this task, trapezius activity is most consistently related to ratings of discomfort, which suggests that this muscle may be the best indicator of WMSD risk. However, other research indicates that trapezius muscle activity may not be a good predictor of pain (Jensen, Nilsen, Hansen, & Westgaard, 1993). Despite this, the trapezius is active during different physical and psychosocial conditions including overhead work (Nussbaum, 2001; Vasseljen & Westgaard, 1995), typing and office/desk work (Hägg & Åström, 1997), and mental demands (Leyman et al., 2004; McLean & Urquhart, 2002; B. Visser, de Looze, de Graaff, & van Dieen, 2004) which makes it a good candidate for estimating muscle activity.

Muscle activity was negatively correlated between tapping and assembly tasks, meaning that participants with higher activity during the overhead tapping portion had lower activity during the small parts assembly. However, having lower muscle activity during the more active portions of the work cycle may not decrease WMSD risk unless it also results in lower muscle activity during less physically demanding periods, which was not observed in this study. Lower muscle activity during the assembly task in this experiment may be due to moving the arm to a more neutral position rather than overhead or to relaxing during this less strenuous task. While the main reason for lower muscle activity is not known, non-neutral postures have been related to WMSDs (e.g. Werner, Franzblau, Gell, Ulin, & Armstrong, 2005a). The ability to relax physiologically also may have implications for WMSD development. The biopsychosocial model (Melin & Lundberg, 1997) proposes that workers who are unable to physiologically ‘unwind’ during rest periods or after work are at higher risk for WMSDs. One possible explanation is that shoulder pain has been related to fewer EMG gaps (meaning longer periods of static exertions) in females performing repetitive work (Sandsjö, Melin, Rissén, Dohns, & Lundberg, 2000; Veiersted et al., 1990). This indicates that rest periods must be evaluated to determine if workers are able to recover from physiological strain during breaks and less physically demanding work periods. Therefore, muscle activity should be considered during active and rest periods during the workday.

There were several significant relationships between heart rate measures and muscle activity and between heart rate and Borg discomfort ratings. Heart rate and muscle activity may indicate physical workload, although heart rate indicates total energy expenditure while muscle activity may predict localized pain and fatigue. These results are in agreement with a previous study of truck drivers performing heavy work operations which also found high agreement between Borg-CR10 ratings and heart rate (Johansson & Borg, 1993).

Heart rate measures were most highly correlated with perceptions of the psychosocial environment. Previous studies have shown that heart rate is higher for workers experiencing higher strain levels and lower control over their job duties (Holte & Westgaard, 2002; Melin et al., 1999). Therefore, heart rate may be capturing aspects of the work environment that are not detected through EMG, subjective workload ratings, and discomfort ratings due to low correlations (high discriminant validity). While more research is needed to relate heart rate variables with WMSD risk, there appears to be some relationships between heart rate measures and perceptions of the psychosocial environment and perceived discomfort. Heart rate measures should continue to be collected given that heart rate measurement devices are portable and fairly non-intrusive and that heart rate measures can be collected easily.

### *Workload Ratings*

The NASA-TLX and SWAT showed high convergent validity with few exceptions (time load (SWAT) with mental demand and performance (NASA-TLX) and mental load (SWAT) with physical demand (NASA-TLX)). The highest correlations mostly occurred among the total workload scores. Rubio et al. (2004) also found high convergent validity between the NASA-TLX and SWAT rating systems for a laboratory-based experiment. These results suggest that one of the workload ratings is sufficient to obtain an assessment of perceived workload. However, the individual scales should be retained since some discriminant validity was observed both in the current study and previous studies (e.g. Biers & Masline, 1987; Miyake, Kumashiro, Murakami, & Sasaki, 1996).

Because discriminant validity was high between most workload, muscle activity, and heart rate measures, all three measurements should be retained. Frustration and total weighted workload from the NASA-TLX ratings were positively correlated with muscle activity during the assembly task. It may be that participants with high frustration levels were unable to unwind during the less strenuous portions of work tasks, which could increase risk for WMSDs (Melin & Lundberg, 1997). Otherwise few correlations of muscle activity and heart rate measures with perceived workload (NASA-TLX and SWAT) were observed.

To determine which workload scale was most useful, correlations between perceived workload, perceived discomfort, muscle activity, and heart rate measures were examined for convergent and discriminant validity. Because the goal of measurement is to predict WMSD risk, the workload ratings that distinguish the variables from these other categories are most desirable. Ratings of discomfort from the Borg ratings and from neck and shoulder ratings on the BDM were correlated with both workload scales except for mental demand ratings, so discomfort ratings were not distinguishable by workload type. Heart rate measures also did not provide insight into choosing a workload measure because only one low (though significant) correlation was found. To the make the final decision, muscle activity measures showed more correlations with NASA -TLX ratings than SWAT ratings, so using the NASA-TLX may provide a better indication of workload as it relates to WMSD risk. Additionally, data from the first study (Chapter 2) showed that the NASA-TLX was sensitive to both demand type (psychosocial versus physical exposure) and demand level (high or low) whereas the SWAT appeared to be sensitive only to demand level.

### *Discomfort Ratings*

The high convergent validity between BDM ratings and Borg discomfort ratings indicates that only one measure of discomfort is needed. The BDM had the advantage of being non-intrusive during work since it was completed at the conclusion of each trial. It also recorded discomfort for multiple areas of the body. The Borg scale collects ratings over a period of time, so it is possible to determine any time trends during the duration of work (in this experiment no significant time trends were found). Several significant relationships existed between discomfort ratings and heart rate and muscle activity, but few useful patterns could be detected. A previous study comparing discomfort ratings with muscle activity in a manufacturing setting also found inconsistencies between these two measures supposedly due to workers becoming acclimatized to their work demands (Zetterberg et al., 1997).

Both sets of discomfort ratings showed several significant correlations with the NASA-TLX ratings and SWAT ratings. If the NASA-TLX is used as suggested previously, either method of collecting discomfort ratings would be sufficient. The decision would lie in the ability to provide discomfort ratings during work versus at the end of the task. Alternatively, Borg ratings could be obtained for multiple body parts during task performance to gain a more complete picture of discomfort.

### *Psychosocial Questionnaire*

The constructs of the psychosocial questionnaire exhibited good discriminant validity: few significant correlations existed between the different constructs. Psychosocial ratings showed sensitivity to different outcome measures as well. Psychological work demands, physical exertion, and physical loads were sensitive to different components of workload. For instance, only psychological work demands were related to mental demand (NASA-TLX) and time load

(SWAT) whereas physical exertion and physical loads were related to physical demands (NASA-TLX). Physical exertion and physical loads were related to shoulder discomfort, and physical exertion was related to muscle activity during the tapping task. Coworker and supervisor support were highly correlated ($r$ = .705) which suggests that support is viewed in more general terms rather than discriminating coworker support from supervisor support. However, coworker support was related to outcomes in all other measurement methods (17 significant correlations total) except the SWAT ratings whereas supervisor support was only related to one workload rating (effort, NASA-TLX), neck discomfort, normalized heart rate mean, and 3 muscle activity measures. It should be noted that due to the structure of the task, supervisor support and skill discretion were not directly manipulated, and no major differences were expected in these ratings. Epidemiological studies have shown significant relationships between psychosocial factors and WMSDs of the neck and shoulder (Ariëns et al., 2001; Bongers et al., 1993), so it is important to include these factors in ergonomic evaluations. Given the ease of administration of this questionnaire and discriminant validity showing sensitivity to different conditions, the entire questionnaire will be retained in the final battery of outcome measures.

### *Conclusions and Limitations*

The highest correlations were found between measures assessing the same constructs: ratings from the NASA-TLX and SWAT were highly correlated as were Borg-CR10 ratings and BDM ratings. Based on evaluations of convergent and discriminant validity among the chosen outcome measures along with consideration of choosing methods most likely to predict WMSD risk, the following measurement methods are included in a shortened evaluation set for the simulated manufacturing task:

- NASA-TLX ratings of perceived workload
- EMG of the dominant-side trapezius during ‘on’ and ‘off’ duty portions of the task
- Heart rate recording for heart rate mean and heart rate variability
- Borg-CR10 ratings of discomfort for the shoulder and potentially other areas of the body
- Psychosocial questionnaire (based on JCQ items)

The methods chosen represent an efficient way to assess a range of physiological and subjective measures that may be related to WMSD risk. These measurements are relatively easy to collect and were not intrusive or uncomfortable to participants in the current study. Workload ratings, discomfort ratings, and the psychosocial questionnaire may be collected on paper or on a portable computing device. The heart rate monitor is completely mobile and wireless, only requiring a computer to download heart rate files at the conclusion of a work day. The heart rate monitor used in the current study was able to record several hours of data at once. EMG data can be collected through a wireless EMG device. The setup procedure, which included putting on the heart rate monitor and electrodes, answering the NASA-TLX pair-wise comparisons, and conducting MVC testing, took 30 minutes or less during each trial, and this time may be reduced if fewer muscles are chosen for EMG recording. The questionnaires given at the conclusion of the trial required approximately 15-20 minutes, and this time was reduced as participants became more familiarized with the questions.

The use of the selected measurement tools is interpreted within the experimental setting of manufacturing tasks. Caution is needed when extending these recommendations to other occupations or settings. Due to the nature of the task, mental demands may have been perceived as lower than physical demands. Ratings of workload support this idea: the average mental demand rating from the NASA-TLX was 5.134 while the average physical demand rating was 8.076. The lower levels of mental workload may also explain the lack of significant correlations between heart rate variability and mental workload and the lack of distinction between different workload components.

Another potential limitation is that the experimenter did not rate the work environment or task. Observations and direct measurement can be used to measure exposure directly at the job site, thus avoiding any potential subjective influences in estimating physical or psychosocial exposure. However, there are some limitations to direct observations. Observations cannot be used to estimate past exposure, and they may not be accurate for inconsistent exposure since they are often done for short periods of time (Punnett & Wegman, 2004). Observations also require trained observers, are time-consuming, and often require measures to be adapted to fit specific jobs, which limits the ability to generalize the measures (Hurrell et al., 1998). Direct observation and measurement of psychosocial factors are inherently more difficult because psychosocial factors rely on subjective interpretations of the work environment. Objective ratings would be incomplete without psychosocial environment ratings, so until measures are developed to objectively interpret the psychosocial environment (for instance, by counting opportunities for coworker interaction as a measure of social support), observations will be limited to estimations of physical demands.

Epidemiological and experimental evidence shows a relationship between physical and psychosocial factors with WMSD risk; therefore, measurement methods used to assess work environments should assess both classes of factors. By using the MTMM approach, a set of measurement methods was determined that minimized overlap between measures and retained measures most related to WMSD risk. A comprehensive method of assessing risk from psychosocial and physical exposures in the work environment is the first step towards determining relative influences of various risk factors and directions for interventions that reduce WMSD rates.

## Chapter 4: Reliability of physiological and subjective outcome measures under different physical and psychosocial exposures

### Abstract

Exposure to physical and psychosocial factors can be measured using a variety of tools that assess physiological and subjective responses to the work environment. However, there is limited evidence regarding the reliability of these measures under different types of exposures. The purpose of the current study was to determine the test-retest reliability of several classes of measurements for evaluating psychosocial and physical exposure in an experimental environment. Objective measures were obtained of physiological responses and task performance, and subjective measures were obtained of perceptions of discomfort, workload, and the psychosocial environment. Twenty-four participants divided into four exposure groups (high or low physical exposure, favorable social support, or favorable job control) completed two identical trials. Test-retest reliability was quantified using intraclass correlation coefficients (ICC) and coefficients of variation (CV). Roughly half of the measures had high reliability (ICC ≥ .70 and CV ≤ 30%), but reliability depended on the type of exposure. Discomfort ratings had the highest reliability when no psychosocial manipulations were present, and perceptions of the psychosocial environment were most reliable under favorable social support. Workload had the highest reliability for high physical exposure and favorable social support, and task performance had high reliability for all conditions except favorable job control. Less than 50% of the physiological measures were reliable for any condition. Based on this, future work should include larger sample sizes and a wider variety of work conditions in order to better characterize exposures and responses to physical and psychosocial aspects of the work environment.

***Keywords*:** test-retest reliability, psychosocial factors, EMG, heart rate, workload, discomfort ratings

## Introduction

The National Research Council has recommended that measurement methods for assessing WMSD risk under various psychosocial and physical demands be improved (National Research Council, 1999). Other researchers (e.g. Hurrell et al., 1998) have also called for improvement of the validity and reliability of methods to measure WMSD risk. One component of improving measurement methods is to provide information on the reliability of measures. In developing a system of evaluating psychosocial and physical exposures in the workplace, measures chosen must have high validity, which includes the component of reliability. Reliable measures are reproducible, meaning they provide similar results when applied repeatedly under the same circumstances (Batterham & George, 2000). In other words, taking a measurement on one day with a highly reliable method means that a researcher can assume a similar result would be obtained under the same conditions but on a different day.

Reliability of physiological measures, such as muscle activity and heart rate and of physical discomfort, have been evaluated in the context of physical demands (e.g. Elfving, Németh, Arvidsson, & Lamontagne, 1999; Gamelin, Berthoin, & Bosquet, 2006; Nordander et al., 2004) but not in response to psychosocial demands to our knowledge. Conversely, measures of perceptions of the psychosocial environment have been assessed for reliability under varying psychosocial conditions (e.g. Karasek et al., 1998) but not in response to physical demands. Psychosocial and physical risk factors are both associated with WMSD risk (Ariëns et al., 2001; Bongers et al., 1993; Buckle, 1997; National Institute of Occupational and Safety Health, 2001), so it is useful to consider the reliability of several classes of measures under varying physical and psychosocial conditions. The reliability of such measures has not been assessed when multiple risk factors are present. Such information on reliability can guide researchers in choosing appropriate measurement tools and in interpreting their results.

The current study tested the reliability of physiological and subjective measurement methods for assessing exposure to physical and psychosocial demands. The study was designed to consider the reliability of measures under different levels of physiological and psychosocial exposure to determine if and to what extent reliability may differ depending on exposure levels.

## Methods

Twenty four participants completed two identical experimental sessions at least two days apart but no more than two weeks apart. Participants were part of a larger study evaluating the effects of psychosocial and physical exposure on physiological and subjective outcomes (Chapter 2). Participants were divided into four groups, each under a different combination of physical and psychosocial exposures:

1. High physical exposure, no psychosocial manipulation: 6 participants
2. Low physical exposure, no psychosocial manipulation: 6 participants
3. Favorable job control, low physical exposure: 6 participants
4. Favorable social support, low physical exposure: 6 participants

Evaluated conditions were chosen to represent a more demanding work environment (high physical exposure) and a more favorable work environment (lower physical exposure, more control over the job (job control), or a better social environment/ social support).

### *Task*

The task was a simulation of an automotive assembly line of alternating tasks: overhead tapping, which represents nut and bolt tightening on the automobiles' chassis, and performing a simple small parts assembly task (screwing and unscrewing nuts and bolts). Further details about the task are provided in Chapter 2. Overhead height was set to the 40% difference between each participant's overhead reach and having the upper arm parallel to the ground with the elbow bent to 90°. Activities were rotated through a 54 s cycle with either a 33% or 66% duty cycle for each task. Participants switched between the 33% and 66% duty cycles every 15 minutes when there was no psychosocial manipulation. Under the favorable job control and favorable social support conditions, participants could change between the 33% and 66% duty cycles as requested as long as half of each trial was spent at each duty cycle level. In addition, participants in the favorable social support condition worked with a partner of their choice and were allowed to chat while completing the tasks. Each trial lasted one hour.

### *Dependent Variables*

Independent variables were divided into three classes: objective measures, subjective ratings, and perceptions of the psychosocial environment. Objective measures included task performance and physiological responses. Physiological responses consisted of EMG of the upper trapezius, middle deltoid, and anterior deltoid on the dominant side and heart rate measures to assess muscle activity, energy expenditure, and, indirectly, mental demand. EMG was recorded during the last 10 s of the tapping and assembly tasks, and recorded variables are denoted as EMG-$mean_T$, EMG-$mean_A$, EMG-$max_T$, and EMG-$max_A$ to distinguish mean and maximum values for tapping (T) and assembly (A) portions of cycles. Heart rate variables included heart rate mean, heart rate variability (the standard deviation of all recorded heart rate), normalized heart rate, and normalized heart rate variability. Subjective workload ratings were captured using the NASA task-load index (NASA-TLX) and Subjective Workload Assessment Technique (SWAT) scales. Discomfort ratings were captured using the Borg-CR10 scale and a body discomfort map (BDM). Several parameters for each trial were created from the Borg ratings including the maximum rating, the difference between the minimum and maximum rating, mean ratings over 33% duty for tapping, mean ratings over 66% duty for tapping, and overall mean rating. BDM ratings were analyzed for the neck, dominant shoulder, and low back. Responses to the psychosocial environment were collected using items from the Job Content Questionnaire. Details on the background, recording, and analysis of these measures are provided in Chapter 2.

### *Participants*

Twenty-four participants completed the experiment with demographic characteristics described in Table 8. All participants in the larger study were informed of the possibility of performing the additional session in the consent form, but participation in this session was described as being additional to the main study and optional. The distribution of age and gender was similar to the main study. Participants were required to perform upper-body strengthening exercise on a regular basis or have recent manual labor experience, and they could not have any medical condition that would limit upper body strength or mobility. To minimize physiological differences between replications, participants were asked to avoid smoking, alcohol, caffeine, and heavy lifting for 24 hours prior to each experiment trial.

Table 8. Participant gender distribution and age.

| Experiment type | Males | Females | Age (SD) |
|---|---|---|---|
| High physical exposure | 4 | 2 | 25.8 (5.0) |
| Low physical exposure | 5 | 1 | 22.3 (3.3) |
| Favorable social support | 3 | 3 | 20.8 (1.8) |
| Favorable job control | 4 | 2 | 26.0 (5.7) |

### *Procedure*

Participants were part of a larger study (Chapter 2) who volunteered to complete an extra experimental session at the conclusion of the original experiment. Participants were informed that they would be repeating one of the four conditions they had already performed. Each trial was scheduled at approximately the same time of day to avoid influences due to circadian rhythm differences. In a preceding orientation session, participants completed informed consent documents and demographics and personality questionnaires. Participants also practiced the experimental task and the use of the Borg scale, viewed pictures of the actual task being simulated, and had their resting heart rate recorded during this session. During the experimental trials, participants were first instrumented with electrodes and the heart rate monitor and completed the NASA-TLX pair-wise comparisons. After completing the MVC exercises, participants performed the task for one hour. At the conclusion of the task, they completed the BDM, NASA-TLX, SWAT, and psychosocial questionnaire.

### *Analysis*

Three issues will be considered in determining reliability of each measure. First, the presence of systematic bias between replications (testing day one or two) was determined using a 2-way mixed-factors ANOVA with "replication" and "participant" as factors ($\alpha = .05$). Second, random error was evaluated through the intraclass correlation coefficient (ICC). ICC determines reliability for a single observation while accounting for any systematic bias. There are six variations of the ICC, and for this research, the variation denoted (3,1) according to the Shrout and Fleiss nomenclature (1979) was used, and is determined as follows:

$$ICC_{(3,1)} = \frac{MS_B - MS_R}{MS_B + (k-1)(MS_R)}$$

Where
$MS_B$ = between-subjects mean square
$MS_R$ = residual mean square (error term)
$k$ = number of observations (current study $k = 2$) (Baumgartner & Chung, 2001)

There is no standard scale for determining what range of ICC values that are considered acceptable (Atkinson & Nevill, 1998), so instead an F-test was performed on the ICC to determine the probability that the ICC was actually zero (meaning no reliability). The significance level was set at $\alpha = .05$, meaning that any parameter having $p < .05$ had high reliability. Third, absolute reliability was assessed using the coefficient of variation (CV). This measure of variability provides a percentage by dividing the typical error (standard error of measurement or SEM) by the grand mean (Batterham & George, 2000). CV was reported rather than SEM so that comparisons could be made across measurement methods. A high CV indicates a high level of error, which may mean that a measurement with a high ICC may not be reliable if error is too high. ICC can over or underestimate reliability (Denegar & Ball, 1993), so ICC and CV should be considered together. ICC values of approximately 0.70 or higher had a significance level of $p < .05$, so this level was classified as high reliability provided that the CV was at an acceptable level. Although defining acceptable CV levels is somewhat arbitrary, 10% seems to be acceptable (Atkinson & Nevill, 1998). All calculations were performed using SPSS 13.0.

## Results

### *Perceived Workload Measures: NASA-TLX and SWAT*

Significant differences between replications were found in five cases of NASA-TLX ratings (Figure 16). Except in one case (effort ratings under low physical exposure), workload ratings were higher in the first replication than the second replication. Specifically, effort was higher on day one under high physical exposure, physical demand was higher on day one under favorable job control, and performance and weighted workload were both higher on day one under favorable social support. SWAT ratings showed no differences between replications for any of the scales.

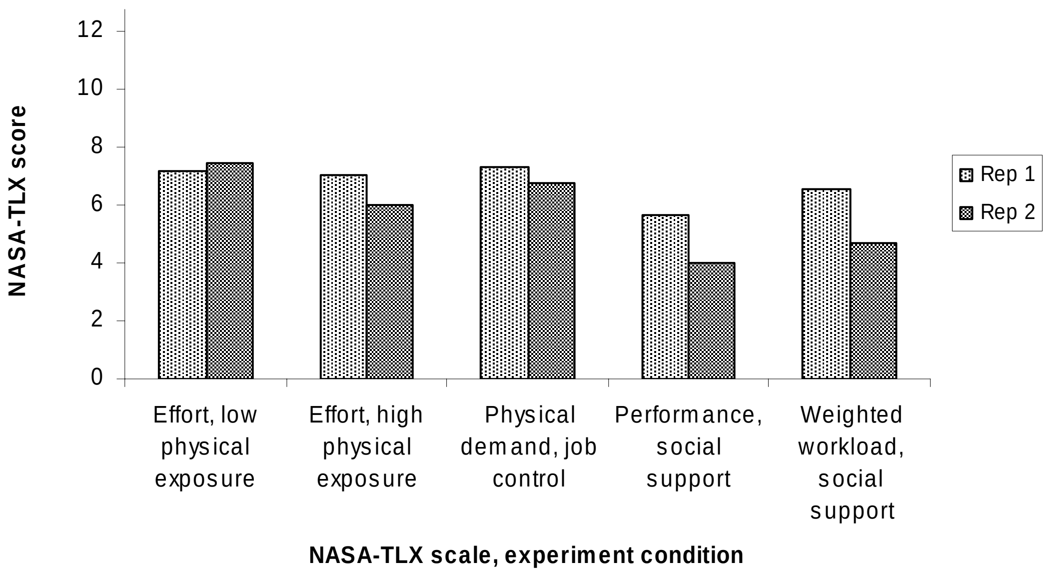


Figure 16. Significant differences ($p < .05$) between replications 1 and 2 for NASA-TLX parameters.

Six of eight parameters of the NASA-TLX were reliable under high physical exposure and under favorable job control conditions (Table 2). The corresponding CVs were relatively lower for the high physical exposure group than for the favorable job control condition. Only two parameters were reliable under favorable social support (mental demand and frustration) and three parameters under low physical exposure (temporal demands, effort, and frustration). The CVs for these ICCs were higher for favorable social support than low physical exposure. SWAT ratings had high ICCs (all significant) except under high physical exposure in which none of the SWAT scales appear to have adequate reliability. Time load only had high reliability in the favorable social support condition. The CVs are in the same range as those in the NASA-TLX with the exception of stress load in the favorable job control condition which had a CV of 53.8%.

Table 9. Perceived workload measures for high and low physical exposure (no psychosocial manipulations).

| | High physical exposure | | | | Low physical exposure | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *NASA-TLX* | | | | | | | | |
| Mental Demand | 0.245 | 0.929 | 0.001* | 19.35% | 0.889 | -0.248 | 0.666 | 68.88% |
| Physical Demand | 0.118 | 0.874 | 0.002* | 11.10% | 0.634 | 0.046 | 0.466 | 34.47% |
| Temporal Demand | 0.899 | 0.359 | 0.243 | 27.23% | 0.672 | 0.869 | 0.007* | 21.39% |
| Effort | 0.028* | 0.761 | 0.004* | 16.59% | 0.037* | 0.814 | 0.003* | 15.07% |
| Performance | 0.298 | 0.686 | 0.041* | 22.59% | 0.526 | 0.647 | 0.066 | 7.96% |
| Frustration | 0.731 | 0.928 | 0.002* | 23.48% | 0.474 | 0.842 | 0.010* | 33.20% |
| Unweighted Workload | 0.897 | 0.804 | 0.020* | 8.53% | 0.799 | 0.533 | 0.132 | 18.54% |
| Weighted Workload | 0.860 | 0.660 | 0.069 | 13.70% | 0.637 | 0.308 | 0.271 | 18.76% |
| *SWAT* | | | | | | | | |
| Time Load | 0.839 | 0.614 | 0.090 | 22.04% | 0.856 | 0.644 | 0.076 | 18.01% |
| Mental Load | 0.396 | 0.296 | 0.263 | 42.23% | 0.640 | 0.781 | 0.024* | 26.27% |
| Stress Load | 0.521 | -0.086 | 0.566 | 91.61% | 0.370 | 0.896 | 0.003* | 25.15% |
| Total Workload | 0.839 | 0.162 | 0.383 | 31.64% | 0.980 | 0.840 | 0.013* | 15.08% |

* ICC significantly reliable when $p < .05$

Table 10. Perceived workload ratings for favorable coworker support and favorable job control (low physical exposure).

| | Favorable coworker support | | | | Favorable job control | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *NASA-TLX* | | | | | | | | |
| Mental Demand | 0.378 | 0.785 | 0.019* | 33.02% | 0.285 | 0.662 | 0.047* | 52.32% |
| Physical Demand | 0.310 | 0.400 | 0.180 | 32.83% | 0.019* | 0.990 | 0.000* | 4.01% |
| Temporal Demand | 0.080 | 0.534 | 0.056 | 24.73% | 0.422 | 0.642 | 0.064 | 37.28% |
| Effort | 0.106 | 0.525 | 0.069 | 30.09% | 0.642 | 0.933 | 0.001* | 17.30% |
| Performance | 0.043* | 0.250 | 0.184 | 21.70% | 0.293 | 0.755 | 0.022* | 33.20% |
| Frustration | 0.421 | 0.835 | 0.010* | 36.15% | 0.625 | 0.466 | 0.166 | 86.99% |
| Unweighted Workload | 0.070 | 0.336 | 0.148 | 20.25% | 0.494 | 0.778 | 0.023* | 28.39% |
| Weighted Workload | 0.039* | 0.243 | 0.183 | 20.44% | 0.498 | 0.769 | 0.025* | 29.70% |
| *SWAT* | | | | | | | | |
| Time Load | 0.933 | 0.786 | 0.025* | 29.34% | 0.404 | 0.052 | 0.457 | 53.84% |
| Mental Load | 0.832 | 0.958 | 0.001* | 16.47% | 0.990 | 0.966 | 0.000* | 20.83% |
| Stress Load | 0.263 | 0.752 | 0.022* | 36.54% | 0.375 | 0.796 | 0.016* | 53.84% |
| Total Workload | 0.489 | 0.884 | 0.005* | 17.86% | 0.222 | 0.831 | 0.008* | 26.51% |

* ICC significantly reliable when $p < .05$

### *Discomfort Ratings: Borg and BDM Ratings*

Maximum Borg ratings and differences between the highest and lowest Borg ratings for the low physical exposure group significantly increased in the second replication (maximum Borg rating replication 1: 4.17 (1.83) and replication 2: 5.17 (2.04), difference replication 1: 3.83 (1.69) and replication 2: 4.92 (2.01)) as shown in Table 11. All Borg parameters had high ICCs for low and high physical exposure groups, but only three of five ICCs were significant for the psychosocial manipulations (Table 12). CVs corresponding to significant ICCs ranged from around 9-31% except for the mean for 33% duty cycle for tapping under high and low physical exposure. Shoulder and low back ratings from the BDM showed high ICCs for low and high physical demand groups, and the corresponding CVs were in a similar range as the Borg rating parameters. Only the shoulder appeared reliable for the favorable social support condition, and only the low back appeared reliable for the favorable job control condition. Both corresponding CVs were less than 20%.

Table 11. Discomfort ratings for high and low physical exposure (no psychosocial manipulations).

| | High physical exposure | | | | Low physical exposure | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *Borg Parameters* | | | | | | | | |
| Maximum Rating | 0.363 | 0.850 | 0.008* | 15.99% | 0.012* | 0.843 | 0.001* | 9.58% |
| Difference | 0.695 | 0.889 | 0.005* | 14.90% | 0.021* | 0.786 | 0.002* | 12.95% |
| 33% Mean | 0.382 | 0.746 | 0.028* | 47.94% | 0.279 | 0.812 | 0.011* | 43.29% |
| 66% Mean | 0.283 | 0.751 | 0.023* | 23.98% | 0.521 | 0.898 | 0.004* | 19.78% |
| Overall Mean | 0.308 | 0.747 | 0.025* | 28.98% | 0.160 | 0.933 | 0.001* | 14.65% |
| *BDM Ratings* | | | | | | | | |
| Neck | 0.497 | -0.020 | 0.515 | 78.88% | 0.259 | 0.520 | 0.103 | 34.86% |
| Shoulder | 0.363 | 0.906 | 0.002* | 13.86% | 0.058 | 0.831 | 0.003* | 25.44% |
| Low back | 0.091 | 0.823 | 0.005* | 38.31% | 0.175 | 0.918 | 0.001* | 33.71% |

* ICC significantly reliable when $p < .05$

Table 12. Discomfort ratings for favorable coworker support and favorable job control (low physical exposure).

| | Favorable coworker support | | | | Favorable job control | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *Borg Parameters* | | | | | | | | |
| Maximum Rating | 0.415 | 0.744 | 0.029* | 24.89% | 0.259 | 0.497 | 0.115 | 33.16% |
| Difference | 0.732 | 0.812 | 0.018* | 24.49% | 0.202 | 0.549 | 0.081 | 39.95% |
| 33% Mean | 0.154 | 0.623 | 0.045* | 31.51% | 0.922 | 0.762 | 0.032* | 52.13% |
| 66% Mean | 0.285 | 0.555 | 0.090 | 28.46% | 0.146 | 0.653 | 0.036* | 28.77% |
| Overall Mean | 0.211 | 0.579 | 0.070 | 27.58% | 0.319 | 0.783 | 0.017* | 30.17% |
| *BDM Ratings* | | | | | | | | |
| Neck | 0.317 | 0.295 | 0.254 | 47.18% | 0.465 | 0.361 | 0.223 | 84.81% |
| Shoulder | 0.363 | 0.915 | 0.002* | 13.86% | 0.135 | 0.444 | 0.115 | 33.16% |
| Low back | 0.809 | 0.624 | 0.084 | 59.10% | 0.175 | 0.926 | 0.001* | 19.05% |

* ICC significantly reliable when $p < .05$

### *Physiological Measures: EMG, Heart Rate, and Task Performance*

Only two measures of muscle activity were significantly different between replications: middle deltoid EMG-mean$_A$ under low physical exposure (replication 1: 0.68% (0.44%) and replication 2: 0.90% (0.85%)) and anterior deltoid EMG-mean$_A$ under favorable social support (replication 1: 1.79% (0.91%) and replication 2: 1.20% (0.84%)) as shown in Table 13 and Table 14. Heart rate and task performance showed no differences between replications. Under high physical exposure, only muscle activity of the anterior deltoid appeared to be reliable whereas heart rate and task performance had high ICCs and fairly low CVs (≤ 20%). Low physical exposure had opposite results. All mean muscle activity measures appeared highly reliable (with the exception of a high CV for anterior deltoid EMG-mean$_A$), and no heart rate measures appeared reliable. Similarly, task performance was reliable under low physical exposure.

Table 13. Reliability measures of physiological variables for high and low physical exposure (no psychosocial manipulations).

| | High physical exposure | | | | Low physical exposure | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *EMG* | | | | | | | | |
| Trap EMG-mean$_T$ | 0.905 | 0.482 | 0.163 | 21.44% | 0.479 | 0.797 | 0.018* | 15.87% |
| Mid EMG-mean$_T$ | 0.610 | 0.661 | 0.064 | 24.12% | 0.274 | 0.961 | 0.000* | 8.60% |
| Ant EMG-mean$_T$ | 0.490 | 0.949 | 0.001* | 10.47% | 0.246 | 0.952 | 0.000* | 13.52% |
| Trap EMG-mean$_A$ | 0.484 | 0.549 | 0.110 | 35.63% | 0.831 | 0.973 | 0.000* | 24.47% |
| Mid EMG-mean$_A$ | 0.488 | 0.506 | 0.134 | 55.96% | 0.017* | 0.950 | 0.000* | 20.91% |
| Ant EMG-mean$_A$ | 0.349 | 0.823 | 0.011* | 38.93% | 0.524 | 0.902 | 0.003* | 58.22% |
| Trap EMG-max$_T$ | 0.536 | 0.638 | 0.071 | 45.15% | 0.308 | 0.519 | 0.110 | 24.15% |
| Mid EMG-max$_T$ | 0.100 | 0.293 | 0.197 | 26.05% | 0.178 | 0.898 | 0.002* | 12.87% |
| Ant EMG-max$_T$ | 0.175 | 0.790 | 0.011* | 17.43% | 0.361 | 0.852 | 0.007* | 18.47% |
| Trap EMG-max$_A$ | 0.310 | 0.704 | 0.082 | 39.41% | 0.707 | 0.439 | 0.185 | 43.18% |
| Mid EMG-max$_A$ | 0.222 | 0.593 | 0.086 | 43.96% | 0.100 | 0.312 | 0.183 | 29.82% |
| Ant EMG-max$_A$ | 0.298 | 0.260 | 0.298 | 57.35% | 0.760 | 0.332 | 0.259 | 37.74% |
| *Heart Rate Measures* | | | | | | | | |
| Mean | 0.351 | 0.107 | 0.418 | 13.64% | 0.555 | -0.291 | 0.709 | 14.56% |
| Variability | 0.082 | 0.799 | 0.010* | 11.27% | 0.856 | -0.263 | 0.676 | 20.42% |
| Normalized Mean | 0.784 | 0.785 | 0.043* | 20.73% | 0.859 | -0.367 | 0.736 | 67.27% |
| Normalized Variability | 0.427 | 0.861 | 0.015* | 14.22% | 0.763 | 0.174 | 0.372 | 18.85% |
| *Task Performance* | 0.892 | 0.913 | 0.003* | 2.74% | 0.992 | 0.967 | 0.000* | 0.89% |

* ICC significantly reliable when $p < .05$
Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid

Under favorable social support conditions, mean muscle activity of the middle and anterior deltoid appeared to be highly reliable during tapping and somewhat reliable during assemblies because CVs were higher despite ICC measures that met the set criterion (Table 14). Only one heart rate measure had high reliability, but performance had high reliability as well. Trapezius activity and heart rate variability had high reliability in favorable job control conditions.

Table 14. Reliability measures of physiological variables for favorable coworker support and favorable job control (low physical exposure).

| | Favorable coworker support | | | | Favorable job control | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| *EMG* | | | | | | | | |
| Trap EMG-mean$_T$ | 0.781 | 0.226 | 0.335 | 25.54% | 0.703 | 0.853 | 0.010* | 26.10% |
| Mid EMG-mean$_T$ | 0.833 | 0.957 | 0.001* | 16.08% | 0.841 | 0.396 | 0.217 | 27.00% |
| Ant EMG-mean$_T$ | 0.239 | 0.662 | 0.043* | 19.64% | 0.329 | 0.337 | 0.226 | 17.76% |
| Trap EMG-mean$_A$ | 0.933 | 0.552 | 0.123 | 51.99% | 0.578 | 0.767 | 0.027* | 32.41% |
| Mid EMG-mean$_A$ | 0.381 | 0.762 | 0.024* | 56.37% | 0.600 | 0.825 | 0.014* | 42.28% |
| Ant EMG-mean$_A$ | 0.041* | 0.546 | 0.036* | 41.10% | 0.806 | 0.233 | 0.331 | 77.01% |
| Trap EMG-max$_T$ | 0.357 | -0.276 | 0.727 | 55.30% | 0.251 | 0.542 | 0.114 | 17.72% |
| Mid EMG-max$_T$ | 0.623 | -0.055 | 0.541 | 70.63% | 0.666 | 0.297 | 0.280 | 33.77% |
| Ant EMG-max$_T$ | 0.472 | 0.686 | 0.073 | 15.61% | 0.430 | -0.451 | 0.828 | 18.29% |
| Trap EMG-max$_A$ | 0.437 | 0.690 | 0.047* | 20.85% | 0.411 | 0.962 | 0.000* | 12.39% |
| Mid EMG-max$_A$ | 0.367 | 0.037 | 0.469 | 89.53% | 0.057 | 0.760 | 0.007* | 28.49% |
| Ant EMG-max$_A$ | 0.610 | 0.893 | 0.011* | 23.94% | 0.634 | 0.124 | 0.407 | 85.55% |
| *Heart Rate Measures* | | | | | | | | |
| Mean | 0.894 | 0.707 | 0.050* | 7.84% | 0.679 | -0.337 | 0.728 | 9.32% |
| Variability | 0.792 | 0.385 | 0.223 | 33.31% | 0.265 | 0.790 | 0.015* | 33.88% |
| Normalized Mean | 0.475 | -0.060 | 0.547 | 26.41% | 0.712 | -0.098 | 0.570 | 36.17% |
| Normalized Variability | 0.875 | 0.319 | 0.270 | 31.69% | 0.306 | 0.739 | 0.027* | 35.54% |
| *Task Performance* | 0.009 | 0.680 | 0.004* | 1.62% | 0.855 | 0.360 | 0.242 | 6.20% |

* ICC significantly reliable when $p < .05$
Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid

### *Psychosocial Questionnaire*

There were no significant differences between replications for any psychosocial category under any experimental condition (Table 15, Table 16). Only skill discretion had high reliability under high physical exposure, but skill discretion, decision authority, and psychological work demands showed high reliability for low physical exposure although the CV for psychological work demands was rather high (38.5%). All six categories analyzed under favorable social support were highly reliable with CVs less than 25%. Finally, skill discretion and physical exertion had high reliability under favorable job control conditions.

Table 15. Reliability of the psychosocial questionnaire for high and low physical exposure (no psychosocial manipulations).

| | High physical exposure | | | | Low physical exposure | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| Skill Discretion | 0.296 | 0.831 | 0.009* | 8.16% | 0.082 | 0.927 | 0.000* | 9.98% |
| Decision Authority | 0.856 | 0.422 | 0.200 | 29.73% | 0.741 | 0.914 | 0.003* | 14.81% |
| Psychological Work Demands | NA | | | | 0.092 | 0.852 | 0.011* | 38.49% |
| Physical Exertion | 1.000[a] | 0.661 | 0.100 | 16.44% | 0.749 | 0.562 | 0.148 | 14.63% |
| Physical Loads | 0.465 | 0.375 | 0.214 | 21.91% | 0.695 | 0.706 | 0.048 | 23.84% |
| Supervisor Support | NA | | | | NA | | | |
| Coworker Support | NA | | | | NA | | | |

* ICC significantly reliable when $p < .05$
[a] Data from 4 participants only
NA: insufficient data to calculate values

Table 16. Reliability of the psychosocial questionnaire for favorable coworker support and favorable job control (low physical exposure).

| | Favorable coworker support | | | | Favorable job control | | | |
|---|---|---|---|---|---|---|---|---|
| | Between-replications significance | ICC | ICC significance | CV | Between-replications significance | ICC | ICC significance | CV |
| Skill Discretion | 0.793 | 0.912 | 0.003* | 10.68% | 0.363 | 0.792 | 0.017* | 14.08% |
| Decision Authority | 0.741 | 0.886 | 0.006* | 11.40% | 0.184 | 0.660 | 0.054 | 17.45% |
| Psychological Work Demands | 0.296 | 0.856 | 0.006* | 24.05% | 0.495 | 0.690 | 0.110 | 33.20% |
| Physical Exertion | 1.000 | 0.747 | 0.037* | 13.09% | 0.741 | 0.817 | 0.017* | 12.88% |
| Physical Loads | NA | | | | 0.363 | -0.238 | 0.696 | 46.81% |
| Supervisor Support | 0.363 | 0.828 | 0.011* | 4.38% | NA | | | |
| Coworker Support | 0.296 | 0.762 | 0.021* | 5.46% | NA | | | |

* ICC significantly reliable when $p < .05$
NA: insufficient data to calculate values

## Discussion

This study assessed the reliability of several objective measures (task performance, muscle activity, and heart rate) and subjective measures (NASA-TLX and SWAT ratings, Borg and BDM ratings, and a psychosocial questionnaire) when used in differing physical and psychosocial exposure. Task performance showed high reliability under all conditions except favorable job control. Muscle activity and heart rate measures in general had low reliability when viewed as a percentage of parameters with high reliability, but the highest percentage of high-reliability measures occurred under low physical exposure. Workload and discomfort ratings had highest levels of reliability under low and high physical exposure, and favorable job control also showed high reliability for workload ratings. The psychosocial questionnaire had the highest reliability under favorable social support.

Very few variables showed significant differences between replications, and those variables that did show differences were small enough that they did not appear to be practically significant. This suggests that learning effects were minimal and that neither physiological nor perceptual responses were influenced by any systematic effects.

CV values were slightly higher than those found in other studies, which could be due to the lower number of participants (six per condition) and the time between sessions (up to two weeks). Sood et al. (2007) found good reliability (0.86 or higher) and low CV values (19.6% or lower) for Borg exertion ratings during an intermittent overhead task nearly identical to the task used in the current study. Elfving et al. (1999) found a CV of 16.5% for Borg ratings in a study of back muscle fatigue. The reliability measures in both studies are comparable to the CVs found for the low and high physical exposure in the current study, but they are lower than the CVs found for the two psychosocial manipulations in the current study. Nordander (2004) reported CVs ranging from 8-33% for upper body RMS EMG signals, and the current study had a range of 10-58% for CVs corresponding to high ICC values. Elfving et al. (1999) tested 11 subjects a total of six times between one and 15 days apart, Nordander et al. (2004) tested six participants three times on separate days approximately seven days apart, and Sood et al. (2007) had 10 participants complete two trials each between two and seven days apart. The studies considered here all had larger numbers of observations collected over a short time range which may resulted in lower variance in observed data compared to the current study. Most CV values corresponding with significant ICC values were 30% or lower. Therefore, variables with ICCs with $p$-values less than .05 and CVs or 30% or lower were considered to have high reliability in the current study.

Level of reliability for each dependent variable depended on the experimental condition presented. Although each of the four conditions had between 21 and 26 of the 42 dependent variables showing high ICCs, different variables showed high reliability under different conditions. Table 17 presents the percentage of total items that had high reliability for each measurement category under each experiment condition. No single dependent variable was consistently reliable in all four conditions. The highest reliabilities of dependent variables may have resulted under conditions for which the measure was originally intended. Physiological measures had the highest percentage of reliable measures under low physical exposure and not when the psychosocial environment was manipulated. Likewise, discomfort measures, which were originally developed to assess physically demanding work, showed highest reliability for high and low physical exposure. The favorable social support condition provided the most realistic work environment of the four conditions because it included the component of having coworkers. Consequently, favorable social support showed the highest percentage of reliable measures from the psychosocial questionnaire.

Table 17. Percentage of dependent variables with high ICC values ($p < .05$) and CV < 30% for each experiment condition

| | Workload ratings | Discomfort ratings | Physiological measures | Task performance | Psychosocial questionnaire |
|---|---|---|---|---|---|
| High physical | 50% | 63% | 31% | 100% | 25% |
| Low physical | 42% | 63% | 44% | 100% | 60% |
| Favorable social support | 25% | 38% | 31% | 100% | 100% |
| Favorable job control | 50% | 25% | 19% | 0% | 40% |

The percentage of reliable measures was approximately 50% overall, but was lower for physiological measures. EMG mean values tended to have higher reliability than maximum values, indicating that maximum readings should be interpreted with caution. Previous studies on EMG reliability have shown mixed results. One study of the reliability of trunk muscle activity did not find good reliability, although it should be noted that median power frequency parameters were evaluated rather than RMS measures (Elfving et al., 1999). A study of intermittent overhead work, which used a task almost identical to the current study's high physical exposure condition, found high reliability in only two of six muscle activity measures using RMS EMG data (Sood et al., 2007). Another study using median power frequency parameters of low back extensors found good reliability of EMG measures, (Dederling, Roos af Hjelmsäter, Elfving, Harms-Ringdahl, & Németh, 2000). RMS values for leg muscles had high reliability (ICC = 0.83 to 0.98) in a dynamic extension exercise (Larsson et al., 1999), and a study of reliability for a heavy assembly task found fairly low CV values (8% to 33%) for shoulder and forearm muscles (Nordander et al., 2004).

Heart rate measures have been shown to be reliable under certain conditions in previous studies. Heart rate is highly repeatable under the same levels of physical work (Åstrand & Rodahl, 1986) but not under mentally demanding tasks (Backs, 1998). This is somewhat supported by the current results in that high physical exposure had three of four heart rate measures show high reliability, while the only measure (mean heart rate) with high reliability was found for favorable social support. In a review of workload measures, Miyake (1997) concluded that heart rate variability has low reliability when breathing patterns are not controlled, and Kamath & Fallen (1993) have also noted changes in variability due to respiratory sinus arrhythmia. Heart rate variability may have been less reliable under the current study's conditions as breathing was not controlled. However, controlling breathing patterns would have limited the external validity of the experiment (i.e. breathing cannot be controlled in the workplace).

Previous studies suggest that the NASA-TLX and SWAT are stable in test-retest conditions (Battiste & Bortolussi, 1988; Reid & Nygren, 1988), although the NASA-TLX has lower between-subjects variation than SWAT (Battiste & Bortolussi, 1988). However, the results of the current study were again dependent on the experimental condition, and reliability of specific workload parameters may have been affected by the absolute level of workload in the experimental environment. For instance, the low physical exposure and favorable job control conditions may have been perceived as having extremely low mental demands making it difficult to choose a rating between 'low' and 'high' on the NASA-TLX scale. Under high physical exposure, the only 'demanding' part of the task was holding the heavier tool which could have made the SWAT ratings, none of which relate directly to physical loads, difficult for the same reasons.

Only one area of the body that was rated on the BDM was reliable under each condition. A different area (neck, shoulder, or low back) was reliable for each condition even though the same task was completed in each condition (with the exception of using the heavier drill under high physical exposure). This may be due to changes in posture over the course of each trial and between trials as participants learned to adjust their body position as discomfort and fatigue increased. Borg-CR10 discomfort ratings were reliable for high and low physical exposure but became less reliable once psychosocial manipulations were added in the other two conditions. Previous studies have found high reliability for rating discomfort of the back during physical exercise (Dederling et al., 2000; Elfving et al., 1999). Dederling noted the need to practice using the Borg scale to improve reliability, and this suggestion was followed in the current experiment by providing a guided practice session during the experiment orientation. Also, since the repeated trials usually occurred during the third, fourth, or fifth sessions of the entire experiment, variance due to a familiarization period with the Borg scale was minimized.

The questions used in the psychosocial questionnaire have shown high agreement within occupations across countries as part of the Job Content Questionnaire (JCQ) in a collection of studies (Karasek et al., 1998). Test-retest reliability of this questionnaire is also high (Karasek & Theorell, 1990). The current study found fairly low reliability of the psychosocial questionnaire categories with the exception of the favorable social support group. This was most likely due to a lack of external validity of the experimental environment. The JCQ was designed for workplace settings which would expose workers to multiple physical and psychosocial factors, but in the current study conditions were manipulated so as to test only one factor in each condition. Therefore, participants were unable to answer questions in several categories, and other questions that were answered may not have been understood as originally intended due to the limitations in exposure.

Reliability measures may have been influenced by changes in trial execution for the favorable social support and job control trials between repetitions one and two. Since these participants had control over changing between 33% and 66% duty cycles, the changes were not required to be at the same times in the repeated trial. For instance, one participant in the favorable job control condition chose to change from 66% to 33% only at the midpoint of the trial during the first repetition but chose to switch between 66% and 33% every eight trials during the second repetition. Two of six from each group performed the repeated trial with the same sequence of duty cycle changes, so the majority chose to complete the repeated trial in a different manner.

## Conclusions

One component of validity is reliability, so WMSD exposure measurement methods should be reliable if they are to be considered a valid way of assessing risk. While all measures chosen for the current study have shown some evidence of reliability in past research, using these measures under various psychosocial and physical exposure levels may not result in acceptable reliability.

In this study, different psychosocial and physical conditions revealed differing levels of test-retest reliability for physiological and subjective outcome measures that may predict WMSD risk. Workload measures and discomfort ratings appear reliable under high levels of physical exposure but not under psychosocial manipulations. Physiological measures in general were highly reliable for less than 50% of the measurement parameters chosen. The psychosocial questionnaire was reliable under favorable social support conditions but less reliable under high physical exposure and favorable job control. Future work should investigate the reliability of proposed outcome measures using a larger sample size and a wider variety of work conditions before applying measures to studies investigating the effects of physical and psychosocial exposure on WMSD risk. At present, the following recommendations can be made for using these measurement methods under multiple exposure conditions:

- Workload ratings may be used for multiple exposures but used only with caution when social support is being manipulated.
- Discomfort ratings may be used with confidence under physical exposures only.
- Psychosocial questionnaires directed at exposures present in the work environment may be used with confidence due to a high percentage of measures showing adequate reliability.
- Physiological measures should only be used with great caution as they showed reliability in fewer than half of the measures.

# Chapter 5: Validity of a psychosocial questionnaire in a simulated manufacturing environment using factor analysis


## Abstract

The objective of this study was to determine the number of psychosocial factors perceived in a simulated manufacturing environment using a 50-item questionnaire consisting of items from two psychosocial assessment instruments, the Job Content Questionnaire and the Quality of Worklife survey. The experiment involved performing intermittent overhead work and small parts assemblies while manipulating physical demands and psychosocial exposure. Participants were exposed to one of four psychosocial dimensions (job control, job demands, social support, or time pressure) at both favorable and unfavorable levels. Factor analysis revealed five underlying variables comprised of four to nine items and seven additional items that created individual variables. The five factors were interpreted as skill discretion and decision authority, stress level and supervisor support, physical demands, quality of coworker support, and decision-making support. All factors were internally reliable (Cronbach's $\alpha \geq .79$). The factors closely matched JCQ categories, although some JCQ categories were combined in the variables found by the current analysis. These results suggest that psychosocial questionnaires can be used successfully in experimental environments to distinguish perceptions regarding psychosocial dimensions.



***Keywords:*** psychosocial questionnaire, factor analysis, job demands, social support, job control, time pressure

## Introduction

Questionnaires that assess the psychosocial environment have been used for several decades in both longitudinal and cross-sectional studies concerned with the health and well-being of employees. Psychosocial questionnaires are constantly being adapted to reflect changes in the workplace (i.e. globalization and the move to more service-sector jobs) and to increase relevance to specific occupations (Hurrell et al., 1998). However, psychosocial questionnaires have been used rarely in experimental settings to assess the effects of psychosocial manipulations.

Two widely-used questionnaires are the Job Content Questionnaire (JCQ: Karasek et al., 1998) and the Quality of Worklife Survey (QWL) developed by NIOSH (most recent version: 2002). The JCQ has been used in occupational settings to measure perceptions of the work environment, and results of this questionnaire have been used to link heart disease and possibly WMSDs with high strain/low control jobs (e.g. Ariëns et al., 2001; Punnett et al., 2004; Wahlström et al., 2004). JCQ scales have fairly good internal reliability (Cronbach's $\alpha > .70$) although the reliability of the psychological work demands scale ($\alpha = .63$) may be lower (Landsbergis et al., 2000). However, individual items from this questionnaire may cross several categories of psychosocial dimensions depending on interpretation. In a previous study of blue and white collar workers, a factor analysis of JCQ items found four prominent factors, although 10 factors were originally tested (MacDonald et al., 2001). Some items may have influences in several categories of psychosocial factors, and some items may be too vague to assess accurately the psychosocial factor being targeted. For instance, an item on "working fast" may be considered by a respondent to represent physical demands in the context of manufacturing work or psychological work demands in a busy office environment.

The NIOSH Quality of Worklife survey (QWL) is another tool used to assess work environments, with 76 items in the complete version. The current QWL draws approximately half of the items from a previous survey, the Quality of Employment Survey developed at the University of Michigan (Landsbergis et al., 2000). Since 1977, these questions have been distributed across the United States every two years as part of an ongoing research effort to track work organization concerns (National Institute for Occupational Safety and Health, 2002). The QWL covers several more categories than the JCQ, although there are fewer questions per category. Many of the categories between the QWL and JCQ do overlap, making comparisons possible.

Psychosocial questionnaires such as the JCQ and QWL have been used extensively in occupational settings to assess the psychosocial environment. They have not been used in experimental settings, so their sensitivity to experimental manipulations of psychosocial factors is not known. The purpose of this study was to determine categories of psychosocial demands experienced in response to experimentally manipulated levels of these demands. Responses to a psychosocial questionnaire developed from the JCQ and QWL were analyzed using factor analysis to determine underlying variables. If a psychosocial questionnaire is sensitive to different psychosocial dimensions in the current study, it may be used in future laboratory-based studies to assess perceptions of the psychosocial environment and potentially be used to make inferences to the work environment. Because the experimental setting exposed participants to a limited number of psychosocial factors, it was expected that fewer variables would emerge using factor analysis when compared to the number of factors in the original JCQ and QWL.

## Methods

This study is a sub-analysis of a larger study presented in Chapter 2. The methods are briefly summarized here; please refer to Chapter 2 for more complete details.

### *Experimental Design*

A 2x2x4 full-factorial mixed-factors design was used to expose participants to different levels of physical exposure (high or low), psychosocial exposure (favorable or unfavorable), and one of four types of psychosocial dimensions (job control, social support, job demands, or time pressure). Forty-eight participants completed the study, 12 participants per psychosocial dimension. More complete details of the experiment including demographics and inclusion criteria for the participants are provided in Chapter 2.

### *Task*

The simulated automotive manufacturing job involved an intermittent overhead tapping task and a small parts assembly task which consisted of tightening and loosening nuts and bolts. The tapping task was performed at a constant rate of 80 beats per minute (regulated by a metronome), and there were no set requirements for the assembly task other than to perform the task continuously. Each cycle lasted 54 s, and each task was performed for 33% or 66% of the cycle (duty cycle) using an auditory signal to direct participants to switch between the two tasks. Participants continued with this sequence for a one hour trial.

### *Independent Variables*

Physical exposure was manipulated at high and low levels by varying the weight of the tool used for the overhead tapping task (0.50 kg for low exposure and 1.25 kg for high exposure). Psychosocial exposure was manipulated at favorable and unfavorable levels by the presence or absence of a psychosocial dimension. The job demands condition was introduced through additional promptings to maintain high accuracy throughout the trial at the unfavorable level. The presence of the time pressure dimension added a concurrent mental task (math questions) to the simulated manufacturing task, which was considered the unfavorable level. To provide a more favorable level of job control, the presence of job control meant that participants could choose when to switch between 33% and 66% duty cycle for the overhead tapping task as long as half of each trial was performed at each length. Social support participants worked in self-selected pairs during all four trials, and during the favorable social support condition, pairs could chat during the trial and decide together when to switch between 33% and 66% duty cycle of the tapping task.

### *Psychosocial Questionnaire*

A 50-item questionnaire was developed to assess perceptions of the psychosocial environment in a laboratory study. The items were drawn from two sources: the Job Content Questionnaire (JCQ: Karasek, 1985) and the Quality of Worklife Questionnaire (QWL: National Institute for Occupational Safety and Health, 2002). Thirty items from the JCQ were taken from the following categories: skill discretion (6 items), decision authority (3 items), psychological work demands (8 items), physical job demands, which was sub-divided into exertion (3 items) and isometric loads (2 items), supervisor support (4 items), and coworker support (4 items). All items from the full-length JCQ from those categories were included in the current questionnaire. Questions from other categories that were not applicable to the experiment, such as job insecurity, were not included. Twenty questions added from the Quality of Worklife questionnaire were intended to strengthen the categories that were taken from the JCQ. The entire questionnaire is included in Appendix I.

### *Procedures*

To complete the experiment, participants attended a 30-minute orientation session followed by four trials that were between two and 14 days apart. The four trials used each combination of physical and psychosocial exposure level for one psychosocial dimension. During the orientation session, participants filled out informed consent forms, demographics and personality questionnaires, practiced the simulated manufacturing job and discomfort rating scale, and viewed photographs of an actual overhead assembly line in an automotive plant. Participants were told that the experiment was a simulation of this type of work. The pictures provided context for the trials to be considered actual jobs.

During the trials, EMG of dominant side shoulder muscles, heart rate, and discomfort ratings were collected as described in (Chapter 2) as part of assessing physiological and subjective responses to the work environment. Along with other questionnaires on workload (NASA-TLX and SWAT) and discomfort (BDM) given at the end of each trial, participants completed an electronic version of the psychosocial questionnaire. Participants working individually were instructed to skip any questions involving coworker interactions that did not apply to them.

### *Analysis*

All items from the questionnaire were used in the analysis except for one item on workgroup contributions to society. This item was confusing to many participants due to the term "workgroup" because many worked individually, and had participated in a simulated work task in which nothing was produced. Interpretations of the question varied widely, so the item was excluded from analysis.

The 15 items on coworker support could only be answered by the participants in the social support manipulation, and these questions were analyzed separately for these participants only. The remaining 34 items were used in the factor analysis of the psychosocial factors excluding coworker support. Cronbach's alpha was calculated to ensure internal consistency of the questions from each section. Exploratory factor analyses were then used for the coworker support items and the other 34 items of the questionnaire separately to determine which questions formed unique factors. Varimax, quartimax, and equamax rotations were performed on the data to improve separation of factors through stronger loadings on single factors, and eigenvalues of ≥1 (Kaiser's rule) were used as the cutoff for examining unique factors. By choosing a criterion for factor loading of .50 or greater, each question could be associated with a single underlying factor using the quartimax rotation.

Cronbach's alpha (non-standardized) was calculated for the items within each factor derived from the factor analysis to determine internal consistency of each factor. Alpha levels of .70 or greater were considered to have good internal reliability (Nunnally, 1978).

## Results

Cronbach's alpha for the 34 items excluding coworker support was .86, indicating good internal consistency of the items. Eight factors had eigenvalues > 1 that explained 64.9% of the variance observed in responses for these items. Quartimax rotation provided the best separation of variables, yielding three main variables appearing to differentiate skill discretion and decision authority, stress level and supervisor support, and physical demands including the quality and pace of work (Table 18). The remaining five factors included a single question in each, but each factor explained an additional 3-4% variance. Six individual items had no correlations ≥ .50 with any factor and were excluded.

Table 18. Factor loadings for psychosocial questionnaire items not including coworker support.

| Psychosocial Factors (64.9% variance explained) | | Loadings |
|---|---|---|
| Skill Discretion and Decision Authority (n = 9, α = .864, 15.8% variance explained) | | |
| 6* | Lots of say about what happens on job | 0.71 |
| 7 | Freedom to decide how to do work | 0.66 |
| 8 | Make decisions on own | 0.76 |
| 40 | Requires learning new things | 0.74 |
| 41 | Can use skills and abilities | 0.79 |
| 44 | Requires creativity | 0.71 |
| 45 | Requires high level of skill | 0.59 |
| 46 | Get to do a variety of things | 0.60 |
| 47 | Opportunities to develop skills and abilities | 0.77 |
| Stress and Supervisor Support (n = 7, α = .855, 13.9% variance explained) | | |
| 16 | Treated respectfully | 0.83 |
| 17 | Trust management | 0.84 |
| 18 | Receive enough equipment and help | 0.60 |
| 21 | Supervisor concerned about welfare of employees | 0.81 |
| 22 | Supervisor pays attention to what I have to say | 0.81 |
| 23 | Supervisor helps get job done | 0.66 |
| 43 | How often is work stressful? | 0.50 |
| Physical Demands (n = 7, α = .789, 13.6% variance explained) | | |
| 11 | Too much work to do everything well | 0.52 |
| 33 | Requires rapid and continuous physical activity | 0.66 |
| 34 | Require regular repetitive or forceful hand movements or awkward postures | 0.70 |
| 36 | Requires lots of physical effort | 0.72 |
| 38 | Requires working for long periods with body in awkward positions | 0.77 |
| 39 | Requires working for long periods with head or arms in awkward positions | 0.70 |
| 48 | Requires working hard | 0.50 |
| Information Availability (n = 1, 4.82% variance explained) | | |
| 42 | Have enough information to get job done | 0.78 |
| Feedback from Supervisor (n = 1, 4.54% variance explained) | | |
| 31 | Receive feedback from supervisor on job performance | 0.69 |
| Interruptions (n = 1, 4.47% variance explained) | | |
| 1 | Tasks often interrupted before completed requiring attention later | 0.79 |
| Clarity of Expectations (n = 1, 4.11% variance explained) | | |
| 15 | Know what is expected of me | 0.81 |
| Repetitive Work (n = 1, 3.65% variance explained) | | |
| 35 | Involves lots of repetitive work | 0.67 |
| Excluded items | | |
| 2 | Job is very hectic | |
| 10 | Requires working fast | |
| 13 | Not asked to do excessive amount of work | |
| 14 | Have enough time to get job done | |
| 37 | Requires lifting or moving heavy loads | |
| 49 | Requires long periods of intense concentration on task | |

* Refers to questionnaire item Appendix I.

The remaining 15 items regarding coworker support had good reliability (α = .851). The items concerning coworker support could be grouped into four factors that explained 64.8% of observed variance according to the factor analysis. Quartimax rotation provided the best separation of variables into quality of coworker support, support in decision-making, presence of conflicting demands from coworkers, and level of feedback from coworkers (Table 19). One item was not correlated strongly with any factor and was excluded.

Table 19. Factor loadings for coworker support items in the psychosocial questionnaire.

| | Psychosocial Factors: Coworker Support (64.8% variance explained) | Loadings |
|---|---|---|
| Quality of Coworker Support (n = 8, α = .841, 26.9% variance explained) | | |
| 20* | Coworkers can be relied on for help | 0.65 |
| 24 | Supervisor successful in getting people to work together | 0.52 |
| 25 | Coworkers are competent at their jobs | 0.58 |
| 26 | Coworkers take a personal interest in me | 0.79 |
| 27 | Hostility or conflict from coworkers | 0.61 |
| 28 | Coworkers are friendly | 0.75 |
| 29 | Coworkers encourage working together | 0.67 |
| 30 | Coworkers helpful in getting jobs done | 0.69 |
| Decision-Making Support (n = 4, α = .872, 21.7% variance explained) | | |
| 3 | Often take part with others in making decisions | 0.84 |
| 4 | Participate with others in setting how things are done at work | 0.84 |
| 5 | Work group makes decisions democratically | 0.80 |
| 9 | Influence over decisions in work group | 0.75 |
| Presence of Conflicting Demands (n = 1, 8.96% variance explained) | | |
| 19 | Freedom from conflicting demands made by other people | 0.80 |
| Feedback from Coworkers (n = 1, 7.26% variance explained) | | |
| 32 | Coworkers provide feedback on job performance | 0.68 |
| Exlcuded items | | |
| 12 | Enough people to get all work done | |

* Refers to questionnaire item Appendix I.

## Discussion

The current study sought to determine the number of factors that could be distinguished using a psychosocial questionnaire following exposure to four psychosocial dimensions in a simulated manufacturing setting. Factor analysis of all questionnaire items, other than those concerning coworker support, revealed eight factors that explained over 64% of the variance observed with acceptable reliability (α = .79 or higher for each factor). Coworker support items had four factors that explained over 64% of the variance observed with good reliability (α = .84 or higher). The internal consistency of the factors (α ≥ .79) was higher than reported for the JCQ scales (α ≥ .63, Landsbergis et al., 2000), and this may have been due to using an experimental setting in which specific psychosocial dimensions were manipulated while other sources of variance were controlled. Psychosocial questionnaires used in field studies may have lower internal reliability due to several influences that were controlled in the current experimental environment.

The factors approximately matched the categories of the JCQ. Skill discretion and decision authority were combined into one factor which is expected since these two are subcategories of "decision latitude" on the JCQ (Karasek, 1985). Physical demands were distinguished clearly from non-physical aspects of work although the JCQ divides physical demands into "exertion" and "loads." The current study did not involve lifting or other forceful motions, so only one category of physical demands resulted. In fact, the question concerning lifting heavy loads did not load significantly on any factor in the current experiment. MacDonald et al. (2001) found that decision latitude and physical demands loaded on the same factor in their study of blue and white collar workers, and they called this factor "organizational constraint" (p. 710). The same results were not found in the current study possibly due to the defined nature of the tasks. Even under conditions where participants could choose when to switch between the 33% and 66% duty cycles for each task, the total physical requirements remained equivalent in each trial. In actual work environments, employees with more favorable levels of decision latitude may be able to reduce physical demands through scheduling breaks as needed or by asking other employees for assistance, which would then link physical demands with decision latitude. Stress and supervisor support were combined into one factor in the current study, which could be because participants associated poor levels of supervisor support with higher stress. Coworker support items loaded on more than one factor as a quality factor and decision support factor. Karasek's scoring method combines these two areas of coworker support, but the current study may have increased the distinction since the social support manipulation involved different levels of decision authority for the pairs.

Seven items failed to load on any factor with a correlation of .50 or higher, most likely due to confusion about the meaning of the questions within the context of the simulated work environment. The requirements for the two tasks were defined rigidly, making certain items not applicable such as "excessive work" and "enough people to get work done." Poor or inaccurate results from psychosocial questionnaires have been found in other studies in which questionnaire items were not appropriate for the occupation being studied. For instance, in a study of occupations involving high customer demands such as mental health nurses and bank tellers, capturing the exact nature and effects of customer demands was challenging due to differences between occupations (Holte & Westgaard, 2002). Questions that do not accurately or completely capture perceptions of the psychosocial environment could lead to potentially misleading conclusions about the effects of psychosocial factors. Therefore, the context in which people respond to psychosocial questionnaires should be considered when choosing items to include in the instrument.

The results of this study showed that a psychosocial questionnaire based on two commonly used instruments (JCQ and QWL) could be used in an experimental setting to differentiate perceptions of psychosocial exposure. Participant responses could be divided into categories assessing skill discretion and job authority, stress level and supervisor support, physical demands, quality of coworker support, and decision-making support. The psychosocial questionnaire using these JCQ and QWL items may be used in future laboratory-based studies to verify psychosocial manipulations and to record participant perceptions of simulated work environments.

# Chapter 6: Conclusions

Work-related musculoskeletal disorders (WMSDs) continue to have high prevalence rates in many occupations (Bureau of Labor Statistics, 2005), but the causes and pathways of WMSD development are not fully understood. Physical, psychosocial, and individual factors are thought to contribute to WMSD development (National Institute of Occupational and Safety Health, 2001), but research is needed to develop measurement methods that can assess these risk factors simultaneously.

The current research accomplished several steps towards understanding the effects of various exposures on WMSD risk factors and evaluating methods that measure risk factors. First, an experiment was conducted to evaluate the effects of several types of psychosocial and physical exposure on physiological and subjective outcomes for a simulated manufacturing environment. Second, several analyses on different aspects of validity of the measurement methods chosen were conducted. Convergent and discriminant validity of measurement methods were considered in an attempt to create an efficient set of measurements for evaluating exposure, and a small investigation into the critical sample size needed to estimate risk was conducted. The reliability of the proposed outcome measures was evaluated, and factor analysis of a questionnaire for evaluating perceptions of psychosocial factors was performed.

## *Summary of Outcomes*

The first study provided supporting evidence for a link between psychosocial factors, physical stressors, and individual differences with physiological WMSD risk factors as presented in the proposed model of WMSD development (Figure 1). By using an experimental design, gender, Type A personality tendencies, physical exposure, and four psychosocial dimensions (job control, job demands, time pressure, and social support) were shown to have significant effects on outcomes that have been linked with increased WMSD risk. These outcomes include increased muscle activity, increased heart rate, high levels of perceived discomfort, and high workload ratings. The specific pathways connecting these three risk factors were not investigated thoroughly, although the lack of significant interactions between physical and psychosocial exposure levels suggested that there was not a moderating relationship for these factors in the present study. Also, the link between WMSD risk factors and WMSD development could not be investigated with the present experimental design.

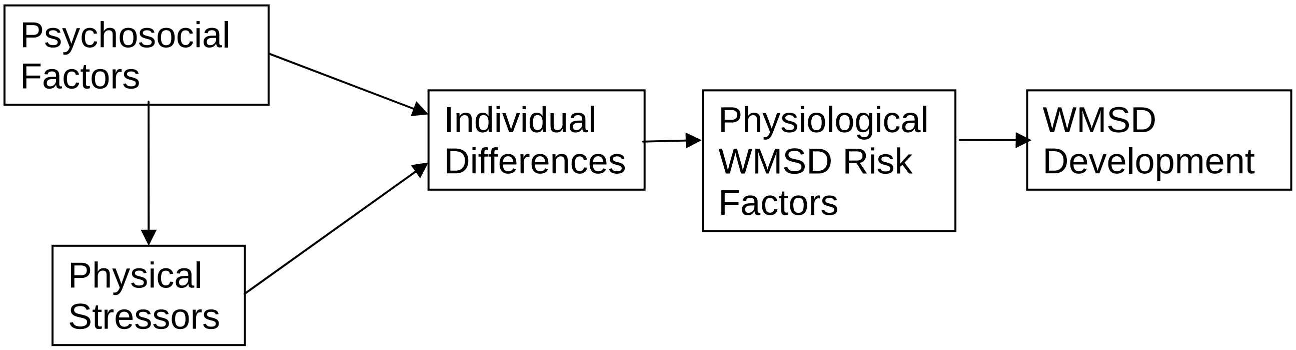


Figure 17. Proposed model of WMSD development

The most prominent results of this study were that favorable social support conditions resulted in the lowest muscle activity during active work activities and higher levels of job demands led to the highest shoulder discomfort ratings along with the lowest heart rate variability of any psychosocial manipulation.

The main conclusion of the first study was that physical and psychosocial exposure contributed to WMSD risk factors in this manufacturing setting. Therefore, analysis of work environments should include physical and psychosocial components when considering WMSD risk. Specifically, social interaction should be a priority over working in isolation to potentially reduce muscle activity, and excessive pressure from management (demonstrated in the job demands dimension) to achieve high performance should be optimized to reduce WMSD risk.

The remaining studies were extended analyses of the measurement methods chosen for the first study. The goal of the second study was to determine an efficient set of measurement methods that could be used to estimate risk efficiently. To do this, convergent and discriminant validity for each measurement method was assessed to retain methods that provided unique information related to the work environment and to minimize overlap between methods that provided similar information. An analysis of the sample size needed to obtain estimates with adequate significance and power levels was also conducted, although the methodology for this analysis was only in the preliminary stage. For the given manufacturing environment, EMG from the trapezius, heart rate mean and variability, NASA-TLX ratings of workload, Borg ratings, and the psychosocial questionnaire were determined to be the best set of measurement methods for assessing WMSD risk. Participant sample sizes of at least 24 (50% of the total experiment population) appeared to provide an adequate estimate of outcome measures.

The third study determined the test-retest reliability of the outcome measures chosen on a subset of participants who completed an extra repeated experimental trial. Although the measures chosen have shown adequate reliability on their own and under specific exposures, these measures have not been evaluated for reliability under multiple risk factor exposure. The results of this study showed that different psychosocial and physical conditions had differing levels of test-retest reliability for physiological and subjective outcome measures that may predict WMSD risk. Workload measures and discomfort ratings appeared reliable under high levels of physical demands but not under psychosocial manipulations. Physiological measures in general were highly reliable for less than 50% of the measurement parameters chosen. The psychosocial questionnaire was reliable under favorable social support conditions but less reliable under high physical demands and favorable job control. Psychosocial exposures may influence the reliability of outcome measures, so measures should be chosen carefully based on their ability to produce results that are repeatable across observations.

The objective of the final study was to determine the number of psychosocial dimensions experienced through participant responses to the psychosocial questionnaire. This questionnaire consisted of 30 items from the Job Content Questionnaire (JCQ) and 20 items from the Quality of Worklife Survey (QWL). The questionnaire was designed to cover seven categories: skill discretion, decision authority, psychological work demands, physical exertion, physical isometric loads, supervisor support, and coworker support. The factor analysis revealed five major categories: skill discretion and job authority, stress and supervisor support, physical demands, quality of coworker support, and decision-making support plus seven questions that created significant factors on their own. The results confirmed that participants were able to distinguish psychosocial dimensions in the work environment, and this questionnaire may be used in experimental settings in the future to verify psychosocial manipulations and measure perceptions of the psychosocial environment.

When considering these studies as a whole, it may be concluded that physical and psychosocial factors are influential in determining WMSD risk, but the measurement methods used to assess WMSD risk should be used with caution. In particular, multiple methods may not be necessary when they overlap, yet a sufficient array of methods should be used to capture all aspects of the work environment. Methods chosen may show different results under various circumstances as evidenced by changes in reliability and in perceived factors of the psychosocial environment.

### *Future Directions*

There are several directions for future research. First, several lingering issues surrounding measurement methods should be addressed. A more complex analysis of sample size requirements is needed, perhaps following a simulation approach used by Mathiassen and colleagues (2002). There are also indications that objective observations of the "micro" environment (e.g. recording specific events) may be more highly related to health outcomes than subjective reports (Theorell & Hasselhorn, 2005). Measurement methods to assess WMSD risk may need to include these types of measurements in the future.

Second, more thorough analyses of the effects of various psychosocial and individual factors should be conducted. In the current research, gender and personality type both showed significant effects on outcome measures, but they were not investigated further at the present time. Other studies have found that individual factors do increase WMSD risk significantly (e.g. Jensen, Ryholt, Burr, Villadsen, & Christensen, 2002; e.g. Schneider, Schmitt, Zoller, & Schiltenwolf, 2005; Werner et al., 2005b), so information on how these pathways operate is needed. Potential interactions between psychosocial dimensions are another area to be investigated. The current study manipulated only one psychosocial dimension, but more dimensions need to be included in experimental designs to increase external validity as work environments are not limited to a single exposure type.

Third, the measurement methods used in this research should be extended to different occupations and to field settings both to further validate the methods and to assess exposure across different work environments. Last, these methods can be used to begin investigations into quantifying acceptable and unacceptable levels of exposure by linking outcome measures to reported WMSD prevalence rates.

### *Final Conclusions*

The current research laid groundwork for measuring the magnitude of physical and psychosocial exposure simultaneously in occupational settings. The research supported epidemiological studies which suggest that both physical and psychosocial exposure contributes to increased WMSD risk factors and provided analysis on choosing appropriate measurement methods. This knowledge will enable practitioners to focus interventions and designs to those factors in the work environment that contribute significantly to increased exposure and thereby more effectively reduce WMSD risk. Specifically, engineering design can benefit from this work by using the following recommendations:

- Both physical and psychosocial exposures should be measured in work environments to detect potentially harmful levels of exposure.
- Opportunities for social interaction should be part of workplace design to potentially reduce muscle activity rather than having individuals work in isolation.
- Excessive pressure from management to achieve high performance should be minimized to reduce WMSD risk.
- The following set of measures can be used to estimate a wide range of WMSD risk exposure of both subjective and physiological outcomes
    - NASA-TLX ratings of perceived workload
    - EMG of the dominant-side trapezius during ‘on’ and ‘off’ duty portions of the task
    - Heart rate recording for heart rate mean and heart rate variability
    - Borg-CR10 ratings of discomfort for the shoulder and potentially other areas of the body
    - Psychosocial questionnaire (based on JCQ items)
- Workload ratings may be used for multiple exposures but used only with caution when social support is being manipulated.
- Discomfort ratings may be used with confidence under physical exposures only.

- Psychosocial questionnaires directed at exposures present in the work environment may be used with confidence due to a high percentage of measures showing adequate reliability.
- Physiological measures should only be used with great caution as they showed reliability in fewer than half of the measures.
- Psychosocial questionnaires designed for use in occupational settings can be used to estimate psychosocial perceptions of experimental-based work simulations.

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## Appendix A: Informed Consent

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants in Research Projects

Project Title: Development of a Comprehensive Measurement Method for Assessing WMSD Risk in Occupational Settings

Investigators: Laura E. Hughes, Dr. Maury Nussbaum, Ali Haskins, Vimala Raman

**Purpose**

This study investigates potential causes of work-related musculoskeletal disorders (WMSDs) such as low back pain, shoulder injuries, carpal tunnel syndrome, etc. that may be reported from a wide variety of occupations ranging from a typists to construction workers. The main object of this study is to develop and test a comprehensive method of collecting data on exposure to individual, physical, and psychosocial (work environment) risk factors in WMSD development that can be applied to occupational settings. This data collection method will allow researchers to obtain information on physical and psychosocial exposure and individual characteristics and relate this information to subsequent reports or perceived workload, discomfort, and WMSD symptoms.

**Procedures**

The experiment has a total of 5 sessions. The first session will last approximately 30 minutes and will be used as an orientation to the procedures of the study and to collect demographic information. The following four sessions will last approximately 1.5 hours each for a total time commitment of 6.5 hours. In addition to these five sessions, you may be given the opportunity to complete a fifth experimental trial of 1.5 hours.

In the orientation session you will first complete the informed consent form followed by a demographic and medical history questionnaire. An experimenter will give you verbal instructions on how to put on the heart rate monitor, which consists of a strap worn around the chest. You will put on the heart rate monitor by yourself in the restroom. An experimenter will visually inspect the monitor’s placement when you return and provide verbal instructions if you need to correct any problems with the monitor’s placement. Please inform the experimenters if you would prefer a matched-gender experimenter to do this inspection (An experimenter will ask your preference, which will be maintained for all experiments.) When you return you will begin a five-minute period of sitting quietly to obtain resting heart rate. Two personality questionnaires will be administered during the five-minute rest period with no interruptions. The experimenter will record your resting heart rate as the lowest rate during any 15-second increment during the five minutes. The experiment will be terminated if the your heart rate exceeds 85% of your maximum heart rate (220 - Age, from Eastman Kodak Company, 2004) at any point during the experiment. You will then be trained on the experimental task and be given the opportunity to practice the procedures for two 10-minute sessions.

You will be asked not to smoke, consume alcohol, or perform heavy lifting for 24 hours prior to each experimental session to ensure quality EMG recordings.

The experimental task consists of two activities that simulate work on an assembly line in an automotive facility: overhead tapping (simulating nut and bolt tightening on the underbody of a chassis) and performing a simple small parts assembly task (screwing and unscrewing nuts from bolts). Overhead tapping will be simulated by attaching a computer keyboard to an adjustable-height overhead tapping surface and having you tap specifically numbered keys on the keyboard using non-powered drills of different weights (0.5kg or 1.25kg). The activities will be rotated through a 54 s cycle with either a 33% or 66% duty cycle for each task, and a 6-second intermission will be allowed at the end of each cycle to change work positions. All task parameters are based on task analysis of actual work tasks (Nussbaum, Sood, & Hager, 2002). During the actual experiment you will switch between the 33% and 66% duty cycles every 15 minutes, and each trial will last a total of one hour.

The control level for all psychosocial factors types will require you to tap at 80 beats/min with 87% accuracy, which is based on an experiment using a similar task (Nussbaum et al., 2002), and to complete 1-2 small parts assemblies during each rotation. You may have additional demands depending on the psychosocial factor manipulation to which you are exposed which include being allowed to adjust the time spent at each duty cycle level, solving simple arithmetic problems (subtraction of two-digit numbers or multiplication of single and double digit numbers), working with another person to divide the work requirements, and reaching a higher level of accuracy and precision in the work tasks.

During the four experimental sessions (and fifth session, if applicable), you will put on the heart rate monitor, complete EMG setup (electrode application, 15 minute stabilization, and MVE tests), and review procedures. EMG data for the middle deltoid, anterior deltoid, and trapezius on the dominant side will be collected by using 10 mm, rectangular Ag/AgCl pregelled bipolar disposable electrodes. These electrodes will cause you no harm, but the skin will be prepared for electrode application by shaving, slightly abrading, and cleaning the skin with alcohol to minimize impedance. You will also be asked to wear your own tank top or a t-shirt we provide that is altered to allow access to the top of the shoulder for EMG electrode placement. The locations of all of the electrodes are at the top of the arm or along the top of your shoulder up to the neck, so there will be no need to remove any clothing during electrode placement. An experimenter will apply two electrodes at each muscle, and an additional ground electrode will be placed on the clavicle (collarbone).

Maximum Voluntary Exertions (MVEs) will be collected before every experimental session by having you perform a separate exercise to elicit a maximum isometric contraction for each muscle. The procedure for each exercise will have you contract your muscle as much as possible for 5 seconds in a ramp-up ramp-down contraction procedure for a series of trials with 45 seconds of rest between each trial.

You will then complete each combination of physical risk factor exposure and the appropriate psychosocial factor. At the end of the session you will be asked to complete the Nordic questionnaire, the NASA-TLX and SWAT ratings, and a psychosocial environment questionnaire. You will be asked to rate their level of discomfort using the Borg CR10 scale every 2 minutes and given the option to stop a task if your perceived discomfort reaches a high level or if you wish to discontinue the activity.

**Risks and Benefits**
There is not more than minimal risk associated with this study that would not be found in daily office activities. Temporary discomfort or fatigue in the arms or shoulder may be experienced; however, you are encouraged to discontinue usage of the equipment if you experience extreme discomfort. By participating in this study, you will be assisting the investigators in possibly identifying factors that may contribute to the development of work-related musculoskeletal disorders in the arms or shoulders due to performing manufacturing-type tasks under different conditions.

**Video Recording**
If you work with another person during the trial, your experimental trials, excluding the setup procedures, will be video and audio recorded to assist the experimenters in data collection. Only your participant number will be associated with the videotapes, and if any images are viewed by anyone other than the investigators, your face will be blurred. However, your body and voice will not be altered. These images may be used for presentation purposes. If you do not wish to be recorded, you can still participate. You will be given that option on the signature page.

**Extent of Anonymity and Confidentiality**
Your anonymity will be kept in the strictest of confidence. No names will appear on questionnaires or surveys, and a coding system will be used to associate your identity with questionnaire answers, data, and video and audio recordings. All information will be collected in a file and locked when not being used.

**Informed Consent**
You will receive two informed consent forms to be signed before beginning the experiment; one copy will be for your records and the other copy will be obtained for the investigator's records.

**Compensation**
You will be compensated at a rate of $8 per hour for your participation, including the optional additional session.

**Freedom to Withdraw**
You are free to withdraw from this study at any time without penalty or reason stated, and no penalty or withholding of compensation will occur for doing so.

**Approval of Research**
The Department of Industrial and Systems Engineering has approved this research, as required, by the Institutional Review Board (IRB) for Research Involving Human Participants at Virginia Polytechnic Institute and State University.

**Participant's Responsibilities**
I voluntarily agree to participate in this study. I have the following responsibilities:

1. To read and understand all instructions.

2. To answer questions, surveys, etc. honestly and completely.
3. To work under the conditions specified by the experimenter to the best of my ability.
4. To inform the investigator of any discomforts I experience immediately.
5. Be aware that I am free to ask questions at any point.

**Participant's Permission**
I have read and understand the Informed Consent and conditions of this research project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I reserve the right to withdraw at any time without penalty. I agree to abide by the rules of this project.

____________________________________________________
Participant’s Signature Date

____________________________________________________
Experimenter’s Signature Date

The research team for this experiment includes Dr. Babski-Reeves and Laura Hughes. Team members may be contacted at the following address and phone number:

Dr. Maury Nussbaum
Grado Department of Industrial and Systems Engineering
250 Durham Hall
Blacksburg, VA 24061
540.231.6053

Laura Hughes
Grado Department of Industrial and Systems Engineering
559 Whittemore Hall
Blacksburg, VA 24061
540.230.1033 (h)

In addition, if you have any detailed questions regarding your rights as participant in University Research, you may contact the following individual:

Dr. David Moore
IRB Chair
Assistant Vice Provost Research Compliance
Director, Animal Resources
1880 Pratt Drive, Suite 2006
Blacksburg, VA 24061
(540) 231-9359

**Signature Page**

I have read the description of this study and understand the nature of the research and my rights as a participant. I hereby consent to participate with the understanding that I may discontinue participation at any time if I choose to do so.

Participant's Signature Date

Printed Name

Experimenter's Signature Date

**Participant's Permission for Video and Audio Recording**

I have read and understand the manner in which videos will be used for subsequent presentation of information related to this study. I understand that my face will not be identifiable because it will be obscured or blocked. I understand that my body and voice will not be altered. I grant permission to researchers to present this information as necessary in the manner described on this form.

Participant's Signature Date

Experimenter's Signature Date

I **do not** grant permission to researchers to present this information as necessary in the manner described on this form. I do not want any digitized images of my body or recorded voice to be used for presentation purposes.

Participant's Signature Date

Experimenter's Signature Date

## Appendix B: Demographic Survey

Instructions: Please answer the following questions. You may skip any questions you do not wish to answer.

1. Age: _____
2. Gender: _____ Male _____ Female
3. Dominant Hand: _____ Right _____ Left
4. Ethnicity:
   _____ Caucasian (European-American)
   _____ African-American (Black)
   _____ Hispanic/Latino
   _____ Asian-American
   _____ Other (Please specify: ___________________________ )

5. Are you a native English speaker? (Is English your first language?) _____ Yes _____ No
6. Have you had a significant injury to the shoulder area (dislocation, separation, fracture, tendonitis, rotator cuff tear, impingement syndrome, etc.)? If yes, explain and specify right, left, or both shoulders.

_____________________________________________________________________________________

7. Have you had a significant injury to any body part other than the shoulder? If yes, explain.

_____________________________________________________________________________________

8. Do you have any condition that limits the mobility or strength of your elbow, wrist, hand, or fingers? (Note: if you are currently pregnant or have recently experienced rapid weight gain, please mark “yes”)

_____Yes _____No If yes, please specify: ________________________________________

9. Present Occupation (Part/Full time, Starting Date) ________________________________________
10. How many hours per week? ______________
11. Description of Occupation ____________________________________________________________
12. Do you have previous manual labor experience? (Description, starting date, length of employment)

_____________________________________________________________________________________

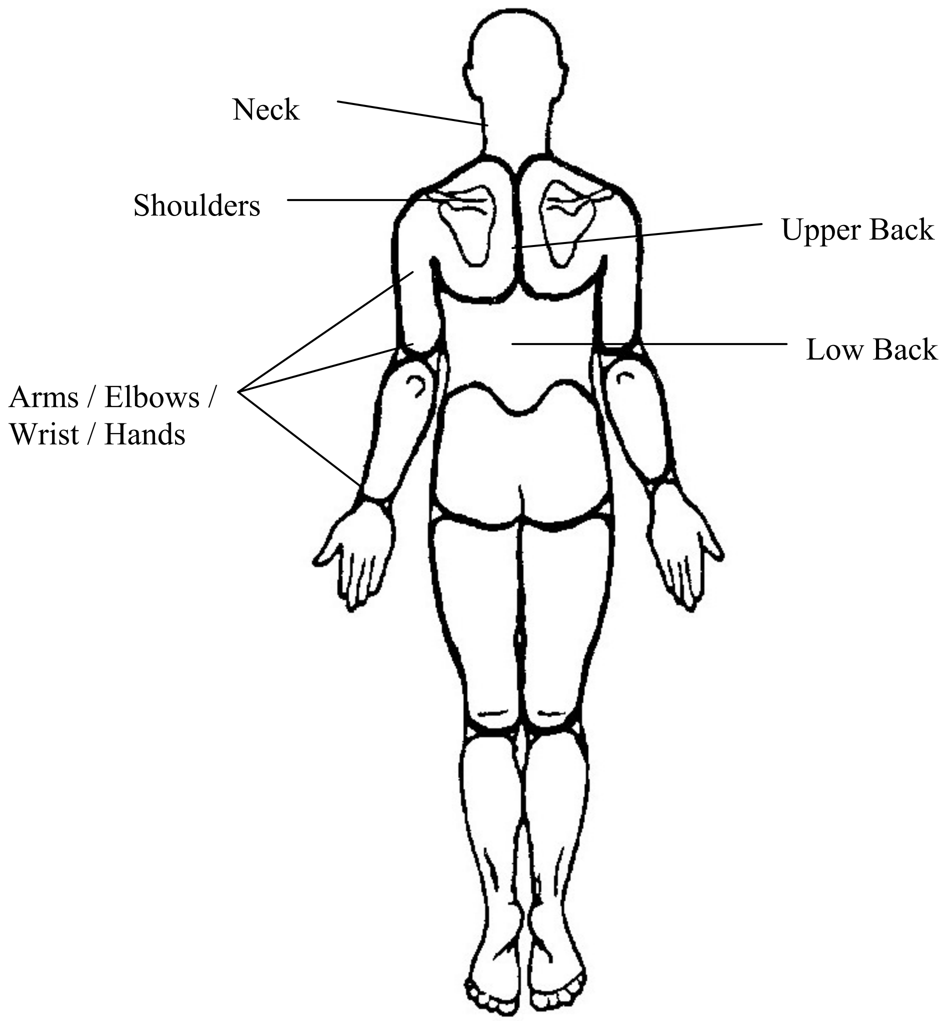
13. How would you describe your general fitness level?

   ☐ Minimal ☐ Moderate ☐ Average ☐ Above Average ☐ Maximal

14. How many hours a week do you work out?_________
15. Since when have you been working out? ____________
16. What type(s) of exercise do you perform regularly? (i.e. weight-lifting, running, etc.)

_____________________________________________________________________________________

**Discomfort Survey**




| Have you had Pain, Ache, Discomfort, Injuries in: | In the past 12 months | | In the last 7 days | |
|---|---|---|---|---|
| | When did it occur | Duration It lasted | When did it occur | Duration It lasted |
| Neck | | | | |
| Shoulders | | | | |
| Arms / Elbows / Wrist / Hands | | | | |
| Upper Back | | | | |
| Low Back | | | | |

## Appendix C: Student Jenkins Activity Survey

In the questions which follow there are no "correct" or "incorrect" answer; the important thing is to answer each question AS IT IS TRUE FOR YOU. Your answers are considered strictly confidential—for research purposes only. In addition, your responses are valuable only if you complete each and every question, so be sure to complete every question.

1. Is your everyday life filled mostly by
   a. Problems needing a solution?
   b. Challenges needing to be met?
   c. A rather predictable routine of events?
   d. Not enough things to keep me interested or busy?

2. When you are under pressure or stress, what do you usually do?
   a. Do something about it immediately
   b. Plan carefully before taking any action

3. Ordinarily, how rapidly do you eat?
   a. I'm usually the first one finished
   b. I eat a little faster than average
   c. I eat at about the same speed as most people
   d. I eat more slowly than most people

4. Has your spouse or a friend ever told you that you eat too fast?
   a. Yes, often
   b. Yes, once or twice
   c. No, no one has ever told me this

5. When you listen to someone talking, and this person takes too long to come to the point, how often do you feel like hurrying the person along?
   a. Frequently
   b. Occasionally
   c. Almost never

6. How often do you actually "put words in the person's mouth" in order to speed things up?
   a. Frequently
   b. Occasionally
   c. Almost never

7. If you tell your spouse or a friend that you will meet somewhere at a definite time, how often do you arrive late?
   a. Once in a while
   b. Rarely
   c. I am never late

8. Do most people consider you to be
   a. Definitely hard-driving and competitive?
   b. Probably hard-driving and competitive?
   c. Probably more relaxed and easygoing?
   d. Definitely more relaxed and easygoing?

9. Nowadays, do you consider yourself to be
   a. Definitely hard-driving and competitive?
   b. Probably hard-driving and competitive?
   c. Probably more relaxed and easygoing?
   d. Definitely more relaxed and easygoing?

10. Would your spouse (or closest friend) rate you as
    a. Definitely hard-driving and competitive?
    b. Probably hard-driving and competitive?
    c. Probably more relaxed and easygoing?
    d. Definitely more relaxed and easygoing?

11. Would your spouse (or closest friend) rate your general level of activity as
    a. Too slow—should be more active?
    b. About average—busy much of the time?
    c. Too active—should slow down?

12. Would people you know well agree that you have less energy than most people?
    a. Definitely yes
    b. Probably yes
    c. Probably no
    d. Definitely no

13. How was your temper when you were younger?
    a. Fiery and hard to control
    b. Strong but controllable
    c. I almost never get angry

14. How often are there deadlines in your courses?
    a. Daily or more often
    b. Weekly
    c. Monthly or less often
    d. Never

15. Do you ever set deadlines or quotas for yourself in courses or other things?
    a. No
    b. Yes, but only occasionally
    c. Yes, regularly

16. In school, do you ever keep two jobs moving forward at the same time by shifting back and forth rapidly from one to the other?
    a. No, never
    b. Yes, but only in emergencies
    c. Yes, regularly

17. Do you maintain a regular study schedule during vacations such as Thanksgiving, winter break, and spring break?
    a. Yes
    b. No
    c. Sometimes

18. How often do you bring your work home with you at night, or study materials related to your courses?
    a. Rarely or never
    b. Once a week or less
    c. More than once a week

19. When you are in a group, how often do the other people look to you for leadership?
    a. Rarely
    b. About as often as they look to others
    c. More often than they look to others

In the next two questions, please compare yourself with the average student at your university.

20. In sense of responsibility, I am
    a. Much more responsible
    b. A little more responsible
    c. A little less responsible
    d. Much less responsible

21. I approach life in general
    a. Much more seriously
    b. A little more seriously
    c. A little less seriously
    d. Much less seriously

## Appendix D: Bortner Rating Scale

Participant #:_____

**Instructions:** Each pair represents two extremes. Please mark with a vertical line where you fall, at either extreme or somewhere in the middle.

| | | |
|---|---|---|
| Never Late | \|————\| | Casual about appointments |
| Not competitive | \|————\| | Very competitive |
| Anticipates what others are going to say (nods, interrupts, finishes for them) | \|————\| | Good listener, hears others out |
| Always rushed | \|————\| | Never feels rushed, even under pressure |
| Can wait patiently | \|————\| | Impatient when waiting |
| Goes "all out" | \|————\| | Casual |
| Takes things one at a time | \|————\| | Tries to do many things at once, thinks about what one is going to do next |
| Emphatic in speech (may pound desk) | \|————\| | Slow, deliberate talker |
| Wants good job recognized by others | \|————\| | Only cares about satisfying self no matter what others may think |
| Fast (eating, walking, etc.) | \|————\| | Slow doing things |
| Easy going | \|————\| | Hard driving |
| "Sits" on feelings | \|————\| | Expresses feelings |
| Many interests | \|————\| | Few interests outside work/school |
| Satisfied with job | \|————\| | Ambitious |

**Appendix E: Borg-CR10 Discomfort Rating Scale**

| | |
|---|---|
| 0 | Nothing at all |
| 0.5 | Extremely weak (just noticeable) |
| 1 | Very weak |
| 2 | Weak (light) |
| 3 | Moderate |
| 4 | Somewhat strong |
| 5 | Strong (heavy) |
| 6 | |
| 7 | Very strong |
| 8 | |
| 9 | |
| 10 | Extremely strong (almost max) |

**Appendix F: Body Discomfort Map (BDM)**

## Discomfort Survey

Please circle Yes or No for each body part to indicate if you are experiencing discomfort currently, and give a rating using the Borg Scale used earlier if you answer Yes.

Neck: Yes / No
Rating: _____

Left Shoulder: Yes / No
Rating: _____

Right Shoulder: Yes / No
Rating: _____

Upper Back: Yes / No
Rating: _____

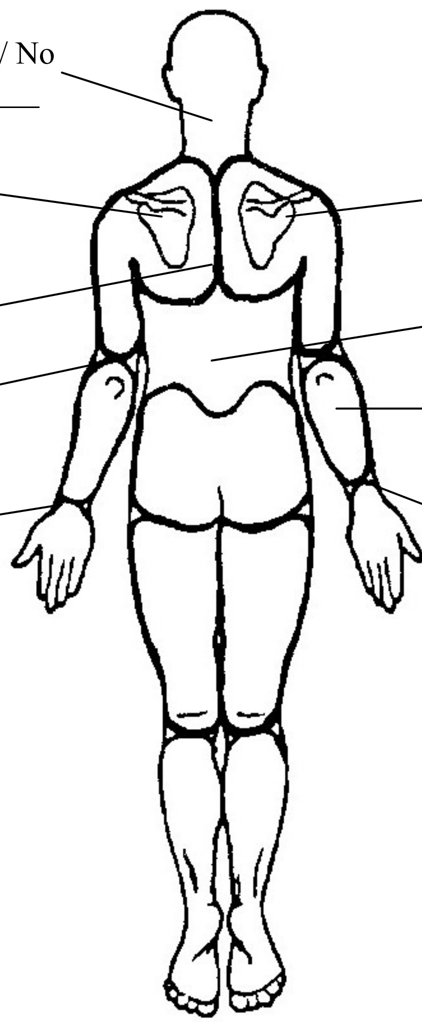
Low Back: Yes / No
Rating: _____

Left Arm: Yes / No
Rating: _____

Right Arm: Yes / No
Rating: _____

Left Wrist / Hand:
Yes / No
Rating: _____

Right Wrist / Hand:
Yes / No
Rating: _____



Are you currently experiencing discomfort anywhere else on your body as a result of the task? Please indicate where and give a rating of the discomfort.

_______________________________________________________________________________

_______________________________________________________________________________

_______________________________________________________________________________

## Appendix G: NASA-TLX

NASA-TLX Descriptions
*Refer to these descriptions as you complete the Workload Rating sheet.*

**Mental Demand**: *Low/High* How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

**Physical Demand**: *Low/High* How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

**Temporal Demand:** *Low/High* How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

**Performance**: *Excellent/Poor* How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

**Effort**: *Low/High* How hard did you have to work (mentally and physically) to accomplish your level of performance?

**Frustration Level**: *Low/High* How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

For each pair of demands, circle the demand that you feel will be a greater source of workload in the task you are about to complete. Please refer to the description sheet for each demand if needed.

| | |
|---|---|
| Physical Demand | Mental Demand |
| Temporal Demand | Mental Demand |
| Temporal Demand | Physical Demand |
| Performance | Physical Demand |
| Temporal Demand | Frustration |
| Temporal Demand | Effort |
| Performance | Mental Demand |
| Frustration | Mental Demand |
| Effort | Mental Demand |
| Frustration | Physical Demand |
| Effort | Physical Demand |
| Temporal Demand | Performance |
| Performance | Frustration |
| Performance | Effort |
| Effort | Frustration |

# Workload Rating

Instructions: Place a vertical mark on each scale that represents the magnitude of each factor in the task you just performed.

Mental Demand

Low High

Physical Demand

Low High

Temporal Demand

Low High

Performance

Excellent Poor

Effort

Low High

Frustration Level

Low High

## Appendix H: SWAT Ratings

Form D

Participant # _____

Trial # _____

**Time Load, Mental Effort Load, and Stress Load Ratings**

| | | |
|---|---|---|
| Often have spare time. Interruptions or overlap among activities occur infrequently or not at all. | Occasionally have spare time. Interruptions or overlap among activities occur frequently. | Almost never have spare time Interruptions or overlap among activities are very frequent, or occur all the time. |
| Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention. | Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required. | Extensive mental effort and concentration are necessary. Very complex activity requiring total attention. |
| Little confusion, risk, frustration, or anxiety exists and can be easily accommodated. | Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance. | High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required. |

## Appendix I: Psychosocial Questionnaire

Work Perceptions

*Please complete the statements assuming the task is your "job," any other participants are your "coworkers," and the experimenters are your "supervisors."*

* JCQ Items used in Chapter 2, 3, and 4

| | | | | | | |
|---|---|---|---|---|---|---|
| *1 | My tasks are often interrupted before they can be completed, requiring attention at a later time. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *2 | My job is very hectic. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 3 | In your job, how often do you take part with others in making decisions that affect you? | Often | Sometimes | Rarely | Never | NA |
| 4 | How often do you participate with others in helping set the way things are done on your job? | Often | Sometimes | Rarely | Never | NA |
| 5 | My work group or unit makes decisions democratically. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 6 | I have a lot of say about what happens on my job. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 7 | I am given a lot of freedom to decide how to do my own work. | Very true | Somewhat true | Not too true | Not at all true | NA |
| *8 | My job allows me to make a lot of decisions on my own. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *9 | I have significant influence over decisions in my work group or unit. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *10 | My job requires that I work very fast. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 11 | I have too much work to do everything well. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 12 | How often are there not enough people or staff to get all the work done? | Often | Sometimes | Rarely | Never | NA |
| *13 | I am not asked to do an excessive amount of work. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *14 | I have enough time to get the job done. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 15 | On my job, I know exactly what is expected of me. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 16 | At the place where I work, I am treated with respect. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 17 | I trust the management at the place where I work. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 18 | I receive enough equipment and help to get the job done. | Very true | Somewhat true | Not too true | Not at all true | NA |
| *19 | I am free from the conflicting demands that other people make of me. | Very true | Somewhat true | Not too true | Not at all true | NA |

| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | The people I work with can be relied on when I need help. | Very true | Somewhat true | Not too true | Not at all true | NA |
| *21 | My supervisor is concerned about the welfare of those under him/her. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *22 | My supervisor pays attention to what I say. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *23 | My supervisor is helpful in getting the job done. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *24 | My supervisor is successful in getting people to work together. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *25 | People I work with are competent in doing their jobs. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *26 | People I work with take a personal interest in me. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *27 | I am exposed to hostility or conflict from the people I work with. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *28 | People I work with are friendly. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *29 | The people I work with encourage each other to work together. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *30 | The people I work with are helpful in getting the job done. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *31 | I get information/feedback from my supervisor about how well I do my job. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *32 | I get information/feedback from my coworkers about how well I do my job. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *33 | My work requires rapid and continuous physical activity. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 34 | My job regularly requires me to perform repetitive or forceful hand movements or involves awkward postures. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *35 | My job involves a lot of repetitive work. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *36 | My job requires lots of physical effort. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *37 | I am often required to move or lift very heavy loads on my job. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *38 | I am often required to work for long periods with my body in physically awkward positions. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *39 | I am required to work for long periods with my head or arms in physically awkward positions. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *40 | My job requires that I keep learning new things. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| 41 | My job lets me use my skills and abilities. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |

| | | | | | | |
|---|---|---|---|---|---|---|
| 42 | I have enough information to get the job done. | Very true | Somewhat true | Not too true | Not at all true | NA |
| 43 | How often do you find your work stressful? | Always | Sometimes | Hardly ever | Never | NA |
| *44 | My job requires me to be creative. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *45 | My job requires a high level of skill. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *46 | I get to do a variety of different things on my job. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *47 | I have an opportunity to develop my own special abilities. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *48 | My job requires working very hard. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *49 | My job requires long periods of intense concentration on the task. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |
| *50 | My work group or unit makes an important contribution to society. | Strongly Agree | Agree | Disagree | Strongly Disagree | NA |

## Appendix J: Descriptive statistics for physiological outcomes and task performance

| | Job Control Mean (stdev) | n | Job demands Mean (stdev) | n | Social support Mean (stdev) | n | Time pressure Mean (stdev) | n | High physical Mean (stdev) | n | Low physical Mean (stdev) | n | Unfavorable psychosocial Mean (stdev) | n | Favorable Psychosocial Mean (stdev) | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trap EMG-mean$_T$ | 16.8% (7.19%) | 48 | 13.1% (5.22%) | 48 | 8.2% (7.03%) | 47 | 14.2% (7.18%) | 48 | 13.7% (6.74%) | 95 | 12.5% (7.50%) | 96 | 13.4% (7.65%) | 96 | 12.7% (6.64%) | 95 |
| Mid EMG-mean$_T$ | 9.6% (3.86%) | 48 | 10.2% (4.50%) | 48 | 5.6% (7.95%) | 47 | 9.7% (3.87%) | 48 | 9.6% (5.92%) | 95 | 8.0% (4.66%) | 96 | 9.0% (5.33%) | 96 | 8.6% (5.44%) | 95 |
| Ant EMG-mean$_T$ | 20.3% (6.37%) | 48 | 17.1% (8.47%) | 48 | 8.6% (9.38%) | 47 | 15.7% (6.70%) | 48 | 16.7% (9.07%) | 95 | 14.1% (7.73%) | 96 | 15.1% (8.40%) | 96 | 15.7% (8.63%) | 95 |
| Trap EMG-mean$_A$ | 2.4% (1.71%) | 48 | 2.2% (2.61%) | 48 | 7.5% (6.17%) | 47 | 1.7% (1.94%) | 48 | 3.2% (3.91%) | 95 | 3.7% (4.68%) | 96 | 3.6% (4.45%) | 96 | 3.3% (4.18%) | 95 |
| Mid EMG-mean$_A$ | 1.0% (0.99%) | 48 | 0.8% (1.35%) | 48 | 4.2% (4.60%) | 47 | 0.6% (0.70%) | 48 | 1.5% (2.48%) | 95 | 1.8% (3.22%) | 96 | 1.7% (3.04%) | 96 | 1.6% (2.70%) | 95 |
| Ant EMG-mean$_A$ | 0.8% (0.93%) | 48 | 0.7% (1.12%) | 48 | 9.6% (8.42%) | 47 | 0.6% (0.97%) | 48 | 3.1% (6.13%) | 95 | 2.8% (4.99%) | 96 | 2.8% (5.57%) | 96 | 3.0% (5.60%) | 95 |
| Trap EMG-max$_T$ | 55.2% (31.5%) | 48 | 43.6% (16.0%) | 48 | 58.9% (52.3%) | 47 | 51.8% (24.9%) | 48 | 54.9% (37.2%) | 95 | 49.9% (30.6%) | 96 | 55.1% (39.8%) | 96 | 49.8% (27.1%) | 95 |
| Mid EMG-max$_T$ | 36.5% (31.9%) | 48 | 34.8% (24.8%) | 48 | 36.5% (30.0%) | 47 | 35.4% (25.7%) | 48 | 35.8% (23.7%) | 95 | 35.8% (32.3%) | 96 | 39.1% (32.8%) | 96 | 32.5% (22.4%) | 95 |
| Ant EMG-max$_T$ | 63.4% (18.4%) | 48 | 61.6% (46.5%) | 48 | 58.7% (61.0%) | 47 | 61.1% (29.4%) | 48 | 63.5% (33.8%) | 95 | 58.9% (48.2%) | 96 | 58.9% (31.7%) | 96 | 63.5% (49.8%) | 95 |
| Trap EMG-max$_A$ | 47.3% (36.6%) | 48 | 25.2% (18.5%) | 48 | 56.3% (42.0%) | 47 | 37.4% (34.1%) | 48 | 42.6% (38.2%) | 95 | 40.5% (33.6%) | 96 | 3.6% (40.5%) | 96 | 3.5% (3.0%) | 95 |
| Mid EMG-max$_A$ | 35.3% (50.3%) | 48 | 22.8% (41.2%) | 48 | 36.6% (45.9%) | 47 | 23.8% (32.8%) | 48 | 31.0% (45.3%) | 95 | 28.2% (41.4%) | 96 | 4.5% (41.5%) | 96 | 4.5% (45.3%) | 95 |
| Ant EMG-max$_A$ | 40.0% (53.4%) | 48 | 27.6% (20.3%) | 48 | 52.1% (32.8%) | 47 | 28.2% (22.5%) | 48 | 39.2% (44.0%) | 95 | 34.7% (26.7%) | 96 | 3.7% (43.6%) | 96 | 3.7% (27.2%) | 95 |
| HR mean | 90.2 (8.70) | 46 | 88.4 (13.59) | 48 | 94.8 (15.0) | 45 | 96.2 (17.4) | 47 | 94.3 (14.7) | 93 | 90.6 (13.7) | 93 | 92.1 (14.1) | 92 | 92.7 (14.5) | 94 |
| HR stdev | 9.59 (4.94) | 46 | 7.43 (1.61) | 48 | 10.0 (5.95) | 45 | 12.0 (10.2) | 47 | 10.5 (7.47) | 93 | 9.04 (5.61) | 93 | 9.35 (5.67) | 92 | 10.17 (7.49) | 94 |
| HR norm mean | 18.0% (8.82%) | 46 | 18.6% (9.26%) | 48 | 18.2% (6.68%) | 45 | 21.9% (12.1%) | 47 | 20.3% (9.85%) | 93 | 18.0% (9.10%) | 93 | 19.2% (9.24%) | 92 | 19.1% (9.85%) | 94 |
| HR norm stdev | 7.5% (3.86%) | 46 | 5.6% (1.46%) | 48 | 8.1% (4.61%) | 45 | 9.1% (7.48%) | 47 | 8.2% (5.67%) | 93 | 7.0% (4.19%) | 93 | 7.2% (4.27%) | 92 | 7.9% (5.64%) | 94 |
| Task performance | 86.2% (12.2%) | 48 | 94.9% (3.07%) | 48 | 85.5% (8.63%) | 48 | 89.9% (9.74%) | 48 | 87.1% (10.5%) | 96 | 91.1% (8.55%) | 96 | 89.1% (10.3%) | 96 | 89.1% (9.20%) | 96 |

Shaded values denote significant main effects ($p < .05$).
HR = heart rate, norm = normalized, stdev = standard deviation
Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid, T = tapping task, A = assembly task

## Appendix K: Descriptive statistics for subjective outcomes

| | Job Control | | Job demands | | Social support | | Time pressure | | High physical | | Low physical | | Unfavorable psychosocial | | Favorable psychosocial | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n | Mean (stdev) | n |
| NASA-TLX: Mental Demand | 3.71 (3.11) | 48 | 5.05 (3.21) | 48 | 6.18 (3.13) | 48 | 5.56 (4.26) | 48 | 5.16 (3.47) | 96 | 5.10 (3.59) | 96 | 6.24 (3.61) | 96 | 4.02 (3.08) | 96 |
| NASA-TLX: Physical Demand | 8.84 (3.12) | 48 | 7.91 (3.01) | 48 | 8.15 (2.50) | 48 | 7.75 (3.25) | 48 | 9.34 (2.57) | 96 | 6.99 (2.94) | 96 | 8.14 (2.99) | 96 | 8.18 (2.98) | 96 |
| NASA-TLX: Temporal Demand | 7.78 (2.96) | 48 | 6.79 (2.78) | 48 | 6.61 (2.75) | 48 | 7.41 (2.39) | 48 | 7.54 (2.57) | 96 | 6.76 (2.88) | 96 | 7.63 (2.56) | 96 | 6.67 (2.84) | 96 |
| NASA-TLX: Performance | 6.63 (2.77) | 48 | 5.58 (2.06) | 48 | 6.23 (2.97) | 48 | 6.25 (2.74) | 48 | 6.43 (2.62) | 96 | 5.91 (2.69) | 96 | 6.38 (2.75) | 96 | 5.96 (2.56) | 96 |
| NASA-TLX: Effort | 7.73 (3.30) | 48 | 7.78 (2.21) | 48 | 8.26 (1.87) | 48 | 7.97 (2.80) | 48 | 8.62 (2.51) | 96 | 7.25 (2.53) | 96 | 8.02 (2.55) | 96 | 7.86 (2.63) | 96 |
| NASA-TLX: Frustration | 5.40 (3.44) | 48 | 5.06 (3.06) | 48 | 5.88 (4.04) | 48 | 5.11 (3.12) | 48 | 5.80 (3.63) | 96 | 4.93 (3.20) | 96 | 5.92 (3.59) | 96 | 4.80 (3.23) | 96 |
| NASA-TLX: Total unweighted | 6.68 (2.11) | 48 | 6.36 (1.68) | 48 | 6.89 (1.80) | 48 | 6.67 (1.82) | 48 | 7.15 (1.71) | 96 | 6.16 (1.81) | 96 | 7.05 (1.80) | 96 | 6.25 (1.75) | 96 |
| NASA-TLX: Total weighted | 6.58 (2.24) | 48 | 6.51 (1.86) | 48 | 7.27 (1.80) | 48 | 6.68 (1.91) | 48 | 7.24 (1.84) | 96 | 6.27 (2.00) | 96 | 7.21 (1.97) | 96 | 6.30 (1.86) | 96 |
| SWAT: Time Load | 11.83 (4.95) | 48 | 12.51 (4.77) | 48 | 11.9 (4.99) | 48 | 12.1 (4.82) | 48 | 12.7 (4.67) | 96 | 11.4 (5.00) | 96 | 12.5 (4.61) | 96 | 11.63 (5.08) | 96 |
| SWAT: Mental Load | 7.01 (5.01) | 48 | 8.96 (4.01) | 48 | 8.26 (4.82) | 48 | 7.92 (5.32) | 48 | 8.67 (4.83) | 96 | 7.40 (4.80) | 96 | 9.12 (4.88) | 96 | 6.95 (4.56) | 96 |
| SWAT: Stress Load | 6.80 (5.76) | 48 | 5.97 (3.87) | 48 | 8.46 (4.99) | 48 | 7.28 (4.60) | 48 | 8.13 (5.13) | 96 | 6.12 (4.44) | 96 | 7.82 (5.07) | 96 | 6.44 (4.68) | 96 |
| SWAT: Total workload | 25.6 (11.42) | 48 | 27.5 (8.51) | 48 | 28.6 (11.3) | 48 | 27.3 (12.1) | 48 | 29.5 (10.6) | 96 | 24.7 (11.0) | 96 | 29.4 (10.5) | 96 | 25.0 (10.8) | 96 |
| Borg ratings: Maximum | 5.03 (2.07) | 48 | 5.35 (2.03) | 48 | 5.08 (2.17) | 48 | 5.60 (2.02) | 48 | 6.23 (1.85) | 96 | 4.30 (1.81) | 96 | 5.35 (2.11) | 96 | 5.18 (2.05) | 96 |
| Borg ratings: Difference | 3.95 (1.64) | 48 | 4.80 (1.79) | 48 | 3.92 (1.68) | 48 | 4.87 (1.87) | 48 | 5.06 (1.66) | 96 | 3.70 (1.66) | 96 | 4.43 (1.79) | 96 | 4.33 (1.81) | 96 |
| Borg ratings: 33% mean | 2.00 (1.49) | 48 | 1.23 (0.99) | 48 | 2.00 (1.28) | 48 | 1.67 (0.96) | 48 | 2.10 (1.31) | 96 | 1.36 (1.03) | 96 | 1.78 (1.23) | 96 | 1.67 (1.24) | 96 |
| Borg ratings: 66% mean | 3.63 (1.67) | 48 | 3.60 (1.70) | 48 | 3.92 (1.77) | 48 | 3.75 (1.51) | 48 | 4.42 (1.52) | 96 | 3.03 (1.49) | 96 | 3.80 (1.76) | 96 | 3.65 (1.58) | 96 |
| Borg ratings: Overall mean | 2.82 (1.49) | 48 | 2.41 (1.26) | 48 | 2.96 (1.47) | 48 | 2.70 (1.10) | 48 | 3.26 (1.29) | 96 | 2.19 (1.18) | 96 | 2.79 (1.40) | 96 | 2.66 (1.30) | 96 |
| BDM: Neck | 3.18 (2.15) | 48 | 2.55 (1.85) | 48 | 3.69 (2.49) | 48 | 2.39 (2.13) | 48 | 3.01 (2.18) | 96 | 2.90 (2.26) | 96 | 2.98 (2.27) | 96 | 2.93 (2.17) | 96 |
| BDM: Dominant shoulder | 4.60 (2.03) | 48 | 3.61 (2.47) | 48 | 5.04 (2.12) | 48 | 4.78 (2.53) | 48 | 5.33 (2.26) | 96 | 3.69 (2.17) | 96 | 4.43 (2.33) | 96 | 4.59 (2.40) | 96 |
| BDM: Low Back | 1.58 (1.77) | 48 | 2.17 (1.80) | 48 | 2.35 (2.13) | 48 | 2.63 (2.40) | 48 | 2.40 (2.15) | 96 | 1.97 (1.96) | 96 | 2.23 (2.13) | 96 | 2.13 (2.00) | 96 |
| Skill Discretion | 21.06 (7.57) | 47 | 19.8 (6.00) | 48 | 19.5 (4.06) | 48 | 18.2 (3.41) | 46 | 19.4 (5.28) | 95 | 19.9 (5.85) | 94 | 19.7 (5.22) | 96 | 19.6 (5.92) | 93 |
| Decision Authority | 26.6 (9.00) | 44 | 23.2 (7.24) | 42 | 25.5 (7.36) | 48 | 20.7 (7.22) | 46 | 23.9 (8.01) | 91 | 24.2 (8.04) | 89 | 22.8 (7.08) | 88 | 25.2 (8.69) | 92 |
| Work Demands | 2.38 (1.80) | 39 | 2.80 (1.52) | 37 | 3.50 (1.79) | 46 | 2.50 (1.93) | 20 | 2.67 (1.60) | 73 | 3.06 (1.96) | 69 | 2.90 (1.88) | 72 | 2.81 (1.71) | 70 |
| Physical Exertion | 6.25 (1.48) | 47 | 6.29 (1.80) | 48 | 6.04 (1.49) | 48 | 6.47 (1.37) | 43 | 5.86 (1.49) | 94 | 6.66 (1.49) | 92 | 6.27 (1.65) | 92 | 6.24 (1.43) | 94 |
| Physical Loads | 2.92 (1.07) | 48 | 3.73 (1.41) | 48 | 3.27 (1.16) | 48 | 3.17 (1.17) | 48 | 3.20 (1.14) | 96 | 3.34 (1.33) | 96 | 3.25 (1.26) | 96 | 3.29 (1.22) | 96 |
| Supervisor Support | 11.7 (1.72) | 20 | 10.59 (2.30) | 22 | 12.9 (1.80) | 47 | 10.3 (2.26) | 10 | 11.8 (2.34) | 49 | 12.0 (2.07) | 50 | 11.6 (2.24) | 50 | 12.1 (2.14) | 49 |
| Coworker Support | 11.43 (1.09) | 14 | 9.94 (1.12) | 16 | 13.4 (1.72) | 46 | 9.75 (0.96) | 4 | 12.3 (2.11) | 38 | 12.0 (2.08) | 42 | 11.9 (2.18) | 40 | 12.4 (1.99) | 40 |

Shaded values denote significant main effects ($p < .05$).

Lower psychosocial scores indicate more negative perceptions.

**Appendix L: Tukey's post hoc comparisons for psychosocial dimension**

| Dependent Variable | Psychosocial Dimension | Mean | Groups* | Dependent Variable | Psychosocial Dimension | Mean | Groups* |
|---|---|---|---|---|---|---|---|
| NASA-TLX: Mental Demand | Job Control | 3.71 | A | HR stdev | Job Control | 9.59 | A |
| | Demands | 5.05 | B | | Demands | 7.43 | A B |
| | Social Support | 6.18 | B | | Social Support | 10.0 | A B |
| | Time Pressure | 5.56 | B | | Time Pressure | 12.0 | B |
| Trap EMG-mean$_T$ | Job Control | 16.8% | C | HR norm stdev | Job Control | 7.54% | B |
| | Demands | 13.1% | B | | Demands | 5.56% | A |
| | Social Support | 8.19% | A | | Social Support | 8.09% | B |
| | Time Pressure | 14.2% | B | | Time Pressure | 9.09% | B |
| Mid EMG-mean$_T$ | Job Control | 9.60% | B | BDM: Neck | Job Control | 3.18 | A B |
| | Demands | 10.2% | B | | Demands | 2.55 | A |
| | Social Support | 5.59% | A | | Social Support | 3.69 | B |
| | Time Pressure | 9.75% | B | | Time Pressure | 2.39 | A |
| Ant EMG-mean$_T$ | Job Control | 20.3% | C | BDM: Shoulder | Job Control | 4.60 | B |
| | Demands | 17.1% | B | | Demands | 3.61 | A |
| | Social Support | 8.61% | A | | Social Support | 5.04 | B |
| | Time Pressure | 15.7% | B | | Time Pressure | 4.78 | B |
| Trap EMG-mean$_A$ | Job Control | 2.38% | A | Borg Difference | Job Control | 3.95 | A |
| | Demands | 2.21% | A | | Demands | 4.80 | B |
| | Social Support | 7.48% | B | | Social Support | 3.92 | A |
| | Time Pressure | 1.66% | A | | Time Pressure | 4.87 | B |
| Mid EMG-mean$_A$ | Job Control | 0.95% | A | Borg 33% Mean | Job Control | 2.00 | B |
| | Demands | 0.80% | A | | Demands | 1.23 | A |
| | Social Support | 4.24% | B | | Social Support | 2.00 | B |
| | Time Pressure | 0.62% | A | | Time Pressure | 1.67 | A B |
| Ant EMG-mean$_A$ | Job Control | 0.80% | A | Task Performance | Job Control | 88.2% | A B |
| | Demands | 0.71% | A | | Demands | 95.3% | C |
| | Social Support | 9.65% | B | | Social Support | 86.7% | A |
| | Time Pressure | 0.60% | A | | Time Pressure | 91.2% | B |
| Trap EMG-max$_A$ | Job Control | 55.3% | A B | Decision Authority** | Job Control | 26.6 | B |
| | Demands | 43.6% | A | | Demands | 23.2 | A B |
| | Social Support | 58.9% | B | | Social Support | 25.5 | B |
| | Time Pressure | 51.8% | A B | | Time Pressure | 20.7 | A |
| Ant EMG-max$_A$ | Job Control | 0.80% | A B | Work Demands** | Job Control | 2.38 | A |
| | Demands | 0.71% | A | | Demands | 2.76 | A B |
| | Social Support | 9.65% | B | | Social Support | 3.50 | B |
| | Time Pressure | 0.60% | A | | Time Pressure | 2.50 | A B |
| HR mean | Job Control | 90.2 | A B | Physical Loads** | Job Control | 2.92 | A |
| | Demands | 88.4 | A | | Demands | 3.73 | B |
| | Social Support | 94.8 | B C | | Social Support | 3.27 | A B |
| | Time Pressure | 96.2 | C | | Time Pressure | 3.17 | A B |

*Types with the same letter are not significantly different.
**Kruskal-Wallis test performed, post hoc analysis using methods from Siegel & Castalan (1988)
HR = heart rate, norm = normalized, stdev = standard deviation
Trap = trapezius, Mid = middle deltoid, Ant = anterior deltoid, T = tapping task, A = assembly task

## Vita

Laura Hughes graduated Summa Cum Laude as a valedictorian from North Carolina State University with a Bachelor's of Science in Industrial Engineering and a minor in Psychology in May 2002. Additionally as an undergraduate she completed requirements for the University Honors Program and participated in the cooperative education program by working as a management engineer in several hospitals for Premier, Inc. She directly continued her education at Virginia Tech in the Human Factors Option of the Industrial and Systems Engineering Department and received her master's of science degree in August 2004 under the direction of Dr. Kari Babski-Reeves (Thesis: Effects of Time Pressure and Mental Workload on Physiological Risk Factors for Upper Extremity Musculoskeletal Disorders While Typing). She received the National Institute for Occupational and Safety Health Fellowship and the Pratt Fellowship to fund her master's studies. Laura went on to pursue a PhD. at Virginia Tech in the same area. She received the Walter/Grado fellowship from the department, which fully funded her studies for three years. Laura is an active member of the Human Factors and Ergonomics Society (HFES), the American Society of Safety Engineers (ASSE), Phi Kappa Phi, Alpha Pi Mu, and the Institute of Industrial Engineers.