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## PSYCHOPHYSICAL ASSESSMENT OF SIMULATED ASSEMBLY LINE WORK: COMBINATIONS OF TRANSFERRING AND SCREW DRIVING TASKS

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Upper extremity cumulative trauma disorders have been linked to the repeated and/or forceful exertions and/or awkward postures sometimes required by upper extremity intensive work. The combined effect of these physical stressors can be evaluated using psychophysical methods. The purpose of this study was to examine different combinations of repetitive upper extremity work using established psychophysical methods to determine design recommendations for upper extremity tasks. The tasks studied simulated assembly line type work where a part is transferred from a storage bin and attached with a pneumatic tool to another larger part.

Twenty-four experienced industrial workers performed five combination tasks of transferring an object along a conveyor and screw driving using a pistol shaped pneumatic screwdriver: 100% transfer; 75% transfer and 25% screw drive; 50% transfer and 50% screw drive; 25% transfer and 75% screw drive; and 100% screw drive. The cycle time was 24 seconds. Each combination task was performed for an hour. Overall, transferring, and screw driving perceived exertions were measured using 10 cm visual analog scales (VAS) with verbal descriptions at the endpoints. The left and right sides corresponded to "Easiest imaginable work" at 0 cm, and "Hardest imaginable work" at 10 cm, respectively. Body part discomfort surveys were utilized to assess discomfort from each of the tasks.

The overall perceived exertion (VAS) rating increased, as the task utilized more of one upper extremity than the other and involved more of either the transferring or screw driving tasks. The mean overall VAS ratings were 5.3, 4.3, 3.5, 4.4, and 5.3 for the five combination tasks, respectively. As the transferring (or screw driving) proportion of the task increased, the transferring (or screw driving) VAS increased. A repeated measures ANOVA showed that the combination task effect was significant ( $p < 0.01$ ). This psychophysical data can provide guidance in the analysis and design of upper extremity work. Since less varied work which utilized more of one upper extremity than the other had greater overall perceived exertion, upper extremity tasks should be designed as varied as possible utilizing as many body parts as possible. Body part discomfort surveys verified that this decreased discomfort severity and distributed the discomfort more evenly throughout the different body parts. This study provides evidence of the positive effects of work enlargement.

### INTRODUCTION

The U.S. Department of Labor, Bureau of Labor Statistics (1983, 1993) reports that disorders associated with repeated trauma are at an all time high. In 1981, the number of disorders associated with repeated trauma was 23,000 which comprised 18% of all occupational illnesses. In 1991, there were 223,600 new cases, which comprised 61% of all occupational illnesses. Hence, the number of reported cases have increased both absolutely and proportionately.

Upper extremity Cumulative Trauma Disorders (CTDs) have been linked to the repeated and/or forceful exertions and/or awkward postures sometimes required by upper extremity intensive work (Armstrong, Fine, Goldstein, Lifshitz, and Silverstein, 1987; Armstrong, Foulke, Joseph, and Goldstein, 1982; Luopajarvi, Kuorinka, Virolainen, and Holmberg, 1979; Phalen, 1966; Silverstein, Fine, and Armstrong, 1987; Tichauer, 1966; Wieslander, Norbäck, Göthe, and Juhlin, 1989). The combined effect of these physical stressors can be evaluated using a psychophysical methodology.

Psychophysical methods have been used extensively in the evaluation and design of manual materials handling tasks (Asfour, Ayoub, Mital, and Bethea, 1983; Baxter, Stålhammar, and Troup, 1986; Ciriello, Snook, and Blick, 1990; Gamberale, Ljungberg, Annwall, and Kilbom, 1987; Karwowski and Yates, 1986; Legg and Myles, 1981; Ljungberg, Gamberale, and Kilbom, 1982; Mital, 1983; Snook, 1978). Recently, upper extremity intensive work has been examined using psychophysical methods (Fernandez, Dahalan, Klein, and Marley, 1993; Krawczyk and Armstrong, 1991; Krawczyk, Armstrong, and Snook,

1992; Örtengren, Cederqvist, Lindberg, and Magnusson, 1991; Ulin, Snook, Armstrong, and Herrin, 1992).

The purpose of this study was to examine different combinations of repetitive upper extremity work using established psychophysical methods to determine design recommendations for upper extremity tasks. The tasks studied required varying amounts of transferring and screw driving. The tasks simulated assembly line type work where a part is transferred from a storage bin and attached to another larger part using a pneumatic tool.

### METHOD

#### Subjects

Twenty-four (twelve males and twelve females) right-handed experienced industrial workers participated in the experiment. The mean subject age was 34 years (range 24-47). The mean subject stature was 168 centimeters (range 139-187), which included both 5th and 95th percentile statured males and females (Marras and Kim, 1993). The mean subject weight was 72 kg (range 47-103 kg). The mean grip strength measured using Chaffin's (1975) strength testing guidelines was 401 Newtons (range 206-647).

#### Apparatus

All subjects performed five combination tasks of transferring a container along a conveyor and screw driving with a pistol shaped pneumatic screwdriver. The five combination tasks had different proportions of transferring and screw driving: 100% transfer; 75%

transfer and 25% screw drive; 50% transfer and 50% screw drive; 25% transfer and 75% screw drive; and 100% screw drive. The cycle time was 24 seconds, which consisted of 4 segments of either transferring or screw driving. For example, 75% transfer and 25% screw drive entailed 3 transfers and 1 screw drive segments.

Each combination task utilized the same workstation, which required the transfer to be completed with the left hand and the screw driving with the right hand. For the transfer part of each work cycle, the subject grasped a 4.1 cm diameter (Grant, Habes, and Steward, 1992) vertically oriented handle of a 6.8 kg container with the left hand and transferred it to a location 1 meter to the right. After releasing the container, a conveyor returned the container to its original position. The height of the conveyor was adjusted so that each subject kept their upper arm at the side of the body with the elbow flexed at a 90 degree angle while transferring the container. For the screw driving part of each work cycle, subjects used a pistol shaped pneumatic screwdriver (Atlas Copco, model LUM24HR012-Q) to drive number six, slotted, hex-head screws into vertically oriented perforated sheet metal located at elbow height.

### **Experimental Design and Procedure**

Each subject performed all five combination tasks for a randomized complete block factorial design. The independent variables were gender, time, combination task, and subject. The dependent variables were overall, transferring, and screw driving perceived exertions. Body part discomfort was also recorded.

Each subject completed a learning/training session where the five combination tasks were practiced for ten minutes each. Subjects also practiced using the different visual analog scales. After this learning/training session, a mandatory twenty minute break was observed. Subsequently, each combination task was performed for an hour. After each of these hours, a mandatory twenty minute break was observed. The presentation of the five combination tasks was randomized.

Subjects rated their perceived exertion at 30 and 60 minutes for each combination task. Perceived exertions were measured using 10 centimeter visual analog scales (VAS) with verbal descriptions at the endpoints as done in previous studies (Krawczyk and Armstrong, 1991; Krawczyk, Armstrong, and Snook, 1992; Price, McGrath, Rafii, and Buckingham, 1983; Ulin, Snook, Armstrong, and Herrin, 1992). The left and right sides corresponded to "Easiest imaginable work" at 0 cm, and "Hardest imaginable work" at 10 cm, respectively. Subjects were instructed to base their ratings on what they felt it would be like to complete the task for a "normal eight hour work day", similar to Snook's (1978) instructions.

In addition, at 60 minutes, a body part discomfort survey (shown in Figure 1) was completed to assess discomfort from each of the tasks. Body part discomfort was measured for eleven different body parts using 10 centimeter visual analog scales (VAS) with verbal descriptions at the endpoints. The left and right sides corresponded to "No discomfort at all" at 0 cm, and "Worst imaginable discomfort" at 10 cm, respectively.

## **RESULTS**

### **Overall Perceived Exertion (VAS)**

The mean overall perceived exertion (VAS) ratings with their respective 95% confidence intervals are shown in Figure 2. The mean overall VAS ratings were 5.3, 4.3, 3.5, 4.4, and 5.3 for the respective five combination tasks: 100% transfer; 75% transfer and 25% screw drive; 50% transfer and 50% screw drive; 25% transfer and 75% screw drive; and 100% screw drive. The minimum overall perceived exertion occurred when the combination task was evenly divided between the two upper extremities at 50% transfer and 50% screw drive. The overall

perceived exertion increased as the task utilized more of one upper extremity than the other and involved more of either the transferring or screw driving tasks.

A repeated measures ANOVA (SYSTAT, 1992) with one between factor (gender) and two within factors (time and combination task) tested main effects and the interactions between them using overall VAS rating as the dependent variable. This four-factor ANOVA (gender, time, combination task, and subject) showed that gender and time were not significant. Additionally, the interactions were not significant. Thus, gender and time were removed from the model and the two overall VAS ratings from 30 and 60 minutes were averaged. A two-factor repeated measures ANOVA (combination task and subject) showed the task effect to be significant with  $p=0.009$  using the Huynh-Feldt (Bramwell, Bittner, and Morrissey, 1992) adjustment for degrees of freedom.

Subject age, stature, weight, and strength were each added in the model as covariates. None of these were found to be significant.

*F* tests were used to examine the relationship between overall perceived exertion (VAS) rating and combination task for a linear effect; a quadratic given a linear effect; a cubic given linear and quadratic effects; and a quartic given linear, quadratic, and cubic effects. The relationship was quadratic ( $p<0.0005$ ) as shown in Figure 2, with a minimum value of 3.5 at 50% transfer and 50% screw drive. The cubic and quartic terms were not significant.

### **Transferring Perceived Exertion (VAS)**

The mean transferring perceived exertion (VAS) ratings with their respective 95% confidence intervals are shown in Figure 3. The mean transferring VAS ratings were 5.3, 4.5, 3.6, and 2.9 for the respective combination tasks that included a transferring component: 100% transfer; 75% transfer and 25% screw drive; 50% transfer and 50% screw drive; and 25% transfer and 75% screw drive. As the transferring proportion of the task increased, the transferring VAS increased.

The transferring VAS ratings were analyzed identically to the overall VAS ratings. This analysis showed that gender and time were not significant. Additionally, the interactions were not significant. The combination task effect was significant with  $p<0.0005$  using the Huynh-Feldt adjustment for degrees of freedom.

*F* tests were used to examine the relationship between transferring perceived exertion (VAS) rating and combination task for a linear effect, a quadratic given a linear effect, and a cubic given linear and quadratic effects. The relationship was linear ( $p<0.0005$ ) as shown in Figure 3. Transferring perceived exertion increased with the transferring proportion of the task. The quadratic and cubic terms were not significant.

### **Screw Driving Perceived Exertion (VAS)**

The mean screw driving perceived exertion (VAS) ratings with their respective 95% confidence intervals are shown in Figure 3. The mean screw driving VAS ratings were 2.2, 3.0, 4.4, and 5.3 for the respective combination tasks that included a screw driving component: 75% transfer and 25% screw drive; 50% transfer and 50% screw drive; 25% transfer and 75% screw drive; and 100% screw drive. As the screw driving proportion of the task increased, the screw driving VAS increased.

The screw driving VAS ratings were analyzed identically to the overall VAS ratings. This analysis showed that gender and time were not significant. Additionally, the interactions were not significant. The combination task effect was significant with  $p<0.0005$  using the Huynh-Feldt adjustment for degrees of freedom.

*F* tests were used to examine the relationship between screw driving perceived exertion (VAS) rating and combination task for a linear effect, a quadratic given a linear effect, and a cubic given linear and quadratic effects. The relationship was linear ( $p<0.0005$ ) as shown in

Figure 1. The Body Part Discomfort Survey Completed after 60 Minutes of Performing Each Combination Task.

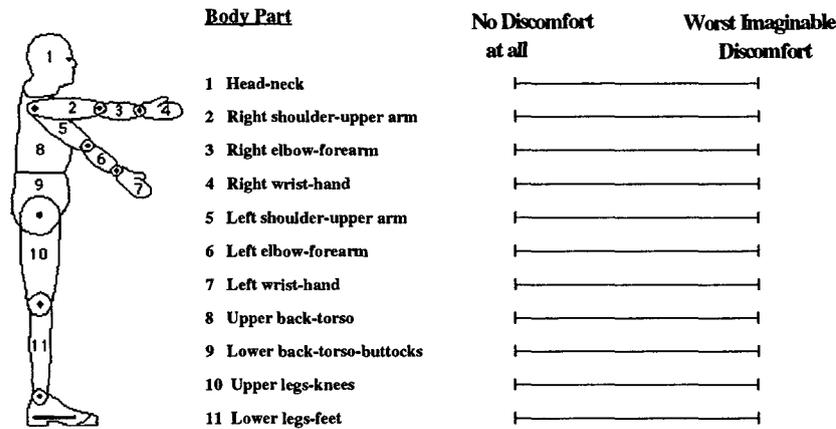


Figure 2. Overall Perceived Exertion: Visual Analog Scale Ratings with 95% Confidence Intervals.

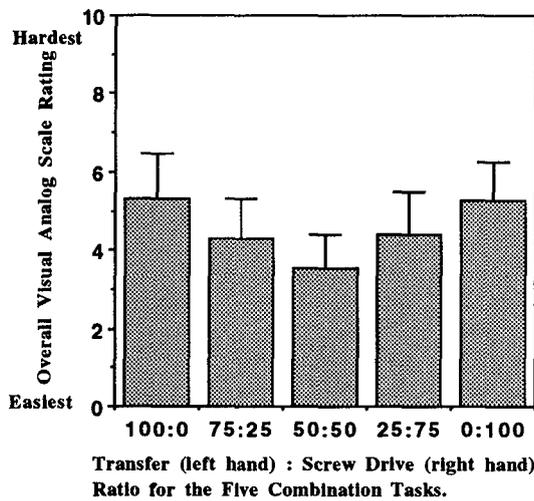


Figure 4. Body Part Discomfort Frequency: Total Number of Body Part Discomfort Responses for all Combination Tasks.

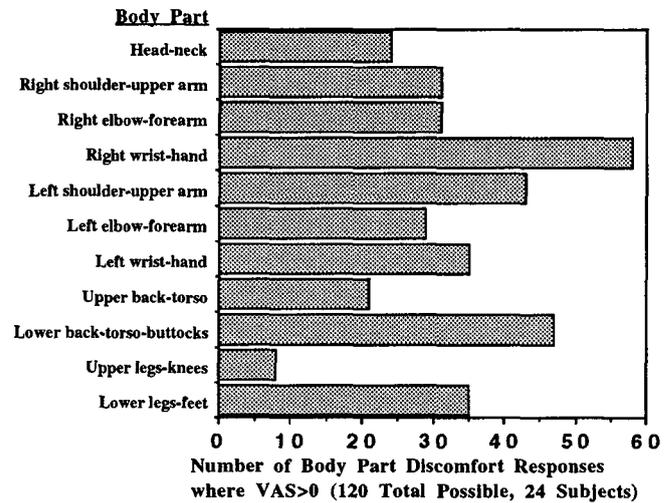


Figure 3. Transferring and Screw Driving Perceived Exertion: Visual Analog Scale Ratings with 95% Confidence Intervals.

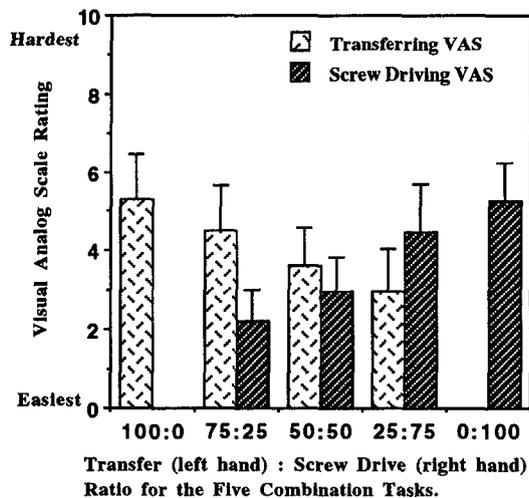


Figure 5. Body Part Discomfort Severity: Overall Mean Body Part Discomfort Visual Analog Scale Ratings with Standard Deviations for all Combination Tasks.

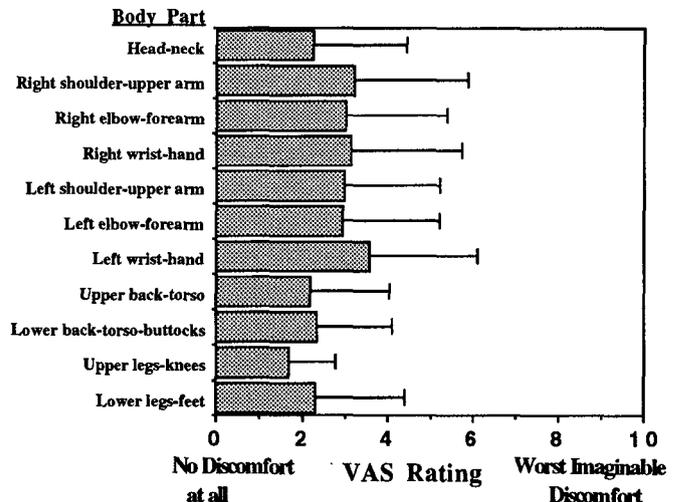


Figure 3. Screw driving perceived exertion increased with the screw driving proportion of the task. The quadratic and cubic terms were not significant.

#### **Body Part Discomfort: Frequency**

The total number of body part discomfort responses for the eleven body parts are shown in Figure 4. The total number of possible complaints was equal to 120 (5 combination tasks X 24 subjects). Any VAS>0 was considered a positive response. A value of 0 corresponded to "No discomfort at all". The number of discomfort responses varied throughout the different body parts. The largest number of discomfort responses were found in the upper extremities and also in the lower back-torso-buttocks and lower legs-feet areas. The maximum number of discomfort responses was for the right wrist-hand at 58, less than half that possible.

#### **Body Part Discomfort: Severity**

The overall mean body part discomfort visual analog scale ratings for all five combination tasks are shown in Figure 5. A VAS value of 0 corresponded to "No discomfort at all" while 10 corresponded to "Worst imaginable discomfort". The mean body part discomfort severity did not vary much throughout the different body parts. The mean severity ranged from 1.7 in the upper legs-knees to 3.5 in the left wrist-hand.

### DISCUSSION

Figure 2 shows that the lowest mean overall perceived exertion (VAS) rating was for the 50% transferring and 50% screw driving task. The workload of this task was evenly distributed between the left and right upper extremity since the transferring was done with the left hand and the screw driving was done with the right hand. Consequently, this task allowed the maximum amount of physiological recovery time (12 seconds) for both the left and right upper extremities that could be provided simultaneously. Most subjects reported a preference for the balanced nature of this combination task.

Overall perceived exertion (VAS) increased as the combination task utilized more of one upper extremity than the other and involved more of either the transferring or screw driving tasks. Thus, either component (transferring or screw driving) of the combination tasks would become the limiting factor. For the right-handed subjects, the left upper extremity (transferring) or the right upper extremity (screw driving) could become the limiting factor of the work. Even though the less varied tasks affected only one extremity, this limiting factor affected overall VAS ratings. Likewise, Yoshitake (1971) found that general fatigue correlated well with symptoms of fatigue in some part of the body.

The highest overall perceived exertion was for the combination tasks which required only transferring or only screw driving. These tasks allowed the least amount of physiological recovery time for the upper extremity (left or right) that was responsible for performing the task. When there is not enough recovery time, the body part experiences discomfort. The body part discomfort surveys showed a proportional increase in discomfort frequency and severity (VAS) in the respective upper extremity that was required to perform a greater proportion of the combination tasks. Morphological tissue changes (resembling peritendinitis crepitans) may occur in over exercised limbs and have been experimentally induced by over exercising the hind limb in rabbits (Rais, 1961). Thus, Rais was the first to correlate time and load characteristics to a subsequent cumulative trauma injury. Likewise, an accumulation of strain was found to occur in tendinous tissues of the upper extremity during physiologic loading in human cadaver hands (Goldstein, Armstrong, Chaffin, and Matthews, 1987).

As shown in Figure 3, as the transferring proportion of the task increased, the transferring perceived exertion increased. Likewise, as the screw driving proportion of the task increased, the screw driving perceived exertion increased. Psychophysical methods are usually used to combine the effects of physical stressors such as weight, frequency, height, and distance for manual materials handling tasks such as lifting, lowering, pushing, pulling, carrying, and walking (Asfour, Ayoub, Mital, and Bethea, 1983; Baxter, Stålhammar, and Troup, 1986; Ciriello, Snook, and Blick, 1990; Gamberale, Ljungberg, Annwall, and Kilbom, 1987; Karwowski and Yates, 1986; Legg and Myles, 1981; Ljungberg, Gamberale, and Kilbom, 1982; Mital, 1983; Snook, 1978). However, in these upper extremity combination tasks that required two components, transferring and screw driving, subjects were able to do the opposite: to separate the effects of physical stressors. Subjects were able to discriminate between the transferring and screw driving parts of the tasks, and give a psychophysical rating accordingly.

The total number of body part discomfort responses for all combination tasks varied by body part as shown in Figure 4. The body part discomfort response frequency gave some indication of the stressed body parts. The maximum number of discomfort responses was in the right wrist-hand, which was responsible for the screw driving component of the combination tasks. Both upper extremities had a large number of discomfort responses, reflective of the upper extremity intensive work that was being performed. Note that even though the combination tasks were upper extremity intensive, a substantial number of discomfort responses occurred in the lower back-torso-buttocks and the lower legs-feet areas since the subjects were standing while working. The upper legs-knees had the least number of discomfort responses. The mean body part discomfort severity (VAS) ratings, which indicate discomfort intensity, are shown in Figure 5. The mean body part discomfort severity ratings were similar for all of the eleven body parts.

Inspection of the body part discomfort surveys by combination task revealed that the less varied work that utilized more of one upper extremity than the other and involved more of one particular task component (transferring or screw driving) had greater body part discomfort severity concentrated in fewer body parts. Conversely, the more varied work had decreased body part discomfort severity and the discomfort was more evenly distributed throughout the different body parts.

### SUMMARY

This psychophysical data can provide guidance in the design of upper extremity work. Work that utilized more of one upper extremity than the other and involved more of one particular task component (transferring or screw driving) had greater perceived exertion. Thus, upper extremity tasks should be designed as varied as possible utilizing as many body parts as possible. Body part discomfort surveys verified that the discomfort was in the upper extremities that was performing the transferring and screw driving tasks. In addition, the more varied work that utilized both upper extremities and involved both transferring and screw driving tasks had less body part discomfort severity and the discomfort was more evenly distributed throughout the different body parts. This study provides evidence of the positive effects of work enlargement.

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