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Perceived exertion and discomfort associated with driving screws at various work locations and at different work frequencies

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Eighteen subjects drove screws with air-powered tools into perforated sheet metal at three vertical and two horizontal work locations using three different work paces (8, 10, and 12 screws/min). Subjects drove screws with a pistol-shaped tool on the vertical orientation at knee, elbow, and shoulder height. They used an in-line tool to drive screws on the horizontal surface. A horizontal beam was placed just below each subject's elbow height and they drove screws into it with the lower arm perpendicular to the torso and with the arms fully extended. Subjects drove screws for 10 min at each work location and frequency combination before they assessed the condition using the Borg ten-point ratio rating scale. Subjects also ranked seven body areas according to discomfort for each work location. A two-factor ANOVA (and comparable non-parametric statistics) showed that both work location and frequency were significant factors in determining the Borg ratings. As work pace increased, so did the Borg ratings of perceived exertion for each work location. For each incremental increase in work pace, the Borg ratings of perceived exertion increased 12% to 25%, depending on the work location. Driving screws at elbow height on the vertical surface and with the lower arm close to the body on the horizontal surface were the work locations with the smallest ratings of perceived exertion. The ratings of perceived exertion for driving screws at elbow height on the vertical surface were 18% to 50% lower than the ratings for driving screws at knee or shoulder height and the ratings of perceived exertion for driving screws with the lower arm close to the body on the horizontal surface were 21% to 24% lower than driving screws with the arms fully extended. No significant difference was found among the discomfort ranks given to the various body parts for the two horizontal work locations. Differences were found among the body part discomfort rankings for the vertical work locations. While driving screws at knee height, the torso was most stressed; the wrist and hand were most stressed while driving screws at elbow height, and the shoulder and upper arm were the body parts that were stressed the most while driving screws at shoulder height.

1. Introduction

This study examines the effect of work frequency and work location on subjects' perceived exertion while driving screws on both a vertical and a horizontal surface. Perceived exertion has been shown to be related to the risk of over-exertion injuries for manual materials handling tasks (Baxter *et al.* 1986, Corlett and Bishop 1978, 1976, Fernandez and Ayoub 1988, Karwowski and Burkhardt 1988, Legg and Myles 1985, Ljungberg *et al.* 1982, Snook *et al.* 1970, Snook and Irvine 1966, Snook 1978, 1985). Specifically, the frequency of lifting tasks (Snook and Irvine 1968), the limits of arm work (Hagberg 1981, Hagberg and Sundelin 1986, Harms-Ringdahl *et al.*

1986) and the effect of work location and tool shape (Ulin *et al.* 1990, 1992) have been studied using psychophysical methodologies.

Workplace factors which are associated with the use of hand tools have been linked to many work-related disorders such as carpal tunnel syndrome, tendinitis, DeQuervain's disease, and low back injuries (Cannon *et al.* 1981, Jensen *et al.* 1983, Klein *et al.* 1984, and Margolis *et al.* 1987). Specifically, certain postures assumed while performing work and the repetitiveness or frequency of the work, are two of the identified workplace risk factors that can lead to the development of work-related disorders (Armstrong *et al.* 1987, Armstrong *et al.* 1982, Feldman *et al.* 1987, Silverstein *et al.* 1987, and Tichauer 1966). These two workplace risk factors will be explored using a psychophysical methodology in a laboratory experiment which requires subjects to drive screws with air-powered tools.

The ultimate goal of this study was to collect data that could be used to analyse and design tasks involving the use of hand tools so that the risk of work-related disorders can be reduced. Work-related disorders are a major cause of pain, impairment, disability, and compensation in many hand intensive industries. Psychophysical data are being used as an indicator of where guidelines must be set so the risk of a work-related disorder is minimized. Perceived exertion data can be collected relatively quickly whereas quantitative dose-response relationships for each work-related disorder and each body part will take years of epidemiological studies. Presently, no data are available that can be used as a basis for selecting workstation designs, although several workplace factors have been associated with work-related disorders.

2. Materials and methods

Eighteen university students served as subjects (9 males and 9 females) for this experiment. The sample size was determined using a power computation and the

Work orientation _____

Work Location _____

Rank order the given body parts (see diagram) according to discomfort (where 1 = most uncomfortable body part).

	Rank
1 = head and neck	_____
2 = shoulder and upper arm	_____
3 = elbow and lower arm	_____
4 = wrist and hand	_____
5 = torso	_____
6 = upper leg	_____
7 = lower leg	_____

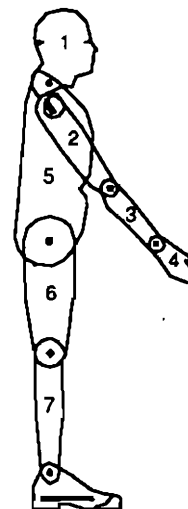


Figure 1. Body part discomfort survey.

average standard deviation from a previously performed study (Ulin *et al.* 1990). All subjects were paid for their participation in the experiment.

Subjects drove screws into perforated sheet metal at two horizontal and three vertical work locations using pneumatic tools. The subjects were required to drive screws at three different frequencies at each work location. Borg's ten-point ratio rating scale (Borg 1970) was used by the subjects to assess the perceived exertion for each work location/frequency combination. Subjects also rank ordered discomfort at seven body regions (see figure 1) for each work location.

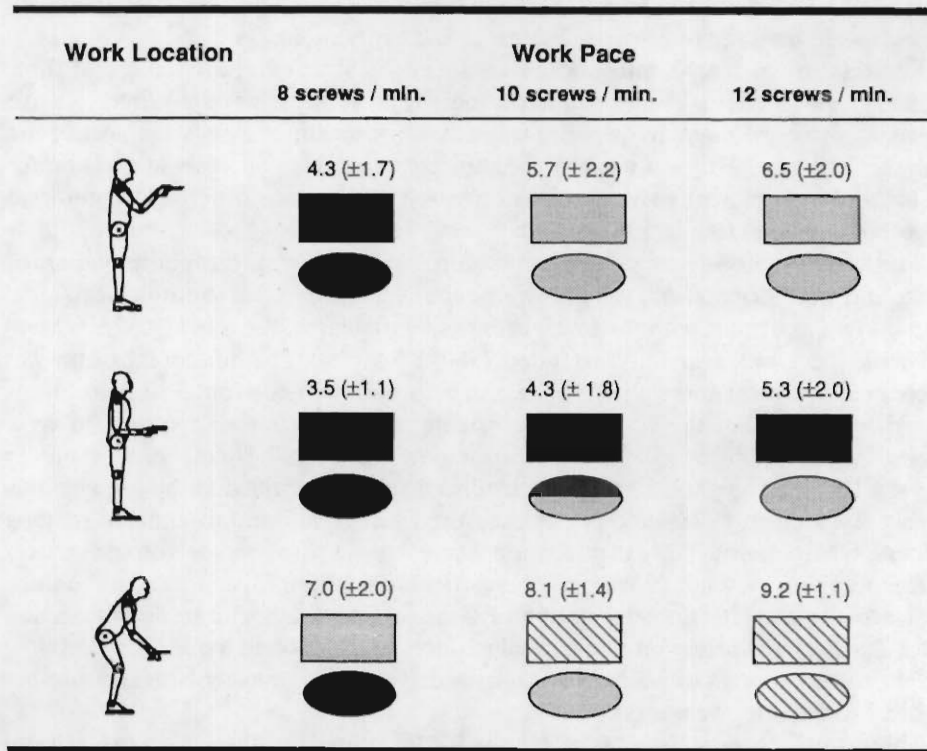
The work locations were determined according to subject anthropometry. For the horizontal work orientation, subjects were required to drive screws into a horizontal beam at two locations; with the lower arm perpendicular to the torso (22.7 ± 5.2 cm) and with the lower arm fully extended (46.6 ± 5.5 cm). The horizontal beam was placed just below the subject's elbow height, before the two horizontal work locations were determined. For the vertical work orientation, subjects were required to drive screws at their knee (55.9 ± 3.8 cm), elbow (115.6 ± 7.4 cm) and shoulder (149.4 ± 10.1 cm) heights. These body landmarks were identified at the joint centers (Webb Associates 1978) and were measured using an anthropometer (sliding calipers, GMP brand). The exact location where subjects drove screws on the vertical surface was the body landmark plus the vertical tool height (distance from the third metacarpal to the bit). Subjects used an in-line tool on the horizontal surface and a pistol-shaped screwdriver on the vertical surface. Each tool had a mass of 1.1–1.4 kg and the torque was set to 3.2 Nm. Both screwdrivers had a magnetic bit and number six hex head screws were used.

Three work paces were used at each work location. The three work paces were identified interchangeably as low, medium, and high or 8, 10 and 12 screws per minute. Subjects were always aware of the upcoming work pace before they began driving screws at a specific work location. Using a methods time measurement™ analysis of the screw driving task, a pace of 10 screws per minute would be considered working at a normal work pace (100%) (Niebel 1982). Driving screws at 8 and 12 per minute is considered working at 80% and 120%, respectively, of a normal work pace.

Each subject participated in three sessions. The initial meeting was considered a learning session. The goals of the learning session included: teaching the subjects how to use the pneumatic tools, familiarizing the subjects with the various horizontal and vertical work locations, achieving the three required work paces, and becoming familiar with the Borg ten-point ratio rating scale. Background information and subject anthropometric data was collected during the learning session.

The other two sessions were used for collection of psychophysical ratings of perceived exertion under the various work location/work pace combinations. Subjects were required to drive screws at each work location for 10 min before determining a rating for that particular work location/work pace combination. A computer beep was the signal for the subjects to begin driving the next screw. All three work paces were used by each subject at each work location. The order of the work paces and the work locations were randomly assigned for each experimental session. After completing each data collection session, subjects were asked to think back to each work location and then rank order the seven body regions according to discomfort (see figure 1).

Analysis of variance (and the comparable non-parametric tests, Kruskal-Wallis and Friedman tests), *t*-test (and the comparable non-parametric test, Mann-Whitney



Note: Subgroups created according to the Newman-Keuls multiple range test ($p=0.05$).

Similar shading defines the subgroups and indicates that the mean values at the work locations are indistinguishable (Newman-Keuls multiple range test, $p=0.05$).

The rectangles designate the subgroups of average Borg ratings stratified by the vertical work locations for each work pace, and the ovals designate the subgroups of average Borg ratings stratified by work pace for each vertical position.

Figure 2a. Average Borg ratings for driving screws on the vertical work surface at three work frequencies ($n=18$).

U test), multiple regression (Neter *et al.* 1985), Wilcoxon signed-rank test (Larsen and Marx 1981) and the Newman-Keuls multiple range test (Duncan 1974) were used to analyse the data. StatView™ (Feldman *et al.* 1986) and Systat™ (Leland 1986) were the statistics software packages used.

3. Results and discussion

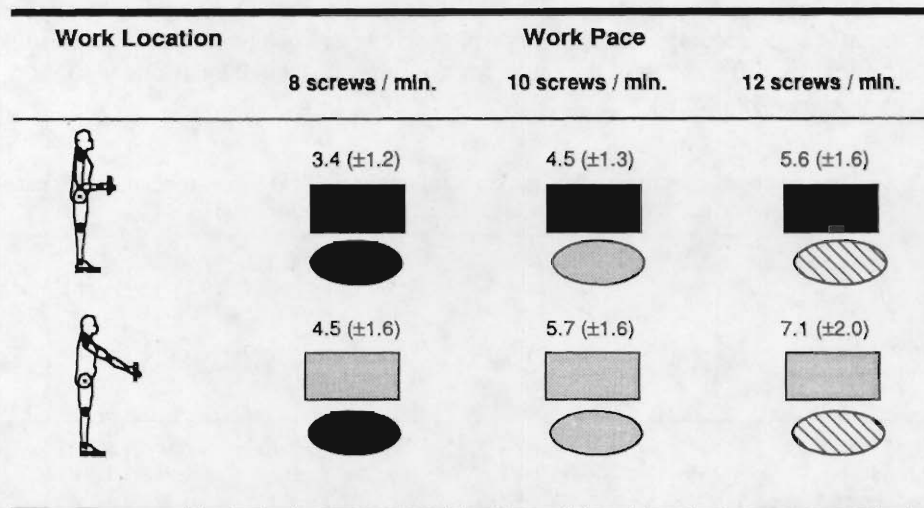
A two-factor ANOVA for both the horizontal and vertical orientations revealed that the independent variables, work location and work pace, were both significant factors ($p=0.0001$), while their interaction was not significant. The impact of each of these independent variables will be explored.

3.1. Work location

The average ratings of perceived exertion for driving screws at three locations with a pistol shaped tool on the vertical surface are displayed in figure 2a. When the ratings

for all three work paces are combined, the ratings from the three work locations, knee (8.1 ± 1.8), elbow (4.3 ± 1.8) and shoulder height (5.5 ± 2.2), are all significantly different ($p < 0.05$, Scheffé *F*-Test). The highest ratings of perceived exertion were at knee height and the lowest ratings were at elbow height (see figure 2a). At the slowest work pace of 8 screws per minute, there was not a distinguishable difference in the ratings of perceived exertion at the elbow and shoulder locations (Newman-Keuls multiple range test, $p = 0.05$), but the ratings at knee height were significantly higher (see figure 2a, rectangles). The ratings of perceived exertion increased 100% between elbow and knee height for a work pace of 8 screws per minute. There was a significant difference between the ratings from each work location at the work paces of 10 and 12 screws per minute (Newman-Keuls multiple range test, $p = 0.05$) and the ratings increased 23% to 88%.

In previous studies, work location was found to be a significant factor in driving screws on both horizontal and vertical work surfaces (Ulin *et al.* 1990, 1992). The results from the present study agree with these earlier studies. For driving screws at 64 cm with a pistol tool on a vertical surface in an earlier study, the Borg rating was 5.4 ± 2.1 , the ratings decreased at 114 cm to 2.4 ± 1.2 and increased again to 3.2 ± 1.4 at 140 cm and 4.9 ± 1.9 at 191 cm. The lowest ratings of perceived exertion for the vertical beam would be predicted at elbow height, and this is based on previous



Note: The horizontal beam was placed just below each subject's elbow height.

Note: Subgroups created according to the Newman-Keuls multiple range test ($p = 0.05$).

Similar shading defines the subgroups and indicates that the mean values at the work locations are indistinguishable (Newman-Keuls multiple range test, $p = 0.05$).

The *rectangles* designate the subgroups of average Borg ratings stratified by the horizontal work locations for each work pace, and the *oblongs* designate the subgroups of average Borg ratings stratified by work pace for each horizontal position.




Figure 2b. Average Borg ratings driving screws on the horizontal work surface at three work frequencies ($n = 18$).

psychophysical data, anthropometric predictions and biomechanical analyses (Armstrong 1986, Eckbreth 1990, Ulin *et al.* 1990, 1992).

On the horizontal surface, the ratings of perceived exertion at the close work location (4.5 ± 1.6) were significantly lower (21%) than the ratings at farthest location (5.7 ± 2.0) for all three work paces combined ($p < 0.05$, Scheffé *F*-Test). Figure 2b displays the average ratings of perceived exertion for the horizontal surface. For all three work paces individually (see figure 2b, rectangles), the ratings from the farthest work location were significantly higher (27% to 33%) than the closest work location (*t*-test, $p < 0.03$). For driving screws on a horizontal surface which is placed just below elbow height, the predicted work position for using an in-line tool would be the distance from the elbow to the center of grip (Ulin *et al.* 1992). Indeed, predictions based on anthropometric data agree with psychophysical data and the lowest ratings of perceived exertion were when subjects drove screws between 13 and 38 cm in front of their body (Ulin *et al.* 1992).

Next, the body part discomfort rankings were examined to detect the changes with respect to work location. Table 1 shows the body part discomfort rankings for the three vertical work locations. For driving screws at knee height, the torso was identified as the most uncomfortable body part and the ranking for the torso at knee height (mean torso rank of 1.8 ± 1.4) was significantly lower (more uncomfortable) than the ranks assigned to the torso for driving screws at elbow (mean torso rank of 4.7 ± 1.2) or shoulder height (mean torso rank of 4.4 ± 1.0) ($p < 0.001$, Wilcoxon signed-rank test). The upper leg and the wrist and hand were body parts which were also identified as uncomfortable while driving screws at knee height and these ranks are significantly different than the ranks for the other two work locations ($p < 0.005$, Wilcoxon signed-rank test).

Table 1. Average body part discomfort rankings following work at three frequencies for each vertical location (standard deviation in parentheses).

Body Part	Work Location		
			
Head and Neck	4.7 (± 1.7)	5.1 (± 1.6)	4.6 (± 1.5)
Shoulder and Upper Arm	4.5 (± 1.6)	2.6 (± 0.6)	1.8 (± 1.0)
Elbow and Lower Arm	4.6 (± 1.4)	2.7 (± 1.5)	2.9 (± 1.4)
Wrist and Hand	3.6 (± 2.0)	1.5 (± 1.0)	2.2 (± 1.4)
Torso	1.8 (± 1.4)	4.7 (± 1.2)	4.4 (± 1.0)
Upper Leg	3.3 (± 1.9)	5.5 (± 1.2)	5.7 (± 1.1)
Lower Leg	5.7 (± 1.7)	6.1 (± 1.1)	6.4 (± 1.2)

At knee height, subjects were not allowed to squat while driving screws, so they were forced to stoop and consequently their torso was flexed. Repeated torso flexion is associated with the onset of low back pain and/or injuries (Kelsey *et al.* 1975, and Magora, 1970). In addition, large forces and moments are created at the L5/S1 disc when subjects must drive screws with a bent torso (Chaffin and Andersson 1984). Consequently, based on biomechanics, high ratings of perceived exertion would be

expected while driving screws at knee height and it is predicted that the torso would be the most uncomfortable body part.

For driving screws at elbow height, the most uncomfortable body parts were the wrist and hand and this rank (mean rank of 1.5 ± 1.0) was significantly lower than the ranks from the other two work locations ($p < 0.005$, Wilcoxon signed-rank test). The shoulder and upper arm (mean rank of 2.6 ± 0.6) and the elbow and lower arm (mean rank of 2.7 ± 1.5) were the next most uncomfortable body regions when driving screws at elbow height.

When driving screws with a pistol shaped tool at elbow height on the vertical work surface, subjects stood upright with their upper arm next to the torso, and their lower arm and hand perpendicular to the work surface. In this posture, all the body joints are in a neutral position (Armstrong 1986, and Keyserling 1986) and this would consequently be considered an acceptable work posture. Also, elbow height is used as a predictor for proper work height (Armstrong 1986). Previous research has shown that predicted work heights based on a subject's elbow height (work height = elbow height + vertical tool height) correspond with psychophysical ratings when subjects are asked to drive screws at several vertical work locations (Ulin *et al.* 1990, 1992). Since none of the other body regions were severely stressed, the body parts which were performing the task and absorbing the reaction force from the tool were rated as most uncomfortable at elbow height.



For driving screws at shoulder height, the shoulder and upper arm received the lowest (most uncomfortable) ranking (mean rank of 1.8 ± 1.0) and this rank was significantly lower than the ranks which the shoulder and upper arm received after driving screws at elbow and knee height ($p < 0.005$, Wilcoxon signed-rank test). The wrist and hand (mean rank of 2.2 ± 1.4) were the next most uncomfortable body region at shoulder height and the rank was significantly different than those from the other two work locations ($p < 0.005$, Wilcoxon signed-rank test).

Working above mid-chest height has been associated with fatigue and shoulder disorders (Chaffin 1973, Feldman *et al.* 1983, Hagberg 1981, 1982, 1984). Driving screws at shoulder height, created a moment at the shoulder that is greater than for driving screws at both knee and elbow height. Because of the findings from previous psychophysical data, epidemiological studies, and biomechanical analyses, the ratings of perceived exertion for driving screws at shoulder height are expected to be larger than the ratings at elbow height.

For the horizontal work surface, no significant difference was found between any of the body part ranks when comparing the ranks for the two work locations (see table 2). At the closest work location, the wrist and hand received the lowest rank (most uncomfortable, mean rank was 1.7 ± 1.3) and this rank was significantly lower than the ranks for the other body regions ($p < 0.05$, Wilcoxon signed-rank test). The elbow and lower arm (mean rank of 3.4 ± 1.1) and the shoulder and upper arm (mean rank of 2.7 ± 0.9) were the next most uncomfortable body regions at the closest horizontal work location ($p < 0.05$, Wilcoxon signed-rank test). The resultant moments created at the elbow and shoulder for driving screws close to the body are relatively low. Since none of the body joints are severely stressed, the body parts which were performing the task and absorbing the reaction force from the tool were rated as most uncomfortable.

At the farthest horizontal work location, the wrist and hand were once again the body parts which received the lowest rank (most uncomfortable) and this rank was significantly lower than the ranks for the other body regions ($p < 0.05$, Wilcoxon

Table 2. Average body part discomfort rankings following work at three frequencies for each horizontal location (standard deviation in parentheses).

Body Part	Work Location	
		
Head and Neck	3.8 (± 1.6)	4.0 (± 1.6)
Shoulder and Upper Arm	2.7 (± 0.9)	2.8 (± 0.9)
Elbow and Lower arm	3.4 (± 1.1)	3.5 (± 1.2)
Wrist and Hand	1.7 (± 1.3)	1.8 (± 1.3)
Torso	4.3 (± 1.9)	3.8 (± 2.0)
Upper Leg	5.7 (± 1.5)	5.6 (± 1.5)
Lower Leg	6.3 (± 1.0)	6.4 (± 0.9)

Note: The horizontal beam was placed just below each subject's elbow height.

signed-rank test). The shoulder and upper arm were the next most uncomfortable body parts, followed by the elbow and lower arm, the torso, and the head and neck ($p < 0.05$, Wilcoxon signed-rank test). Driving screws at this position results in localized fatigue (Chaffin 1973) and the resultant moment at the shoulder and the L5/S1 are two to three times larger than when driving screws with the arms close to the body. For this work location, the wrist and hand were the most uncomfortable body region probably because of the torque which was transmitted to the hands while driving screws. Previous research has shown that driving screws beyond 38 cm in front of the body creates high levels of perceived exertion (Ulin *et al.* 1992), so the results from this study agree with prior experimental research and theoretical arguments.

3.2. Work pace

For the vertical orientation, with the ratings from all work locations combined, the ratings at the slowest work pace (4.9 ± 2.2) were significantly lower (18% and 30% lower) ($p < 0.05$, Scheffé *F*-Test) than the ratings from the other two work paces (6.0 ± 2.4 and 7.0 ± 2.4). Even though the ratings of perceived exertion at 12 screws per minute (7.0 ± 2.4) were larger than the ratings at 10 screws per minute (6.0 ± 2.4), the difference was not significant ($p > 0.05$, Scheffé *F*-Test). As work pace increases, any extra increment of time which may have been previously available for rest or recovery of fatigued muscles is diminished and consequently, the ratings of perceived exertion rose.

To examine the effect of work pace, the Newman-Keuls multiple range test ($p = 0.05$) was used to test the difference between the ratings from the three work paces at each work location. At knee height, the ratings of perceived exertion for the three work paces, 8, 10, and 12 screws per minute, were all different (see figure 2a, oblongs). The ratings increased by approximately one point on the Borg scale with the increasing work pace (see figure 2a); the ratings increased 14% between 8 and 10 screws per minute and the ratings increased 12% between 10 and 12 screws per minute. The ratings of perceived exertion for driving screws at knee height were 24% larger at 12 screws per minute than at 8 screws per minute.

For driving screws at elbow height on the vertical surface, the ratings from the

slowest pace and the middle pace and the ratings from the middle and the fastest pace were not significantly different from each other. With each incremental increase in work pace, the Borg ratings increased by 19%. There was a 34% increase in the ratings of perceived exertion between the fastest and the slowest work paces (see figure 2a, oblongs).

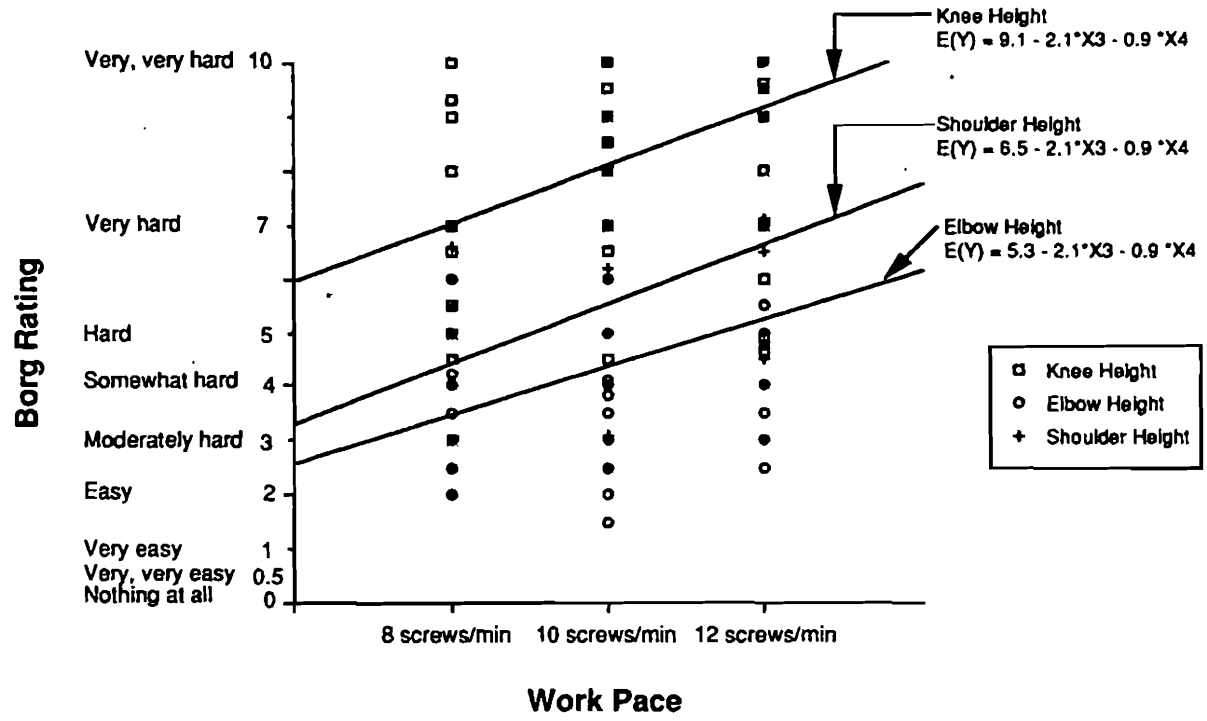
For driving screws at shoulder height on the vertical surface, the ratings from the fastest and the middle work pace were not significantly different from each other, but they were significantly greater than the rating at the slowest work pace of 8 screws per minute (see figure 2a, oblongs). There was a 25% increase in the Borg ratings when the work pace increased from 8 screws per minute to 10 screws per minute. The increase in the ratings between the 10 and 12 screws per minute condition was smaller; the ratings increased by 12%. A 34% increase in the ratings of perceived exertion was observed between the slowest and the fastest work paces studied for driving screws at shoulder height on a vertical surface.

In a cross-sectional study designed to evaluate the relationship between repetitiveness, forcefulness and selected cumulative trauma disorders (Silverstein *et al.* 1987), both the repetitiveness and the forcefulness of a job were defined as two categories (high and low). In this particular sample of 652 workers from seven work sites, epidemiologic data show that the risk of hand and wrist tendinitis is 29 times greater (Armstrong *et al.* 1987), and the risk of carpal tunnel syndrome is 14 times more likely (Silverstein *et al.* 1987), in workers who perform highly repetitive and highly forceful operations than in people who perform jobs that are low in both repetitiveness and force. Repetitiveness appeared to be a greater risk factor than force (Silverstein *et al.* 1987). The present study demonstrated that ratings of perceived exertion increase with work pace and previous research has shown that the risk of injuries increases as psychophysical guidelines are exceeded (Herrin *et al.* 1986, Liles *et al.* 1984, Snook 1978, and Snook *et al.* 1978).

For driving screws on the vertical surface, the lowest ratings of perceived exertion were at elbow height, for all work frequencies. But, at the slowest work pace of 8 screws per minute, there was not a distinguishable difference in the Borg ratings at elbow (3.5 ± 1.1) and shoulder height (4.3 ± 1.7), but the ratings at knee height (7.0 ± 2.0) were significantly larger (Newman-Keuls multiple range test, $p=0.05$) (see figure 2a, oblongs). This suggests that at a slow work pace, there was some recovery time. Because of the increased strain on the torso to drive screws at knee height, even at the slow work pace, the ratings of perceived exertion at knee height were significantly greater than the ratings at shoulder or elbow height (Newman-Keuls multiple range test, $p=0.05$). For both 10 and 12 screws per minute, there was a distinguishable difference in the ratings of perceived exertion for all three vertical work locations (Newman-Keuls multiple range test, $p=0.05$).

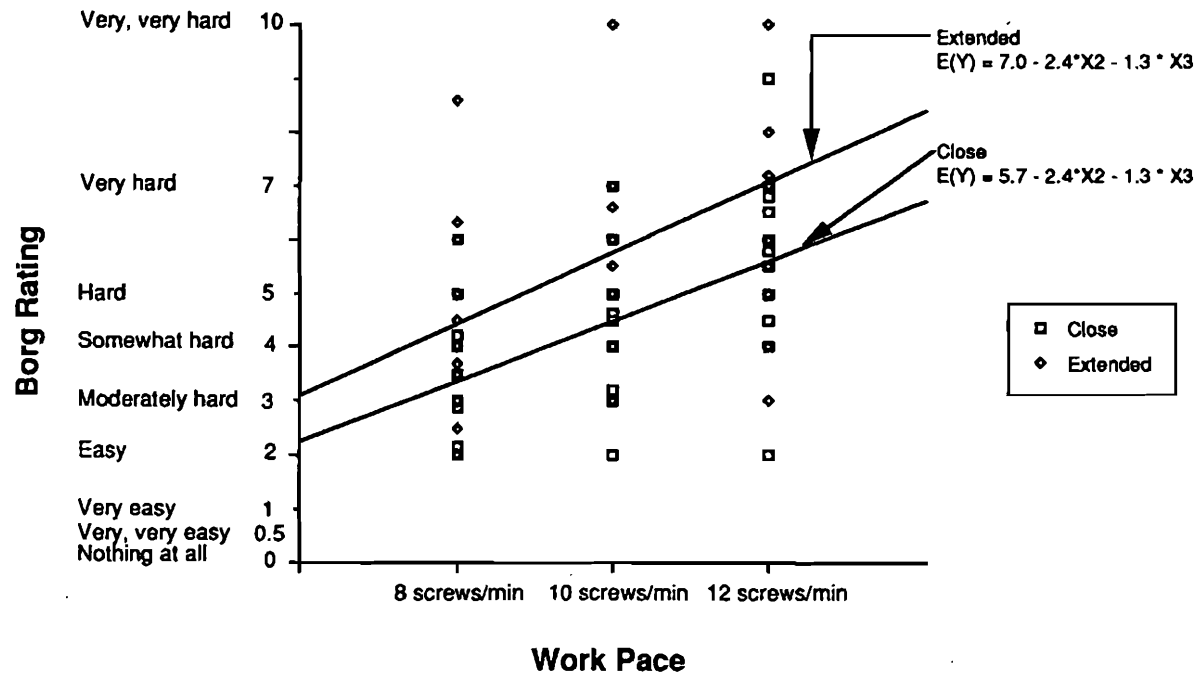
For both horizontal work locations, when the ratings from each work pace were compared, an increase in work pace caused a significant increase in the ratings of perceived exertion (Newman-Keuls multiple range test, $p=0.05$) (see figure 2b, oblongs). Regardless of horizontal work location, for each incremental increase in work pace, the ratings of perceived exertion increased 20% to 24%. At the closest work location, the ratings increased 39% between the slowest and fastest work conditions, while at the farthest work location, the ratings increased 37% between 8 screws per minute and 12 screws per minute.

Multiple regression was used to model the perceived exertion for driving screws with increasing speed at various vertical and horizontal work locations. The



The regression equation for driving screws on the vertical surface is:
 $Y = 6.5 + 2.6 \cdot X_1 - 1.2 \cdot X_2 - 2.1 \cdot X_3 - 0.9 \cdot X_4$, $R^2 = 0.52$
 where: $X_1 = 1$ at knee height, 0 otherwise
 $X_2 = 1$ at elbow height, 0 otherwise
 $X_3 = 1$ at 8 screws per minute, 0 otherwise
 $X_4 = 1$ at 10 screws per minute, 0 otherwise

Figure 3a. Fitted regression function for the vertical surface.



The regression equation for driving screws on the horizontal surface is:
 $Y = 5.7 + 1.3 \cdot X_1 - 2.4 \cdot X_2 - 1.3 \cdot X_3$, $R^2 = 0.38$
 where: $X_1 = 1$ at extended work location, 0 otherwise
 $X_2 = 1$ at 8 screws per minute, 0 otherwise
 $X_3 = 1$ at 10 screws per minute, 0 otherwise

Figure 3b. Fitted regression function for the horizontal surface.

dependent variable, the Borg rating of perceived exertion, was regressed on the work pace and the work locations which were expressed as binary (dummy) variables. For both the vertical ($R^2=0.52$) and the horizontal ($R^2=0.38$) orientations, the fitted regression equations were significantly different since the 95% confidence intervals for the coefficients did not include zero (see figures 3a and 3b). Therefore, both work location and work pace caused detectable increases in the rating of perceived exertion.

4. Conclusions

It was hypothesized that workstation design guidelines which follow from psychophysical research will reduce the occurrence of work-related disorders, fatigue, and localized discomfort. This hypothesis is based on previous research that has shown the risk of back injuries increases as psychophysical guidelines are exceeded (Herrin *et al.* 1986, Liles *et al.* 1984, Snook 1978, and Snook *et al.* 1978), that subjective ratings of body discomfort are consistent with objective fatigue data for various hammering tasks (Schoenmarklin and Marras 1989), and that workstations can be improved based on body part discomfort data (Corlett and Bishop 1976, 1978). Consequently, it is hypothesized that the workstation design guidelines suggested by this research will also reduce the risk of work-related disorders, fatigue and localized discomfort.

Several workstation design guidelines can be formulated based on this research and are listed below.

1. The preferred vertical location for driving screws was at elbow height; the Borg ratings of perceived exertion were lower (18%–50%) than the ratings at knee height or shoulder height, regardless of work pace.
2. Work at knee height should be infrequent or avoided even at a slow work pace. At a work pace of 8 screws per minute, there was not a distinguishable difference in the ratings of perceived exertion for driving screws at shoulder (4.3 ± 1.7) and elbow (3.5 ± 1.1) height. Although, the ratings at knee height (7.0 ± 2.0) were significantly higher.
3. Repetitive work should be placed near elbow height whenever possible, because driving screws at elbow height received significantly lower (23%–88%) ratings of perceived exertion than both shoulder and knee height. For driving screws at both 10 and 12 screws per minute, there was a distinguishable difference in the ratings of perceived exertion for all three vertical work locations.
4. The preferred location for driving screws on the horizontal surface should be close to the body instead of working with the arms fully extended; the Borg ratings of perceived exertion were lower (27%–32%) at the closest work locations, regardless of work pace. Therefore, repetitive work should be placed within a comfortable forearm reach of the worker (<23 cm).

These results can be used as workstation design guidelines, although further research is needed to support the hypothesis that workstations designed based on these guidelines actually reduce the incidence of work-related disorders.

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