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Examination of the effect of tool mass and work postures on perceived exertion for a screw driving task

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Abstract

Eighteen subjects with industrial work experience drove screws into perforated sheet metal at three vertical (64, 114 and 165 cm) locations with a pistol-shaped tool, and at two horizontal (13 and 63 cm) work locations using an in-line tool. Both air-powered tools were varied in mass (1, 2 and 3 kg). Subjects drove screws using each tool mass at all work locations. After driving 25 screws at a particular work location/tool mass combination, subjects assessed their perceived exertion for that condition using the Borg ten-point ratio rating scale and completed a body part discomfort survey. Both tool mass and work location were significant factors in determining the ratings. As tool mass increased, so did the ratings of perceived exertion (18% to 100%). The lowest ratings of perceived exertion were at 114 cm on the vertical surface and at 13 cm on the horizontal surface. For the vertical surface, the body part discomfort data revealed that the low back and the right arm were often cited as uncomfortable at 64 cm, the right arm was identified as uncomfortable at 114 cm, and the right arm and the chest were cited as uncomfortable at 165 cm. For the horizontal surface, at both 13 cm and 63 cm, the neck and the right arm were identified as uncomfortable.

Relevance to industry

This laboratory study simulated industrial work environments and subjects with industrial work experience were used. The guidelines developed through this and other related studies can be readily applied to the design of work stations or the selection of powered hand tools with the goal of minimizing the prevalence of work-related musculoskeletal disorders. It may be possible to generalize these results to other types of hand tools and workstations.

Keywords

Hand tools; Ergonomic design guidelines; Psychophysical assessment

Introduction

A large variety of hand tools and work surfaces can be found throughout industry, but no clear ergonomics design guidelines are available which can aid in the selection of the appropriate tool for a specific application. Psychophysical methods have previously been used by researchers to develop such guidelines for manual materials handling tasks (Baxter et al., 1986; Fernandez and Ayoub, 1988; Karwowski and Burkhardt, 1988; Legg and Myles, 1985; Ljungberg et al., 1982; Snook, 1978, 1985; Snook and Irvine, 1966, 1968; and Snook et a1., 1970). Previous research has demonstrated that psychophysical data from ratings of screw driving tasks favorably agree with biomechanical predictions and contribute to the development of workstation design guidelines (Ulin et al., 1990, 1992a, b, c). Furthermore, they have shown that the Borg rating of perceived

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exertion and the visual analogue scales are comparable and can be used to reliably assess perceived pain (Arstila and Wendelin, 1974; Harms-Ringdahl et al., 1986; and Ulin et al., 1990). The previous studies of screw driving tasks have examined vertical work location, horizontal work location, work frequency, tool shape, and the vertical height of a horizontal surface. This study was designed to examine the effect of tool mass and work location on ratings of perceived exertion and body part discomfort ratings for screw driving tasks.

Materials and methods

Subjects drove screws into perforated sheet metal at three vertical and two horizontal locations. Three levels of tool mass were used. Subjects used Borg's ten-point ratio rating scale (Borg, 1970, 1990) to express their perceived exertion and visual analogue scales to quantify their level of discomfort for various body parts at each tool/work location combination (Arstila and Wendelin, 1974; Gaston-Johansson, 1984; Harms-Ringdahl et al., 1986; Price et al., 1976; and Seymour et al., 1985).

Subjects

Eighteen subjects (9 males and 9 females) with a minimum of one year industrial work experience participated in the experiment and were paid for their participation. The subjects were recruited through an advertisement in a local newspaper. Subject ages ranged from 20 to 61 years (34.4 ± 11.8 years) and their stature ranged from 149 to 197.1 cm (169.9 ± 10.8 cm). Their employment histories included working as an automotive mechanic, electronics technician, aircraft mechanic, pipefitter, electronics assembler, carpenter and press operator.

Equipment

Eighteen gauge perforated sheet metal with a hole size of 0.28 cm was mounted on both a horizontal and a vertical surface. Three vertical (64, 114 and 165 cm from the floor) and two horizontal work locations (13 and 63 cm from the

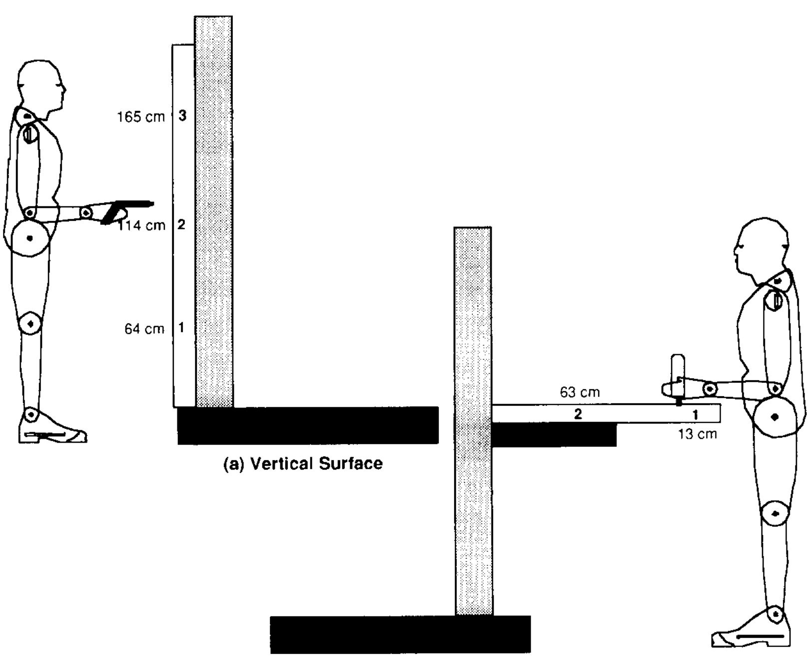

Fig. 1. Experimental apparatus.

edge of the beam) were the identified positions for subjects to drive number six hex head screws (1.9 cm in length) (see Fig. 1). The horizontal beam was placed just below each subject's elbow height.

Subjects used a pistol-shaped tool (Atlas Copco, model no. A 780002; 1600 revolutions per minute) to drive screws on the vertical surface and an in-line tool (Stanley, model no. A 30NRT-18; 1700 revolutions per minute) to drive screws on the horizontal surface. In order to keep the wrist in a neutral posture while using the tool, the pistol tool was chosen for the vertical surface and the in-line tool was chosen for the horizontal surface (Armstrong, 1986). These tools had a mass of 1.0 kg, a shut-off clutch, and the torque was set to 3.2 Nm. Both screwdrivers had philips magnetic bits. The air pressure was set to 620.5 kPa. The distance from the center of the handle to the bit was 23.5 cm for the pistol tool, and 20.3 cm for the in-line tool. Rings of steel were added to each tool, while preserving the center of balance, to increase the mass of the tool to 2.0 and 3.0 kg. These tool masses reflect what is most frequently utilized in automotive assembly (Armstrong et al., 1989). A plastic cuff was positioned over the steel rings so subjects could not see the size of the rings (see Fig. 2). The air hose was attached to the bottom of the pistol tool and the top of the in-line tool. Subjects were allowed to arrange the location of the air hose; however, it was not possible to mount it overhead.

Procedure

Subjects were required to participate in two experimental sessions. The first session was used to collect background information and anthropometric data and to familiarize the subjects with the experimental protocol. During the first session, subjects were familiarized with the tools, the work pace, the work locations, the Borg scale and the visual analogue scales.

The second session was used for data collection. The presentation of the work orientations, work locations and tool masses were all random-

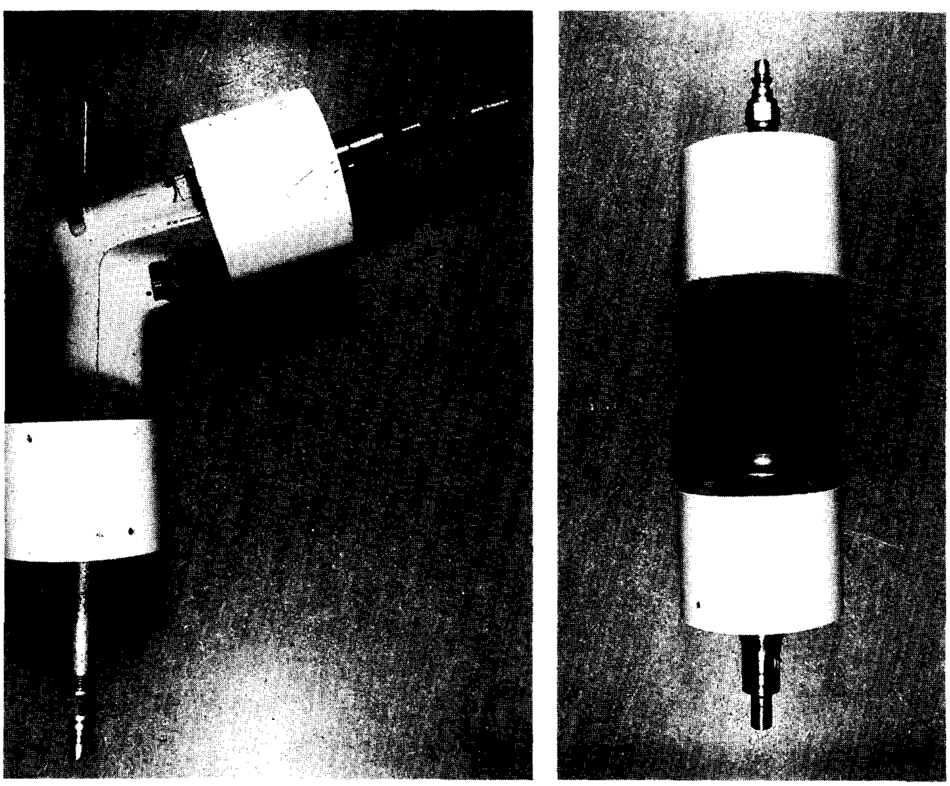

Fig. 2. (a) Pistol tool with plastic cuff; (b) in-line tool with plastic cuff.

ized. Subjects drove screws at each horizontal and vertical work location using all three tool masses. The pistol-shaped tool was used to drive screws on the vertical surface and the in-line tool was used on the horizontal surface. A computer beep which sounded every seven seconds was used to pace the subjects. The work pace was determined by using data from Methods-Time Measurement (Niebel, 1982). Subjects drove 25 screws at each work location/tool mass combination before determining a rating using Borg's ten-point ratio rating scale (Borg, 1970, 1990). To determine a rating, subjects were instructed to imagine that they are a worker on an assembly line who drives screws into sheet metal as part of their job. Their workload is based on working a normal eight-hour shift which allows them to go home without feeling uncomfortable, strained or tired. After driving 25 screws at that particular work location/tool mass combination, subjects rated that condition based on working for a normal eight-hour work day.

The Borg 10-point category ratio rating of perceived exertion (Borg, 1970, 1990) was the dependent variable. The scale was developed while studying both short-term (less than 1 minute) and long-term (several minutes) exercise on the bicycle ergometer (Borg, 1990). The rating of perceived exertion has been used in ergonomic investigations, in studies of heavy aerobic work, and in tasks that consist of short-term static work (Borg, 1990). In a previous investigation (Ulin et al., 1990) the Borg 10-point category ratio rating scale was compared with two visual analogue scales, and the scales were comparable.

Lastly, subjects completed a body part discomfort survey (see Fig. 3). Subjects were asked to shade every area of the body (front and back)

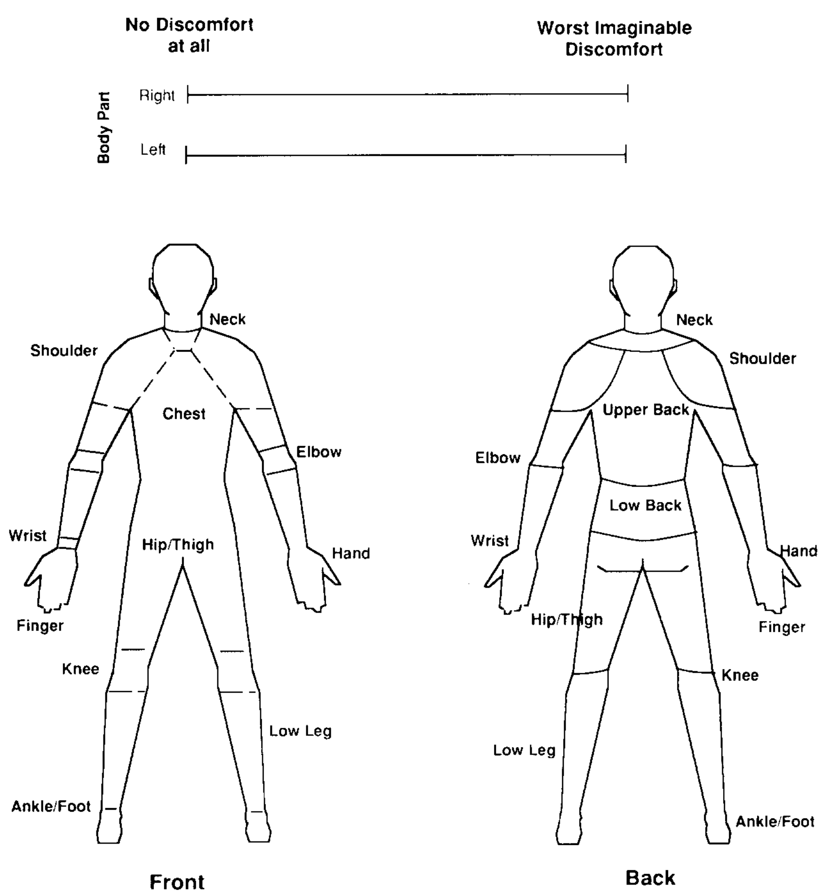

Fig. 3. Sample of body part discomfort form.

where they felt discomfort. Then they used the visual analogue scales to rate the degree of discomfort for each of the shaded body parts. The visual analogue scales were 10 cm lines and the numerical rating was the distance in centimeters from the left endpoint. The endpoints for the visual analogue scale were "no discomfort at all" (rating of zero) and "worst imaginable discomfort" (rating of ten).

Analysis of variance (and the comparable non-parametric tests, Kruskal-Wallis and Friedman tests), multiple regression (Neter et al., 1985), and the Newman-Keuls multiple range test (Duncan, 1974) were used to analyze the data.

Results

A two-factor ANOVA revealed that the independent variables, tool mass and work location, were each significant factors ($p < 0.001$) in determining the rating of perceived exertion for driving screws on both the vertical and the horizontal surface. For driving screws on the vertical surface, $F(2, 153) = 23.0$ and $F(2, 153)$ 28.0 for work location and tool mass, respectively ($p < 0.001$). $F(1, 102) = 22.1$ and $F(2, 102) = 41.8$ for work location and tool mass, respectively, ($p < 0.001$) for driving screws on the horizontal surface. The interaction between tool mass and work location was not significant ($p > 0.001$). Therefore, the impact of tool mass and work location on the rating of perceived exertion and body part discomfort will be presented.

Table 1 shows the changes in the ratings of perceived exertion for driving screws on both a horizontal and a vertical surface using tools which vary in mass. On the vertical surface, at 114 cm, the average ratings were 3.6 ± 1.7 and increased to 6.0 ± 2.5 at 64 cm and to 5.2 ± 2.2 at 165 cm (all tool masses pooled). For driving screws with the in-line tool on the horizontal surface, the average perceived exertion at 13 cm was 3.6 ± 2.0 (all tool masses pooled) and increased to 5.1 ± 2.3 at 63 cm (all tool masses pooled). For all vertical and horizontal work locations, the ratings increased with each incremental rise in tool mass. With increasing tool mass, the ratings of perceived exertion rose from 3.5 ± 1.6 to 6.1 ± 2.2 (all vertical locations pooled) on the vertical surface, and the ratings rose from 2.5 ± 1.0 to 6.0 ± 2.1 (both horizontal locations pooled) on the horizontal surface.

From the body part discomfort data it was seen that, overall, the right lower and upper arms were reported as uncomfortable for all vertical and horizontal work locations, and the median ratings increased with each incremental rise in tool mass (see Tables 2 and 3). For driving screws on the vertical surface, the low back (median ratings of 4.4 to 6.9) and the right upper (median ratings of 3.2 to 4.5) and lower arms (median ratings of 3.2 to 5.0) were often cited as uncomfortable at 64 cm (33.3% to 83.3%) when the subjects were required to stoop; the right upper and lower arms (median ratings of 1.4 to 4.0) were identified as uncomfortable at 114 cm (33.3% to 88.9%); and the right upper and lower arms (median ratings of 2.1 to 5.9) and the chest (median ratings of 1.4 to 3.9) were cited as uncomfortable at 165 cm (22.2% to 88.9%). For the horizontal surface, at both 13 cm and 63 cm, the neck and the right upper and lower arms (median ratings of 1.2 to 5.0) were identified as uncomfortable (22.2% to 88.9%). At 63 cm, a greater percentage of subjects reported low back discomfort (33.3% and median ratings of 2.4 to 5.0).

Tool mass

Perceived exertion

As tool mass increased. so did the ratings of perceived exertion for each vertical location (see

Table 1

Average Borg ratings for driving screws with a pistol-shaped tool on the vertical surface and an in-line tool on the horizontal surface ($n = 18$)

	Tool mass			
	1 kg	2 kg	3 kg	Mean
Vertical work location				
165 cm	4.5 ± 1.9	5.3 ± 2.0	6.8 ± 2.1	5.2 ± 2.2
114 cm	2.3 ± 0.8	3.8 ± 1.8	4.6 ± 1.4	3.6 ± 1.7
64 cm	4.5 ± 1.9	6.4 ± 2.6	7.0 ± 2.3	6.0 ± 2.5
Mean	3.5 ± 1.6	5.2 ± 2.4	6.1 ± 2.2	
Horizontal work location				
13 cm	1.9 ± 0.9	3.8 ± 1.9	5.0 ± 1.8	3.6 ± 2.0
63 cm	3.0 ± 0.9	5.1 ± 1.9	7.1 ± 2.0	5.1 ± 2.3
Mean	2.5 ± 1.0	4.4 ± 2.0	6.0 ± 2.1	

Table 1). Pairwise comparisons of the ratings revealed that for driving screws with the pistol-shaped tool at 64 cm, the ratings associated with a tool mass of 1 kg were significantly lower (42% to 55%) than the ratings associated with a tool mass of either 2 kg or 3 kg (Newman-Keuls multiple range test, $p = 0.05$). Although the average perceived exertion for driving screws at 64 cm using a 3 kg tool was 10% greater than when using a 2 kg tool, this difference was not significant. At 114 cm and 165 cm, perceived exertion increased significantly with increasing tool mass (Newman-Keuls multiple range test, $p = 0.05$); for each 1 kg increase in tool mass there was a significant increase (18% to 65%) in the ratings of perceived exertion at 114 cm and 165 cm.

Accompanying each 1 kg increase in tool mass, was a corresponding increase in the ratings of perceived exertion at both 13 cm and 63 cm on the horizontal surface which was located at elbow height (see Table 1). At both horizontal work locations, pairwise comparisons of the ratings associated with each tool mass revealed that for each 1 kg increase in tool mass there was a significant increase (32% to 100%) in the ratings of perceived exertion (Newman-Keuls multiple range test, $p = 0.05$).

Body part discomfort

When a 1 kg tool was used to drive screws at 64 cm on the vertical surface, the low back was the most cited uncomfortable body part (88.9%). As the tool mass increased to 2 kg and 3 kg, the low back was cited by a slightly lower percentage (77.8% and 66.7%) of the subjects, but the median ratings assigned to the low back increased from 4.4 at 1 kg, to 6.9 at 2 kg and 5.5 at 3 kg (see Table 2). For driving screws at 114 cm and 165 cm, there were not many changes in the percentage of subjects citing the various body parts as

Table 2

Median values of body part discomfort ratings and percentage of subjects reporting discomfort for driving screws on a vertical surface

Horizontal work location & body parts	Tool mass					
	1 kg		2 kg		3 kg	
	Median	Percent	Median	Percent	Median	Percent
165 cm						
Right lower arm (front)	2.8	88.9	4.7	94.4	5.1	88.9
Right lower arm (back)	2.1	33.3	4.3	38.9	4.6	44.4
Right upper arm (front)	2.6	88.9	4.3	83.3	5.9	83.3
Right upper arm (back)	2.1	55.6	3.8	50.0	4.1	55.6
Neck/Chest (front)	1.4	22.2	2.5	33.3	2.1	27.8
Neck/Chest (back)	2.1	33.3	3.9	38.9	3.4	44.4
Low back	4.0	16.7	5.9	11.1	5.4	22.2
114 cm						
Right lower arm (front)	2.0	88.9	2.9	94.4	4.0	83.3
Right lower arm (back)	1.4	38.9	1.9	33.3	3.3	38.9
Right upper arm (front)	2.2	55.6	3.0	50.0	3.2	72.2
Right upper arm (back)	1.4	33.3	1.2	27.8	3.5	44.4
Neck/Chest (front)	1.8	16.7	1.6	11.1	1.0	16.7
Neck/Chest (back)	0.6	16.7	6.8	16.7	4.0	16.7
Low back	1.9	22.2	1.7	22.2	3.9	11.1
64 cm						
Right lower arm (front)	3.3	77.8	3.2	83.3	4.7	83.3
Right lower arm (back)	5.0	38.9	3.2	33.3	3.9	27.8
Right upper arm (front)	3.5	38.9	4.5	55.6	3.3	61.1
Right upper arm (back)	3.2	33.3	3.5	55.6	3.7	50.0
Neck/Chest (front)	3.2	11.1	1.8	27.8	1.9	22.2
Neck/Chest (back)	5.4	27.8	4.7	50.0	4.0	50.0
Low back	4.4	88.9	6.9	77.8	5.5	66.7

Table 3

Median values of body part discomfort ratings and percentage of subjects reporting discomfort for driving screws on a horizontal surface

Horizontal work location & body parts	Tool mass					
	1 kg		2 kg		3 kg	
	Median	Percent	Median	Percent	Median	Percent
13 cm						
Right lower arm (front)	1.9	77.8	3.3	88.9	3.7	88.9
Right lower arm (back)	1.4	22.2	4.6	33.3	3.4	38.9
Right upper arm (front)	1.2	44.4	4.1	55.6	4.6	72.2
Right upper arm (back)	1.3	27.8	3.1	44.4	3.5	38.9
Neck/Chest (front)	0.7	11.1	4.6	16.7	6.2	16.7
Neck/Chest (back)	0.9	22.2	3.2	16.7	3.1	33.3
Low back	2.8	11.1	1.4	22.2	3.3	16.7
63 cm						
Right lower arm (front)	2.5	77.8	4.3	83.3	5.0	83.3
Right lower arm (back)	2.7	27.8	4.4	38.9	3.7	33.3
Right upper arm (front)	2.2	66.7	4.5	83.3	4.8	94.4
Right upper arm (back)	3.0	33.3	4.1	61.1	4.4	61.1
Neck/Chest (front)	1.7	11.1	1.8	22.2	2.1	16.7
Neck/Chest (back)	1.9	22.2	1.9	38.9	4.4	38.9
Low back	2.4	33.3	2.4	33.3	5.0	33.3

uncomfortable as the tool mass increased (see Table 2), although, in general, the median ratings for the identified body parts rose as the tool mass increased.

For driving screws at 13 cm with an in-line tool on the horizontal surface, the percentage of subjects citing the upper arm as uncomfortable increased from 44.4% when the tool mass was 1 kg to 72.9% when the tool mass was 3 kg (see Table 3), and the median ratings increased from 1.2 to 4.6 (see Table 3). At 63 cm, the percentage of subjects identifying the upper arm as uncomfortable rose to 94.4% with a median rating of 4.8 when the tool mass was 3 kg.

Work location

Perceived exertion

For driving screws with a pistol shaped tool on the vertical surface, the ratings of perceived exertion were lowest at 114 cm and then increased 40% to 96% at the higher location of 165 cm, and 52% to 96% at the lower work location of 64 cm, averaged across all tool masses (see Table 1). The ratings of perceived exertion at 114 cm were 48% to 96% lower than the ratings at 64 cm and 165 cm. Pairwise comparisons of the ratings at the three vertical locations for each tool mass, individually, revealed that the ratings at 114 cm were significantly lower than the ratings at 165 cm and 64 cm and that there was not a significant difference in the ratings at 165 cm and 64 cm across all tool masses (Newman-Keuls multiple range test, $p = 0.05$).

The ratings of perceived exertion were lower (34% to 58%) at 13 cm than at 63 cm for driving screws with an in-line screwdriver on the horizontal surface which was placed at elbow height (see Table 3). Across all tool masses, the ratings at 13 cm were significantly lower than the ratings at 63 cm (Newman-Keuls multiple range test, $p = 0.05$).

Body part discomfort

The body part discomfort data (see Table 2) revealed that the right upper (49.1%, averaged over tool mass) and lower arms (57.4%, averaged over tool mass), the low back (77.8%, averaged over tool mass) and the neck (31.5%, averaged over tool mass) were frequently cited as uncomfortable body parts while driving screws at 64 cm. At 64 cm, subjects were not allowed to squat while driving screws, so they were forced to stoop, and consequently their torso was flexed. The median ratings from the visual analogue scale for the low back at 64 cm ranged from 4.4 to 6.9, and in general, these ratings were larger than the ratings assigned to the low back at the other vertical work locations (see Table 2). After driving screws at 165 cm on the vertical surface, subjects cited the right upper and lower arms and the neck and chest as the uncomfortable body parts (see Table 2). The visual analogue ratings (median values) for the arms ranged from 2.1 to 5.9.

For driving screws at both 13 cm and 63 cm on the horizontal surface which was placed just below elbow height, the right upper and lower arms were the most frequently cited uncomfortable body parts (56.9% to 50.5%, respectively, averaged over tool mass and work location) (see Table 3). In general, at 63 cm, the upper arm was identified as uncomfortable (66.7%, averaged over tool mass) by a greater percentage of subjects than at 13 cm (47.2%, averaged over tool mass) and the ratings assigned to the body parts were larger at 63 cm (see Table 3). The median ratings at 13 cm ranged from 1.2 to 4.6 and at 63 cm ranged from 2.2 to 5.0.

Discussion

Tool mass

In a previous investigation, Harms-Ringdahl et al. (1986) applied external weights of 1.5, 2 and 3 kg to the forearm for a duration of two minutes to eight healthy subjects. Subjects rated the intensity of the pain using both visual analogue scales and the Borg ratio rating scale (the one used in this study). An increase in the perceived pain occurred with each increase in joint loading by means of increasing the applied weight. Consequently, even though this is a dynamic task, it would be predicted that the ratings of perceived exertion and the right arm discomfort ratings would increase as the tool became heavier. As the tool mass increased, larger forces and moments were created at the elbow and shoulder and consequently, more subjects were identifying the arms as uncomfortable and the ratings of perceived exertion increased (see Tables 1, 2 and 3).

Work location

In previous studies, work location was found to be a significant factor for driving screws on both a horizontal and a vertical surface (Ulin et al., 1990, 1992a, b, c). In two previous studies (Ulin et al., 1990, 1992c), subjects drove screws with a pistol tool having a mass of 1 kg at 64, 114 and 165 cm on a vertical surface. In these previous studies, the Borg ratings of perceived exertion from college students who served as subjects were similar to the ratings reported from the present study; the ratings were lowest at 114 cm (2.4 ± 1.2) and increased at 64 cm (5.4 ± 2.1) and 165 cm (4.9 ± 1.9) (Ulin et al., 1992c).

Repeated torso flexion is associated with the onset of low back pain and/or injuries (Kelsey and Hardy, 1975; Magora, 1970). Also, large shear, as well as compressive, forces are created at the L5/S1 disc when subjects must drive screws with a bent torso (Chaffin and Andersson, 1984). Consequently, high ratings of perceived exertion would be expected at 64 cm, and it is predicted that a large percentage of subjects would identify the low back as uncomfortable.

For driving screws at 114 cm on the vertical 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 et al., 1986) and this would consequently be considered an acceptable work posture, since postural stresses are minimized. The right upper and lower arms were most often cited as uncomfortable body parts (47.2% and 63.0%, respectively, averaged over tool mass) and the median ratings for these body parts ranged from 1.2 to 4.0 (see Table 2). Since none of the 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 114 cm while using the pistol tool. Consequently, the lowest ratings of perceived exertion would be expected at 114 cm.

Working above mid-chest height has been associated with fatigue and shoulder disorders (Chaffin, 1973; Feldman et al., 1983; Hagberg, 1981; Hagberg, 1982; and Hagberg, 1984), so both the ratings of perceived exertion and the body part ratings are expected to be larger for driving screws at 165 cm. At the 165 cm vertical work location, the moment created at the shoulder is greater than at 114 cm and 64 cm, so consequently, the magnitude of the ratings assigned to the identified body parts were larger than at other vertical locations.

When an in-line tool with a mass of 1 kg was used to drive screws at four locations (13, 38, 63 and 88 cm) on a horizontal surface in a previous study (Ulin et al., 1992c), similar results were obtained. Although the ratings from the present study are smaller in magnitude than the ratings reported in previous studies, the ratings followed the same trend. The ratings of perceived exertion were lowest at 13 cm (2.9 ± 1.8) and then increased as the work locations were farther away from the body (Ulin et al., 1992c). Specifically, the ratings were 4.7 ± 1.9 for driving screws at 63 cm (Ulin et al., 1992c). With the arms extended, larger moments were created at the elbow and shoulder, and consequently, the ratings of perceived exertion and the body part discomfort ratings for the arms increased.

Impact of work experience

A previous experiment examined the effect of work location on subject's ratings of perceived exertion (Ulin et al., 1992c). In that study, university students with little or no industrial work experience served as subjects. The present study utilized subjects with a minimum of one year of industrial work experience. The ratings of perceived exertion from the industrial subjects are very similar to the ratings reported by university students performing the same task in a previous experiment. In the previous study (Ulin et al., 1992c), the ratings from the university students at 165 cm on the vertical surface were 4.9 ± 1.9, at 114 cm were 2.4 ± 1.2, and at 64 cm were 5.4 ± 2.1. For the horizontal surface, the university students reported ratings of 2.9 ± 1.8 at 13 cm and 4.7 ± 1.9 at 63 cm. The mean ratings reported for the subjects with industrial work experience (see Table 1) for driving screws with a 1 kg pistol tool on the vertical surface are 9% to 20% lower than the ratings from the university students and the variance in the ratings was nearly equal ($p = 0.0062$, Wilcoxon signed-rank test). For driving screws with a 1 kg in-line driver on the horizontal surface, the ratings of perceived exertion from the industrial subjects are 32% to 57% lower than the ratings from the university students and the variance in the ratings is 50% lower ($p = 0.0037$, Wilcoxon signed-rank test). The ratings (and the variance in the ratings) from the industrial subjects after using the in-line tool may be lower because they had more experience using tools like an in-line screwdriver, in comparison to the pistol tool, which transmit a very noticeable torque reaction to the hands and requires more force to control the tool. Overall, the data from both subject populations follow the same trends, but university students may report larger ratings of perceived exertion if the tool transmits a large reaction torque to the hands.

Summary

Based on previous research which has shown that overexertion injuries, fatigue and localized discomfort increase when psychophysical guidelines are exceeded (Herrin et al., 1986; Liles et al., 1984; Snook, 1978; and Snook et al., 1978), it is hypothesized that workstation design guidelines which follow from psychophysical research will reduce the occurrence of work-related disorders. Several work station design guidelines can be formulated based on this research and are listed below.

(1) Driving screws at 114 cm with the pistol-shaped tool was the preferred vertical work location. The Borg ratings of perceived exertion at 114 cm were 51% to 72% lower than the ratings at 64 cm and 165 cm, regardless of tool mass.

(2) For driving screws with an in-line driver on the horizontal surface, the preferred work location was 13 cm. At 13 cm, the Borg ratings of perceived exertion were 63% to 75% lower than the ratings at 63 cm.

(3) A tool mass of 1 kg was preferred. For all vertical and horizontal work locations, the ratings of perceived exertion increased 18% to 100% with each 1 kg increase in tool mass.

(4) Industrial subjects rated specific work conditions lower than university students, but the ratings followed the same trends for the work locations and tools studied.

Further research is needed to test the hypothesis that the workstations designed based on these findings actually reduce the incidence of work-related musculoskeletal disorders.

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