Psychophysically determined work durations for limiting shoulder girdle fatigue from elevated manual work

Vernon Putz-Anderson and Traci L. Galinsky

U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science, Cincinnati, OH 45226, USA

Abstract

An early symptom of many soft tissue disorders is excessive muscle fatigue during manual work. This study adopted a psychophysical approach to determine work durations for limiting shoulder-girdle fatigue. In a series of four experiments, each subject monitored his/her level of arm/shoulder discomfort while performing a task requiring repetitive, elevated arm movements. Over the course of a short (3–6 hr) work day, the subject terminated each trial, initiating a 1-min rest period, when the discomfort reached a pre-specified level on Borg's 10-point category-ratio scale. Average trial durations decreased minimally or remained stable over the work day. Nevertheless, increases in task loading variables, including repetition rate, required force, tool weight and reach height, each led to significant decreases in work duration. (Average trial durations associated with varying levels of work demand ranged from 29 to 160 sec.) Rate and force of movement had the largest effects on work duration. The effects of reach height and tool weight were small by comparison. Thus, the former two factors are relatively more crucial in the development of shoulder and arm fatigue. Unexpectedly, males tended to engage in longer work trials than females, despite controlling for upper body strength. The possible role of gender-related experimental demand characteristics is discussed.

Relevance to industry

A technique for limiting musculoskeletal fatigue during manual work is presented, and the influence of manual task characteristics on fatigue accumulation is investigated. The results are useful for the design of job-paced manual tasks such as materials handling, machine assembly, packaging, etc.

Keywords

Musculoskeletal fatigue; shoulder girdle; cumulative trauma disorders; repetitive work; work duration; muscle force; work rate; work height; tool weight; psychophysics; magnitude production.

Introduction

Musculoskeletal impairments of the shoulder, neck, and upper arms account for a considerable proportion of sick leave cases in industry and offices (Anderson, 1984). Repetitive manual work involving awkward arm/shoulder postures has been identified as a primary factor in the etiology of many of these impairments (Komoike et al., 1975; Lascelles et al., 1977; DeLacerda, 1982; Matsen and Kirby, 1982; Neviaser, 1983). An early symptom of such use-related soft tissue disorders, typically referred to as cumulative trauma disorders (CTDs) or repetition strain injuries (RSIs), is local muscle fatigue (Valencia, 1986; Baidya and Stevenson, 1988; Edwards, 1986). Hence, work designs that prevent the accu-

Correspondence to: T.L. Galinsky, NIOSH, Mail Stop C-24, Robert Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226, USA.

mulation of excessive local muscle fatigue should reduce the risk of work-related impairments.

Interventions aimed at minimizing the accumulation of local muscle fatigue require an appropriate index for quantifying its magnitude. To date, most investigators have made use of electromyography (EMG) for this purpose. These measures, however, often produce equivocal results (see Wiker et al., 1989 for a brief review). Moreover, on purely logical grounds, EMG measures are not necessarily ideal for examining fatigue in the shoulder girdle. Specifically, even the simplest work activity requiring exertion of the shoulder girdle involves combinations of as many as 15 different muscles, 4 joints, 12 ligaments, and a host of tendons contributing in varying degrees (Engin, 1980). Hence, information on the level of contraction of one or more muscles would be inadequate to depict the state of the entire shoulder girdle. At present, the only way to obtain such a global assessment is to quantify the worker's perceptual experience of local fatigue sensations using psychophysical techniques. Accordingly, the present study adopted a psychophysical approach to limit the accumulation of local muscle fatigue in the shoulder/arm/neck during repetitive work in which the arm is elevated.

The fatigue which accrues during work is dependent on both the physical requirements of the task (e.g., required force) and the duration of the task. Therefore, when the physical parameters of the job cannot be modified, reductions in fatigue can be accomplished only by shortening the *duration* of the work cycle. Sato and his colleagues recognized this factor by emphasizing the need for data specifying the *time* at which local fatigue sensations occur during manual work (Sato et al., 1984). With this goal in mind, we employed a modified version of Stevens' (1956) method of magnitude production to determine fatigue-limiting work durations for a simulated work task requiring repetitive elevated arm movements. Subjects were trained to monitor levels of perceived shoulder-girdle discomfort while working, and to initiate a rest period each time these sensations exceeded a pre-specified level, as defined by Borg's (1980, 1982) scale of perceived discomfort. A series of experiments was conducted to determine the manner in which these fatigue-limiting work durations vary in response to systematic changes in various task factors.

In order to establish that the Borg scale would serve as a useful metric for determining fatigue-limiting work durations, it was first necessary to ensure that subjects could make reliable discriminations among the scale's values. Consequently, the first experiment employed three of the scale's values as discomfort criteria for work cessation. Force of arm movement was also varied in the first experiment.

Three subsequent experiments involved an assessment of specific task factors which would be expected to play some role in the development of repetition strain injuries of the shoulder girdle. Repetitiveness, of course, is by definition a central factor in the development of repetition strain injury. Thus, of particular interest in the present study was the influence of the *rate* of repetition on fatigue-limiting work durations, and how that influence might compare, and/or interact, with that of other task factors. For this reason, repetition rate was included as an independent variable in the last three experiments. Its effects were examined in conjunction with those of required force output (Experiment 2), tool weight (Experiment 3), and reach height (Experiment 4).

Methods

Subjects

Seventy-two right-handed individuals were recruited from a temporary employment agency to serve as subjects (18 in each experiment). All had prior assembly work experience and were free of any known musculoskeletal impairments. Table 1 contains demographic and anthropometric data for subjects in each experiment. There was no attempt to exclude workers based on anthropometric differences, such as limb length or hand size. Minor anthropometric differences that did exist in the worker sample were accommodated by adjusting the position and height of the chair with respect to the work station.

Apparatus

A Baltimore Therapeutic Equipment work simulator, comprised of an exercise head with an

attached crank shaft and a control console, was used for strength testing and work simulation. A pistol-shaped simulated tool was affixed to the crank shaft of the work simulator. The handle segment was a cylindrical piece of metal measuring 12.0 cm long and 13.0 cm in circumference. The 'barrel' segment was an 11.0 cm × 2.5 cm piece of metal. In Experiment 3, three plastic, cylindrical canisters (16.5 cm long and 13.0 cm in circumference) filled with different amounts of lead shot were used to manipulate tool weight. Weights of 2136, 2506, and 3039 gm were achieved by attaching one of the three canisters (136, 506, and 1039 gm) to the tool (2 kg) using semi-rigid plastic prongs. The three weights are representative of those found in the automotive assembly industry (Armstrong et al., 1989). A 7.0 cm long metal pointer was attached to the end of the barrel segment of the tool handle. Two metal plates, each measuring 25.0 cm × 5.0 cm, were placed vertically, one above the other, on a pole in front of the tool. The tool handle was positioned such that it could be grasped and moved up and down in a 180 degree vertical arcing motion to strike the metal pointer against each metal plate in succession. An illustration of the

Fig. 1. The repetitive motion task shown with the upper-target pacing signal illuminated. Target heights of 120 cm (upper) and 77 cm (lower) from floor were used in Experiments 1–3. The entire set of the three target height pairs was used in Experiment 4.

apparatus is presented in figure 1 (control console not shown).

The subject was seated in a chair positioned behind and to the left of the tool handle. When grasping the handle, the right arm was parallel to

Table 1

Demographic and anthropometric data for subjects in each experiment.

Experiment 1	*Males (n = 8)*		*Females (n = 10)*		*All (n = 18)*	
Attribute	$\bar{X}$	STD	$\bar{X}$	STD	$\bar{X}$	STD
Age (yr)	27	6	32	7	30	7
Height (cm)	179	8	162	6	170	10
Weight (1b)	157	31	139	25	147	28
Experiment 2	*Males (n = 9)*		*Females (n = 9)*		*All (n = 18)*	
Attribute	$\bar{X}$	STD	$\bar{X}$	STD	$\bar{X}$	STD
Age (yr)	29	7	31	7	30	7
Height (cm)	179	8	164	3	171	10
Weight (1b)	155	17	147	37	151	29
Experiment 3	*Males (n = 9)*		*Females (n = 9)*		*All (n = 18)*	
Attribute	$\bar{X}$	STD	$\bar{X}$	STD	$\bar{X}$	STD
Age (yr)	26	6	26	5	26	5
Height (cm)	178	4	164	3	171	8
Weight (1b)	167	19	134	14	151	24
Experiment 4	*Males (n = 9)*		*Females (n = 9)*		*All (n = 18)*	
Attribute	$\bar{X}$	STD	$\bar{X}$	STD	$\bar{X}$	STD
Age (yr)	35	8	31	7	33	8
Height (cm)	175	7	167	4	171	7
Weight (1b)	184	40	147	29	166	39

the mid-sagittal plane. The distance of the chair and the height of the seat pan were adjusted such that when the subject touched the top metal plate with the tool's metal pointer, the elbow joint was flexed at approximately 165 degrees (i.e., about 90% of maximum reach). In Experiments 1–3, the upper and lower target locations were held constant in the (approximate) centers of the top and bottom plates, respectively, with the height of the upper target measuring 120 cm from the floor. In Experiment 4, in which work height was varied, target locations were shifted to upper and lower portions of the two plates. The highest upper target in that experiment was 131 cm, and was used in the initial adjustment to obtain an elbow angle of 165 degrees and a maximum reach of about 90%. In all experiments, the vertical distance between upper and lower targets was held constant at 43 cm (see figure 1).

Strength testing

Static strength testing is used routinely to assess the capacity to perform dynamic tasks (Chaffin, 1975). Thus, prior to introducing the work task, a static strength test was conducted to determine the subject's maximal voluntary contraction (MVC) for the lifting phase of the repetitive vertical arcing motion. [1] For this test, the work simulator was set to the static mode, allowing the experimenter to lock the crank shaft in one position. The subject was instructed to grasp the tool handle and attempt to move it up towards the top metal plate, exerting as much effort as possible, for a count of 3 sec. With this arrangement, the mechanical advantage afforded the subject was greater and lesser at higher and lower positions, respectively. Accordingly, in order to obtain a representative estimate of the subject's maximum exertion capability, three trials were conducted at each of two elevations, with a 1-min rest break between each trial. For the first 3 MVC trials, the tool handle was positioned at chest height to produce a 78.5° angle between the upper and lower arm. With the tool handle locked at this point in the arc which it traverses during move-

ment, the subject was required to pull on the tool handle in a 'backwards/upwards' direction. For the last 3 MVC trials, the tool handle was raised to shoulder height, producing an elbow flexion angle of 65.5°. At this position in the arc, the subject was required to *push* on the locked tool handle in a 'forwards/upwards' direction. The peak torque applied by the subject on each trial was measured and recorded by the work simulator in inch/pounds. The subject's MVC was computed as the mean torque value for the 6 trials. The mean MVC value obtained from the 72 subjects was 201.0 inch/pounds, with a standard deviation of 108.0 inch/pounds.

Force levels

For the work task, the simulator was switched to the dynamic mode, allowing the crank shaft to move in the vertical arcing motion. Force levels were achieved by setting the resistance of the crank shaft (i.e., required force) to a percentage of the subject's MVC. Required force was varied among torque levels of 10, 20, and 30 percent MVC in the first and second experiments. Required force was held constant at 15 percent MVC in Experiments 3 and 4. At each torque level, the resistance was maintained throughout the range of upward and downward movement. In this manner, different levels of task difficulty could be studied without confounding the dependent measure of work duration with differences attributed to each subject's muscle strength (Chaffin, 1975).

The work task

The work task entailed repeated lifting and lowering of the tool handle, striking the metal pointer to one of the metal plates at the end of each excursion to simulate a repetitive assembly job in which the hand tool is supported. A cycle consisted of a 180° (arcing) movement to lift the handle followed by a 180° (arcing) movement to lower the handle. Each complete cycle was regarded as one repetition. Repetition rate was controlled by an electronic timer, which provided subjects with both visual and auditory pacing signals. The timer unit activated two lights, positioned in the lower left corners of the metal plates. The subject was instructed to strike the

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[1] MVC for the lowering phase was not assessed, since the lifting phase, which is more physically-challenging, represents the 'limiting factor' affecting subjects' strength for this task.

pointer on the top plate when its light was illuminated and a concurrent high-pitched tone was sounded. Illumination of the light on the bottom plate and the sounding of a concurrent low-pitched tone signaled to the subject that the bottom plate should be struck. Each subject practiced until s/he demonstrated sufficient accuracy in keeping pace with the lights and tones. Repetition rate was held constant at 24 cycles/min in the first experiment, whereas it varied among 20, 24 and 35 cycles/min in Experiments 2–4. The three rates were chosen in order to encompass a range of values found in industrial assembly tasks (Armstrong, T., 1989. Personal communication).

Subjects also were instructed how to use the Borg (1980, 1982) CR-10 scale of perceived discomfort. This scale is a 10-point category rating scale with ratio properties which yields psychophysical functions similar to those found with magnitude estimation methods. Ratings of muscle discomfort made with the scale have been shown to be significantly correlated with blood lactate and muscle lactate levels (Noble et al., 1981).

Subjects used the Borg scale to gauge the level of muscle fatigue experienced while they performed the repetitive motion task. For each trial, they were instructed to stop working and release the tool handle when the sensations in the neck, shoulder, or upper arm reached the criterion level of discomfort for that trial. In the first experiment, the discomfort criterion was varied among levels 3, 4, and 5 on the scale, labeled as 'moderate', 'somewhat strong', and 'strong' discomfort, respectively. In Experiments 2–4, the criterion was held constant at the 'somewhat strong' level.

A portable microcomputer was used to display the Borg scale, instruct the subjects, and control the duration of rest periods between work trials. The monitor was situated in front of the subject at a distance of approximately 1 m. Before each trial, the Borg scale was shown on the screen for 5 sec. On the next screen, the subject was instructed to establish the correct posture and prepare to grasp the tool handle. Following the video message to 'START', the subject grasped the tool handle and commenced working. The final screen for each trial reminded the subject to stop working and release the tool handle when the level of arm/shoulder discomfort reached the criterion for that trial. The duration of each work trial was measured to the nearest second and recorded by the work simulator. When the subject stopped working, the experimenter prompted the computer to initiate a 1-min rest period, during which the message 'PLEASE WAIT' was displayed on the screen.

Experimental design

Each experiment employed a repeated measures design in which three levels of one task factor were combined with three levels of a second task factor, providing a total of nine task factor combinations per experiment.

In Experiment 1, three discomfort criteria (Moderate, Somewhat Strong, and Strong) were combined with three force levels (10, 20 and 30 percent MVC). Subjects engaged in two work trials per combination, presented in random order in each of four work sessions, for a total of 72 trials.

Table 2

Variables in each experiment.

	Work duration (Sec)	Discomfort criterion Borg scale	Required force (% MVC)	Repetition rate (lifts/min)	Tool weight (kg)	Reach height (cm)	Work session (number)
Experiment 1	D	I	I	C	C	C	I
Experiment 2	D	C	I	I	C	C	I
Experiment 3	D	C	C	I	I	C	I
Experiment 4	D	C	C	I	C	I	I

Key: (The levels for each of the independent variables (I) are defined in the text.)
D = Dependent variable
I = Independent variable
C = Controlled variable

In Experiments 2–4, three repetition rates (20, 24, and 35 cycles/min) were employed. In Experiment 2, the three rates were combined with force levels of 10, 20, and 30% MVC. In Experiment 3, they were combined with three tool weights (2136, 2506 and 3039 gm). In Experiment 4, the three repetition rates were combined with three reach heights (109, 120 and 131 cm), defined as the height from the floor to the upper target in the repetitive motion task. In Experiments 2–4, subjects engaged in three work trials per task factor combination, presented in random order in each of three work sessions, for a total of 81 trials per experiment. Table 2 contains a summary of all independent (I), dependent (D) and control (C) variables for each experiment.

Prior to the first work session in each experiment, the subject engaged in 9 practice trials, which included 3 trials at each combination of task factors employed in that experiment. Subjects were encouraged to concentrate on becoming proficient at using the Borg scale to judge their level of muscle fatigue during the practice phase.

Experiment 1: Results

Work session

The average work trial durations in sessions 1–4 were 77, 71, 66, and 66 sec, respectively. Analysis of variance revealed that the effect of work session was significant, $F(1,16) = 6.46$, $p < 0.004$. [2] The results of post-hoc comparisons, however, indicated that work duration decreased significantly from the first to the second work session, $F(1,16) = 8.08$, $p < 0.01$, but not from the second to the third. Thus, it appears that in this first experiment, our method for limiting shoulder girdle discomfort on individual work trials was successful in moderating the accumulation of fatigue over the course of the work day.

[2] Greenhouse-Geisser conservative degrees of freedom were used for all repeated measures tests in the analyses of variance.

Discomfort criterion

Subjects were able to adjust their work trial durations to attain each of three experimentally-set levels of perceived arm/shoulder discomfort. As the discomfort criterion was raised from 3 (moderate) to 4 (somewhat strong) to 5 (strong), there was a corresponding increment in work duration ($\bar{x} = 47.91$, 66.62, and 93.63 sec, respectively). Analysis of variance confirmed that the main effect of discomfort criterion was significant, $F(1,16) = 71.64$, $p < 0.0001$. This result verifies the Borg scale's utility for making rather subtle discriminations of discomfort magnitude to establish acceptable work durations.

Force

As expected, increases in the force output requirement from 10 to 20 to 30 percent MVC produced corresponding decreases in work trial duration ($\bar{X} = 88.02$, 69.31, and 52.83 sec, respectively). The results of analysis of variance indicated that this effect was significant, $F(1,16) = 48.45$, $p < 0.0001$.

Force X criterion

Mean work trial durations in each Force X Criterion condition are displayed in figure 2. As shown, work trial duration varied inversely with force under each discomfort criterion. It is apparent from the figure, however, that increases in discomfort criterion led to increasingly marked
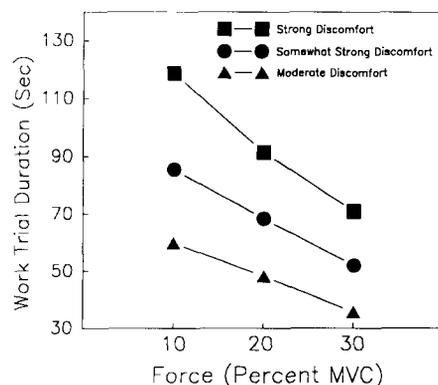

Fig. 2. Interaction between force of movement and discomfort criterion (Experiment 1).

reductions in work-time as a function of force. The impression is confirmed by a significant Force X Criterion interaction, $F(1,16) = 11.83$, $p < 0.0003$. This finding highlights the importance of the designated 'fatigue endpoint' in adjusting work durations for changes in physical demand.

Gender

The average work trial duration produced by men ($\bar{X} = 80.28$ sec) was longer than that produced by women ($\bar{X} = 61.87$ sec). Analysis of variance, however, indicated that this difference was not significant, $F(1,16) = 2.44$, $p > 0.05$.
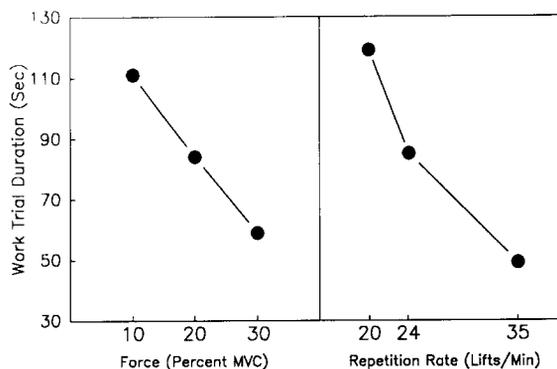

Fig. 3. Mean work trial duration as a function of force and rate of movement (Experiment 2). Values for each factor are averaged across levels of the other factor.

Experiment 2: Results

Work session

The average work trial duration decreased significantly as time progressed from the first to the third work session ($\bar{X} = 92$, 84, and 77 sec in work sessions 1–3), $F(1,16) = 8.84$, $p < 0.001$. Post-hoc comparisons revealed that the decrease in work duration from Session 2 to Session 3 was significant, $F(1,16) = 5.74$, $p < 0.03$, whereas the decrease from Session 1 to Session 2 was marginally significant, $F(1,16) = 4.24$, $p < 0.06$. Thus, subjects in this experiment appear to have experienced some degree of cumulative fatigue over time, despite the practice of limiting the accumulation of shoulder girdle discomfort during individual work trials.

Force and repetition rate

Mean work trial durations obtained under each level of force and repetition rate are plotted separately in figure 3. As shown, work trial duration varied inversely with each of these variables. The analysis of variance indicated that both effects were significant, $F(1,16) = 42.40$, $p < 0.0001$ for force, and $F(1,16) = 133.20$, $p < 0.0001$ for rate. It is apparent from the figure that increases in both force and rate produced substantial decreases in work trial duration; force accounted for 21% of variance in the analysis and rate accounted for 39% of the variance.

The analysis also revealed a significant interaction between force and rate, $F(1,16) = 7.13$, $p < 0.0006$. As shown in figure 4, increases in each variable led to a slight, progressive attenuation of the other variable's effect. This interaction is most likely attributable to the strength of each variable's separate influence upon work duration. For example, the fastest repetition rate could have been so taxing in and of itself that reductions in force were relatively ineffective in forestalling the criterial threshold of discomfort. Hence, the slope relating work duration to force at the fastest rate was less steep than at the slower rates. The same line of reasoning could account for the attenuated effect of rate at the highest level of force.
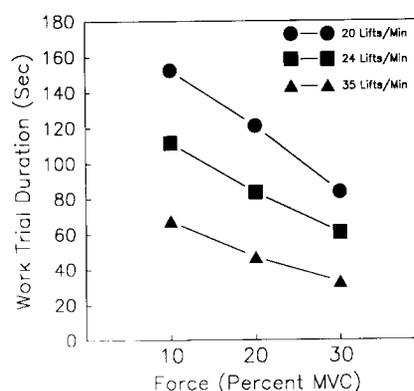

Fig. 4. Interaction between force and rate of movement (Experiment 2).

Gender

The average work duration for women ($\overline{X} = 90$ sec) was somewhat higher than for men ($\overline{X} = 79$ sec) in this study. This difference, however, was not statistically significant, $F(1,16) = 1.06$, $p > 0.05$.

Experiment 3: Results

Work session

A small decrease in average work trial duration was observed as time progressed from Work Session 1 ($\overline{X} = 73$ sec) to Work Session 2 ($\overline{X} = 68$ sec) to Work Session 3 ($\overline{X} = 65$ sec). This decrease was minimal, however, and the results of analysis of variance indicated that the effect of work session was not significant, $F(1,16) = 3.14$, $p > 0.05$. Thus, in this experiment, as in Experiment 1, the method of limiting work-Induced discomfort during individual work trials was successful in deterring excessive accumulation of fatigue over time.

Tool weight and repetition rate

Mean work trial durations obtained with each tool weight and repetition rate are plotted separately in figure 5. As shown, work trial duration varied inversely with each of these variables. Analysis of variance indicated that both effects
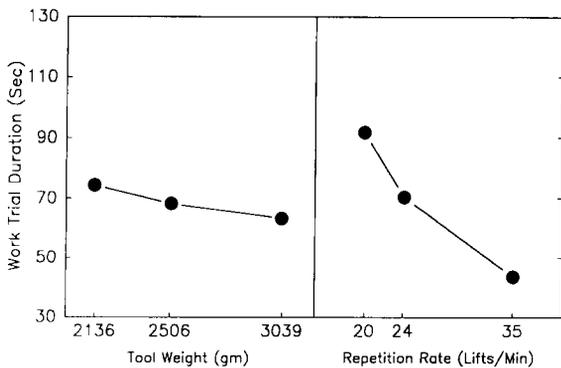
Fig. 5. Mean work trial duration as a function of tool weight and repetition rate (Experiment 3). Values for each factor are averaged across levels of the other factor.
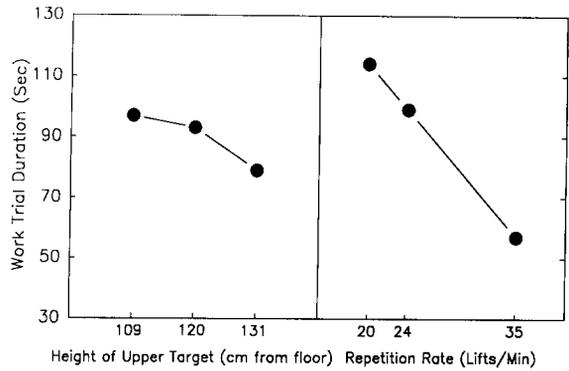
Fig. 6. Mean work trial duration as a function of reach height and repetition rate (Experiment 4). Values for each factor are averaged across levels of the other factor.

were significant, $F(1,16) = 14.36$, $p < 0.0002$ for weight, and $F(1,16) = 69.24$, $p < 0.0001$ for rate. it is apparent from the figure, however, that the magnitude of the effects differed for the two variables. Increases in tool attachment weight led to minor reductions in mean work trial duration, accounting for only 2% of the variance in the analysis. By contrast, increases in repetition rate led to pronounced reductions in work trial duration which accounted for 45% of the variance.

Gender

As in Experiment 1, the mean work duration of male subjects ($\overline{X} = 82$ sec) was longer than that of female subjects ($\overline{X} = 55$ sec). This difference was significant in the present experiment, $F(1,16) = 8.76$, $p < 0.01$.

Experiment 4: Results

Work session

Average trial durations for Work Sessions 1–3 in Experiment 4 were 100, 85, and 85 sec, respectively. The decrease from the first to the second session was significant, $F(1,16) = 9.28$, $p < 0.007$. The finding that work duration did not continue to decrease suggests that the effect of time on fatigue accumulation was negligible in this experiment.

Reach height and repetition rate

Mean work trial durations obtained with each reach height and repetition rate are plotted separately in figure 6. Analysis of variance indicated significant inverse relationships between each of these factors and work duration, $F(1,16) = 38.70$, $p < 0.0001$ for height, and $F(1,16) = 96.47$, $p < 0.0001$ for rate. As is evident in the figure, repetition rate was once again the more powerful variable, accounting for 43% of the variance in the analysis as compared to only 4% accounted for by reach height.

Gender

As in the previous experiment, the average trial duration for men $\overline{X} = 105$ sec) was significantly longer than for women ($\overline{X} = 74$ sec) in this experiment, $F(1,16) = 9.93$, $p < 0.006$.

Discussion

In the present study, subjects were trained to monitor the accumulation of perceived fatigue in the shoulder-girdle during work requiring repetitive arm lifts. Subjects initiated a rest pause each time these sensations exceeded a pre-specified threshold of discomfort. Average work trial durations obtained in this way decreased only slightly, or not at all, over the course of a short work day. This outcome suggests that by limiting the buildup of fatigue on each work trial, the effectiveness of brief recovery periods was maintained over time. To the extent that work loads or work durations can be adjusted to prevent overaccumulation of fatigue during individual work cycles, work capacity can be maintained without increasing the likelihood of cumulative trauma.

Aside from its preventive implications, the method of regulating work durations using a perceived fatigue criterion provides an empirical means for evaluating the influence of various task factors on fatigue. In the present study, repetition rate, force of movement, tool weight and reach height were varied with this objective in mind. Not surprisingly, significant reductions in work duration were required to compensate for the acceleration of fatigue produced by increases in each of these task parameters. Moreover, we found that the four task factors differed in terms of their relative impact upon fatigue-limiting work durations. Specifically, variations among the selected levels of repetition rate and force of movement had considerably more powerful effects upon the rate of fatigue accumulation than did variations among the tool weights and work heights that were selected for this study.

In each experiment, rate accounted for more variance in work duration than the task factor with which it was paired. This finding is consistent with previous work demonstrating the importance of repetition in the etiology of upper-extremity musculoskeletal disorders (Komoike et al., 1975; Lascelles et al., 1977; DeLacerda, 1982; Matsen and Kirby, 1982; Neviaser, 1983). Efforts to minimize the prevalence of these disorders would be aided by establishing duration limits for repetitive work which are commensurate with the pace of that work.

The influence of force of movement was comparable to that of repetition rate in the present study. Moreover, as shown in Experiment 2, a high level of either variable (e.g., rate) leads to rapid accumulation of fatigue that is not slowed considerably by a decrease in the other variable (e.g., force). In regard to job design, low levels of either factor should not be expected to mitigate the other factor's potential for inducing cumulative trauma.

While work durations produced by men and women were not affected differentially by any of the task factors studied, there was some tendency for the overall work duration of men to be longer than that of women. This result was somewhat surprising, since the required force of movement was maintained at an equal percentage of maximum exertion capability across individuals. Although evidence is available to indicate that perceived exertion grows faster in women than in men when their work demand is objectively equivalent (e.g., Arstila et al., 1977), we are unaware of any data suggesting that this difference would remain after a task is equated for strength capacity.

One possible explanation for the gender differences found in the present study involves the well-known psychological phenomenon of demand characteristics (Orne, 1962). Specifically, it

is conceivable that subjects' work durations were influenced to some extent by what they thought was expected of them, given their gender. Some evidence for this possibility comes from a study by Dember et al. (1992), who found that the level of difficulty (in a visual target detection task) chosen by subjects was dependent upon the subject's sex, with more frequent choices of 'easy' and 'difficult' by women and men, respectively. Interestingly, pilot work in that study indicated that the effect was most pronounced when the experimenter was female, although experimenter gender did not have a significant impact in the experiment proper. Nevertheless, it is worth noting that in the present study, significant gender differences occurred only when the experimenter was female (Experiments 3 and 4), and not when the experimenter was male (Experiments 1 and 2). Thus, experimenter gender may account for, or at least may have contributed to, the observed subject gender differences in work duration. Such an effect might be more closely associated with tasks which are primarily physical (e.g., the present study), as opposed to perceptual/cognitive (e.g., the Dember et al. study), in nature. In either case, the issue of experimenter gender certainly deserves further consideration in designing psychophysical research which contains motivational components.

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