Applied Ergonomics 1987, **18**.3, 239–243

Maximum acceptable lifting loads during seated and standing work positions

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The psychophysical method was used to determine the maximal acceptable load that eight males (age 22–30 years) would lift in each of four different positions: (1) seated, two-handed, symmetrical lift from a table, to a position 38 cm forward of the edge, (2) a seated lift from a position at the subject's side, on to a table in front of the subject involving a 90 degree twist of the torso, (3) standing, two-handed, symmetrical lift from the table, to a position 38 cm forward of the edge, and (4) standing, vertical lift from 86 cm to 134·5 cm above the floor. Subsequent to a training period, subjects lifted a tray with slotted handles at the rate of 1 or 4 lifts/min. Each subject chose the weight of the tray which was acceptable to him by adding or removing flat pieces of lead over a 45 min period. The weight of the tray, heart rate, and the perceived exertion were measured at 15, 30 and 45 min. Oxygen consumption was measured during the last 5 min of the 45 min experiment. Statistical analysis revealed a significant frequency and position effect. An increase in frequency from 1 to 4 lifts/min resulted in a decrease of 1·6 to 2·1 kg in the maximum acceptable weight for the various tasks. On average, the maximum acceptable weight of lift for standing positions was 16% greater than for sitting positions. Oxygen consumption and heart rate were significantly higher for 4 lifts/min than for 1 lift/min; however, the rating of perceived exertion did not differ for any factor.

Keywords: Working environment, lifting, physical exertion

Introduction

Injuries due to over-exertion are a costly phenomenon both in terms of lost working time and of pain and suffering of the injured workers. Researchers seeking ways of understanding and controlling this problem have found that most of these injuries involve manual materials handling (NIOSH, 1981) and that the rate of incidence of some injuries is related to the demands of the job (Chaffin and Park, 1973; Chaffin *et al*, 1977; Dehlin *et al*, 1976; Magora, 1972). This type of information has resulted in many investigations designed to determine the amount of weight that can be safely lifted. In 1981, the National Institute for Occupational Safety and Health (NIOSH, United States) summarised this information in a technical report which is widely used in the design of workplaces and to evaluate the stress imposed by a job. However, as stated in the foreword of the manual, the guide does not address all forms of manual materials handling. In fact, the manual does not deal at all with lifts from a sitting position.

Automation and mechanisation in industry has led to an increase in the number of seated workplaces (Eklund *et al*, 1983). Many inspection and assembly type jobs are performed in the seated position (Grandjean, 1982). People who sit for prolonged periods experience more back pain than those not confined to their seats (Magora, 1972). Moreover, the pressures induced in the back by unsupported sitting alone exceed those of standing postures by 40% (Nachemson, 1981). The additional demands of lifting a weight during sitting results in even greater disc pressures (Andersson *et al*, 1975; Nachemson, 1981).

Back pain is not the only problem that results from repetitive work in a sitting position. An epidemiological study on the reasons for long-term sick leave revealed that nearly half of the workers were absent due to musculo-skeletal disorders (Granstrom *et al*, 1985). Interestingly, almost as many neck and shoulder complaints were found as back complaints. Symptoms of the neck and shoulder region are common in both the general population and the industrial population (Allander, 1974; Kvarnstrom, 1983). It has been suggested that local muscular strain during work plays an important role in these occupational disorders (Bjelle *et al*, 1979; Hagberg, 1982; Maeda, 1977; Westgaard and Aaras, 1984). The postural demands of the job may place these regions in an unfavourable position and therefore become an important factor in the development of shoulder and neck problems (Kuorinka and Viikari-Juntura, 1982; Westgaard and Aaras, 1984). Such jobs place little demands on the metabolic system, yet due to their repetitive nature still result in frequent complaints of shoulder and neck pain (Laville, 1985).

Despite the information available concerning the stresses imposed by sitting postures on the shoulder, neck and back regions, little data are available on the abilities of workers to handle the loads imposed by assembly, production and packing jobs. It was the purpose of this study to determine how much weight individuals will voluntarily lift, using the psychophysical method, while in a seated position as compared with a standing position.

Methods and procedures

Eight physically active male college students participated in this project. Each subject signed an informal consent and was cleared by a physician prior to participation None of the subjects had a history of low back pain or other musculoskeletal problems. Age, physical characteristics and maximal oxygen consumption (as determined by a graded exercise treadmill test) of the subjects are shown in Table 1.

Prior to data collection, the subjects completed six training sessions of 45 min each, using the psychophysical method. The instructions given to the subjects were basically the same as proposed by Snook and Ciriello (1974). Four of the lifting sessions were performed in the sitting position and two were performed in the standing position. Only one training session was performed in a 24 h period. Training sessions were performed both at frequencies of 1 and 4 lifts/min.

Table 1: Age, physical characteristics and maximal oxygen consumption of subjects

	Mean	SD	Range
Age (years)	24·5	2·7	22–30
Body weight (kg)	69·5	8·3	56–79
Stature (cm)	175·1	8·9	162–190
VO_2 max (litres O_2/min)	3·11	0·59	2·02–3·71

Subsequent to training, each subject completed eight randomised experimental sessions 45 min in length; four while seated and four while standing. The four testing positions were as follows (see Fig. 1): (a) seated, two-handed, symmetrical lifts from the table, to a position 38 cm forward of the table edge, (b) seated lift from a position at the subject's side (30·5 cm below table height) to table height (85 cm) involving a 90° twist of the torso, (c) standing, two-handed, symmetrical lift from a table, to a position 38 cm forward of the table edge, and (d) standing, vertical lift from 86 cm to 134·5 cm above the floor. During the seated forward lift and the standing forward lift, the subject moved the tray forward at the first time interval and then back during the next time interval. For the seated twist and the standing vertical lifts, the subject only performed the concentric lift; a helper was provided to return the weight to the beginning lift position. Each of the four lifting positions was performed at 1 and 4 lifts/min for a total of eight sessions. Recent work in this laboratory and others has validated this method for frequencies below 6 lifts/min (Karwowski and Ayoub, 1984; Karwowski and Yates, 1986; Mital, 1983). Time was marked by an electronic clock which emitted an audible tone when the weight was to be moved.

The table used during the seated task was 85 cm high with a barrier 2·5 cm in height located 38 cm in front of the table edge. Thus when moving the weight forward, the subject was required to lift the weight instead of sliding it forward. The subject was seated on an adjustable, rotatable stool with a back rest and no arms. During the training sessions the subjects were instructed to adjust the stool and the work station (i e, footrest) to their own comfort. Re-adjustments were allowed during the training sessions, but were held constant once experimental sessions began.

During the twist-lift, subjects lifted the tray from a table located 30·5 cm below table height. In order to perform the lift, subjects were required to twist their upper body while keeping their feet in a forward position. In other words, the

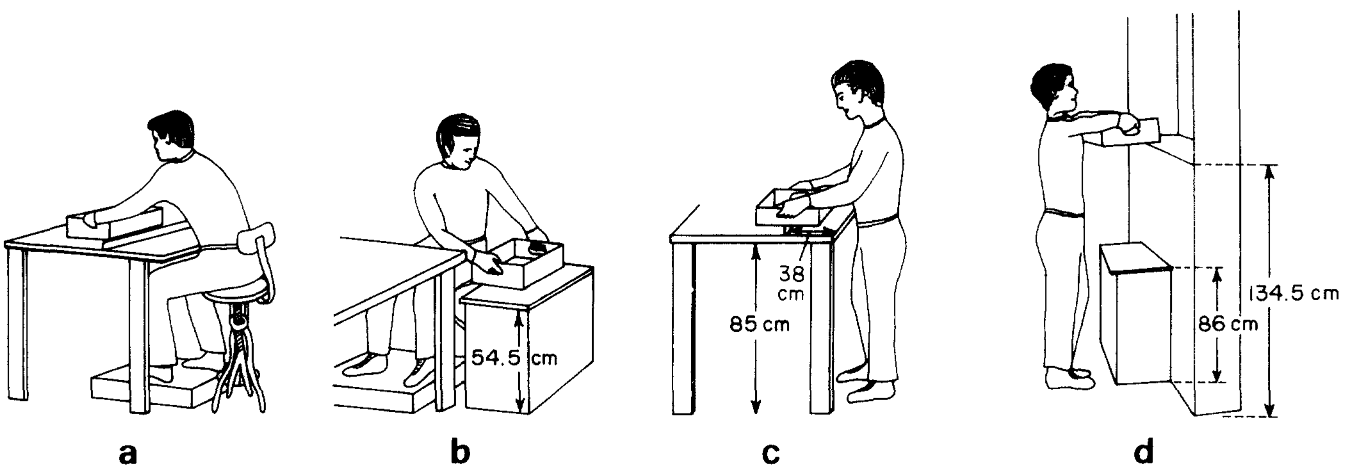

Fig. 1* (a) Sitting – forward lift (b) Lift from below table height to table height with a 90 degree twist (c) Standing – forward lift (d) Standing – vertical lift

*Figures are reproduced from photographs of a subject actually performing the tasks subjects were not allowed to rotate the stool around, pick up the weight and then rotate back to the table. The subject placed the tray on the table surface near the edge of the table.

During the experiment, subjects lifted a tray (45·7 x 30·5 x 12 cm) with slotted handles which contained various amounts of weight. The initial weight was either light (2 kg) or heavy (15 kg) as has been previously recommended (Snook and Irvine, 1967). The subject was then allowed to remove or add weight according to standard psychophysical methodology (Snook and Irvine, 1967). The resistance was provided by thin rectangular pieces of lead of unknown weight. The weight of the tray, heart rate and rate of perceived exertion (Borg, 1970) were measured at 15, 30 and 45 min. Tray weights were not revealed to the subjects.

In order to simulate an industrial task more closely, when seated the subjects were required to perform a small parts assembly task between lifts. The task involved bolting two small blocks of wood together. The nuts were tightened by hand only. Once the supply of materials had been exhausted, the subject disassembled the pieces, returning the parts to their respective bins. While the task was not fatiguing, it did require the movement of the hands, arms and shoulders similar to an industrial assembly task and thus may have had some impact on the weight chosen by the subjects.

During the last 5 min of the experimental sessions, expired air was collected in meteorological balloons. Oxygen and carbon dioxide were measured using Applied Electrochemistry and Beckman LB-2 analysers, respectively. Gas volumes were measured in a Collins tissot spirometer.

Experimental data were analysed using a three-way analysis of variance (ANOVA) with repeated measures on all three factors (2 frequencies x 4 positions x 3 times). The Newman-Kuels test was used for *post hoc* comparisons. An alpha level of $p < 0.05$ was selected as the minimum level of significance.

Results

The weights lifted by the subjects for the four positions are shown in Table 2. The ANOVA revealed that no significant change in weight occurred over time, therefore only the 45 min values are shown. The statistical analysis did indicate a significant difference for both frequency and lifting position. Since only two frequencies were performed and no significant interaction existed, the weight lifted once/minute differed from the weight lifted 4 times/min at each position. The change in frequency from 1 lift/min to 4 lifts/min resulted in slightly less than a 2·0 kg decrease in the maximum acceptable load.

Post hoc comparisons suggested that no significant difference existed between the sitting-forward and the sitting-twist lifts in the amount of weight lifted. Likewise, there was no significant difference between the standing-forward lift and the standing-vertical lifts. However, the loads lifted during both standing positions were significantly greater than during either sitting position. Acceptable weights for standing positions were from 8 to 25% greater than those acceptable for sitting positions. When averaged across frequencies the acceptable weight for the standing-vertical lift was approximately 23% and 15% greater than the sitting-twist and sitting-forward lifts, respectively. When averaged across positions and frequencies, the maximal acceptable weight for standing lifts was 16% greater than for sitting lifts.

Table 2: Weight lifted, oxygen consumption, heart rate and perceived exertion for eight male subjects for various lifting positions and lifting frequencies

Task	Lifts/min	Weight (kg)	VO_2 (l/min)	HR (b/min)	RPE
Sitting – forward	1	11·9 (1·2)	0·38 (0·07)	79 (19)	12·1 (1·4)
	4	10·3 (2·2)	0·49 (0·08)	88 (14)	12·3 (0·5)
Sitting – twist	1	10·9 (1·9)	0·40 (0·07)	79 (11)	11·9 (1·0)
	4	9·1 (2·1)	0·52 (0·11)	80 (13)	12·5 (0·8)
Standing – forward	1	13·3 (2·3)	0·41 (0·06)	84 (14)	11·9 (1·0)
	4	11·2 (2·5)	0·43 (0·09)	87 (12)	12·3 (0·9)
Standing – vertical	1	13·8 (2·6)	0·40 (0·06)	85 (16)	12·0 (1·4)
	4	12·2 (2·4)	0·59 (0·09)	87 (15)	12·3 (0·9)

The oxygen requirements were significantly greater for 4 lifts/min than for 1 lift/min. However, when lifting once/minute no significant differences existed between positions. When lifting 4 times/min, the oxygen requirement for the standing-vertical position was significantly greater than the standing-forward position. No other significant differences were found for oxygen requirements. When expressed as a percentage of VO_2 max, the oxygen requirements ranged from 11·5% for the sitting-forward (1 lift/min) to 18·1% for standing-vertical (4 lifts/min).

Table 2 also shows the heart rate and rate of perceived exertion for the different positions at the end of the testing session. Heart rate was approximately 5 beats lower ($p < \cdot 05$) for 1 lift/min than for 4 lifts/min. No significant differences were found between positions. The rating of perceived exertion (Borg, 1970) did not differ significantly for any factor.

Discussion

Recently, much information has accumulated relative to the stresses imposed by the seated work position (Andersson *et al,* 1975; Bjelle *et al,* 1979; Eklund *et al,* 1983; Mandal, 1981; Magora, 1972; Schultz *et al,* 1982). Many industrial tasks involving manual materials handling are performed in a sitting position. Surprisingly, human lifting capabilities in such situations have not been studied extensively. The data reported here provide much needed information concerning the maximal acceptable weight that can be lifted in certain positions. Since young (ages 22–30 years) undergraduates and graduate students were used as subjects, the absolute data should not be extrapolated directly to industrial situations. However, the use of college students does not, in our opinion, detract from the relationship between the weight lifted in the sitting compared with the standing position. Maximal acceptable weights, as determined by the psychophysical method, are already available for many standing postures. The primary reason for including the standing lifts in this study was to compare the acceptable weights for both positions in the same subject group. When comparing standing positions with sitting positions, the decrease in maximum acceptable weight ranged from 8 to 25%. The sitting-forward lift was 8–9% less than the standing-forward lift while the sitting-twist lift was approximately 24% less than the standing-vertical lift. The decrease across all lifts and frequencies was 16%. Until more data become available, we suggest that a 16% reduction in standing acceptable lifts performed from table height to shoulder height would provide reasonable adjustment.

The comparison between sitting and standing postures provides some unique insight into the requirements of the tasks. The sitting-forward and standing-forward tasks were performed at the same workstation under identical conditions with the exception of moving from a sitting to a standing position. The subjects lifted a significantly greater weight while standing (13·3 kg *vs* 11·9 kg at 1 lift/min), yet the metabolic requirements and the perceived exertion were not significantly different. The above results can be explained by the fact that during the standing lift the subjects tended to brace themselves against the table which, in effect, decreased the length of the lever arm. Therefore, when standing, the subjects were afforded a biomechanical advantage without increasing the metabolic energy requirements. Hence they were able to lift a greater amount of weight at the same level of perceived stress. The lack of an increase in oxygen requirements was probably due to limitation of the task to upper body activity. However, an additional factor may have been the necessity of using the legs to brace themselves during the seated task.

When the subject moved from the standing-forward lift to the standing-vertical lift, there was a significant increase in oxygen requirement when performed at 4 lifts/min. Even so, this task did not result in a significant elevation in heart rate.

The data presented above suggest that, when the weight of the load becomes a critical factor, the designer of a work-station should use a standing position instead of a sitting position. For forward lifts, the amount of weight that can be comfortably lifted is greater, yet the perceived stress of the task does not increase.

Surprisingly, the amount of weight lifted during the twist-lift was not significantly different from the seated-forward lift. This may be partially explained by the fact that the subject was not required to move the weight to the forward position, but merely place it on the table. Even so, the increased stress imposed by including a twist in the lift was not judged to be great by these subjects. The twist-lift using the psychophysical method has not been validated over an extended period of time as have other lifting tasks (Karwowski and Yates, 1986; Mital, 1983). Therefore, the reader is cautioned when using the data provided relative to the twist-lift.

The psychophysical method has been recently confirmed as a valid method for determining the maximum acceptable weight that can be lifted over an extended period of time for frequencies at or below 6 lifts/min (Karwowski and Yates, 1986; Mital, 1983). However, previous investigations determined maximal acceptable weights from standing positions. The data reported here suggest that the amount of weight that individuals will lift using the psychophysical guidelines is less when sitting compared with standing positions. Subjects readily adapted to the psychophysical method in the seated position. During the data collection phase, the subjects quickly determined their maximal acceptable weight so that no significant change in weight occurred after the 15 min time interval.

One should be cautious in any widespread application of this information. This study has provided some preliminary data on lifting capabilities during seated lifting, yet has done little to analyse the limiting factors. Our data suggest that seated lifting is not limited by physiological factors but it does not address biomechanical factors in much detail. Recent work in this laboratory (Karwowski *et al,* 1986) does suggest that frequency of lift and anthropometric data are the best predictors of seated lifting. Overall, the perception of effort was not high but the work of Ljungberg *et al* (1982) suggests that horizontal lifting differs from vertical lifting in the perception of strain. This factor is one that should be considered in determining seated lifting norms.

Conclusions

The data presented here suggest that the maximal acceptable lift while in a sitting position is less than the maximal acceptable lift while standing. Whilst one must be cautious as noted above, until further work is forthcoming we suggest that a 16% reduction in acceptable lifts performed from table height to shoulder height is a reasonable adjustment for seated lifting.

Acknowledgements

This project was supported by grant RO3 OHO2229 from the National Institute for Occupational Safety and Health of the Centers for Disease Control and by a Graduate Research Council Grant (UHSC: 120-85) from the University of Louisville.

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