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Influence of Lift Moment in Determining MAWL

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An experiment was performed to determine whether maximum acceptable weight of lift (MAWL) estimates were consistent with previously reported values when the MAWL was determined without visual feedback during the weight adjustment period. Twelve healthy male students performed four lifting tasks similar to those often performed in previous psychophysical studies: floor to knuckle at 1 lift per min, floor to knuckle at 4.3 lifts per min, knuckle to shoulder at 1 lift per min, and knuckle to shoulder at 4.3 lifts per min. When compared with the previous studies with similar box dimensions, similar trends between the conditions were present, but a slight reduction in weight was usually chosen by the participant in this study. However, the results of this study agreed with previous psychophysical studies when the distance of the load from the spine (moment arm) was taken into consideration by either comparing the MAWLs with those of a large box or by comparing load moments. Hence this study shows that eliminating visual feedback during the adjustment periods did not significantly alter the MAWLs from previous studies. It also indicates that one must use caution when applying the MAWL in the workplace because the MAWL is very sensitive to moment arm.

INTRODUCTION

Manual material handling (MMH) tasks are prevalent in one- third of all industrial jobs (Garg, 1983). Many of the workplace factors that have been associated with low back pain can be found in the typical MMH task. Physically heavy work, static postures, frequent bending and twisting, repetitive work, and vibration have been found to increase spinal loading (Andersson, 1981; Granata & Marras, 1993; Marras & Mirka, 1992; Marras & Sommerich, 1991).

Low back pain is a major source of medical expenses incurred by industry. In 1973, injuries occurring during MMH tasks accounted for up to 23% of all the compensable work injuries; back injuries were predominant (Snook, 1978). During 1989, Liberty Mutual Insurance Company estimated that low back cases represented 33% of all claim costs, totaling $991 million in expenditures (Webster & Snook, 1994). These costs are drastically higher when one considers the indirect costs, such as lost wages, loss of productivity, retraining costs, and absenteeism.

Because of the large impact of these injuries on society, many researchers have undertaken numerous methods to evaluate the workplace in order to determine the level of low back pain risk and acceptable lifting loads. One method for attempting to determine what might be an acceptable weight for lifting is the psychophysical method. The participant selects the weight by monitoring the perception of exertion or fatigue (Snook, 1978). The selected weight is then classified as the maximum acceptable weight of the lift, and lifting tasks with loads at or below this

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level are considered safe for some percentage of the population. The psychophysical approach allows for the assessment of a job with relatively little evaluation effort. Psychophysical data are commonly used in industry and have been the basis for ergonomics guidelines (Waters, Putz-Anderson, Garg, & Fine, 1993). Hence it is important that the psychophysical data are accurate in order to reduce the risk of injury. Snook and Ciriello (1991) developed tables that encompassed a large variety of MMH tasks for males and females.

One possible limitation of the psychophysical methodology is the fact that the participant's perception of an acceptable weight might be influenced by a number of variables. Some researchers have demonstrated that a size-weight illusion exists in industrial lifting tasks (Luczak & Ge, 1989). The size-weight illusion relates both of these parameters to the subjective heaviness of the container. In many previous psychophysical studies, participants added or removed various types of materials from the container being lifted. Although they never knew the exact weight of the materials in the box at any given time, they may have been forming judgments about the weight or consistency of the load based on the volumes and densities of the materials being added and removed (Luczak & Ge, 1989). The materials used have ranged from lead shot (Aghazadeh & Ayoub, 1985; Garg & Saxena, 1980; Snook & Ciriello, 1991), sand (Mital & Manivasagan, 1983), and water (Karwowski & Yates, 1986; Mital & Manivasagan, 1983).

Another possible limitation of previous psychophysical studies is the fact that these lifting limits are based solely on weight. How the worker performs the task could drastically affect the MAWLs, given that these values might be confounded with moment arm distance from the spine during the lifting task. Chaffin and Page (1994) found that the MAWL values used as safe limits were higher than recommended biomechanically predicted load limits. It would appear that the participant's posture during the lift influenced the predicted loading on the spine. Marras et al. (1993) have shown that moment (load × distance) is a better predictor of back injury risk than load weight alone. In most psychophysical studies, participants were allowed to move their feet while lifting the box to the shelf. Therefore, it was possible that the moment being applied to the individuals could have changed throughout the adjusting period (i.e., some participants stepped closer to the shelf than did others). It is also possible that the participant populations of the various studies would have different anthropometric characteristics, preferred lifting styles, experience levels, cultural backgrounds, and ranges of age, all of which could lead to different moment arms being used in the various studies.

These studies have shown that moment arm is an important factor in considering lifting capacity and weight acceptance. In this study we try to consider moment in perspective relative to psychophysics, and in particular how it may interact with weight selection and visual feedback. Hence the objective of this study was to determine MAWLs while controlling for visual feedback about the load and the moment arm between the spine and about the load while determining the maximum acceptable weight of lift.

METHODS

Participants

Twelve male students with no history of low back pain volunteered to participate in the experiment. It is common to use 12 or fewer participants when performing psychophysical experiments (Aghazadeh & Ayoub, 1985; Karwowski, Shumate, Yates, & Pongpatana, 1992; Snook & Irvine, 1967; Wu & Hsu, 1993). Similarly, the use of students is common (Aghazadeh & Ayoub, 1985; Garg, 1989; Garg & Saxena, 1980; Genaidy & Al-Rayes, 1993; Karwowski et al., 1992; Wu & Hsu, 1993). Their mean (STD) age, height, and weight were 26.9 yrs (3.27), 181.8 cm (6.4), and 79.4 kg (8.8), respectively.

Experimental Design

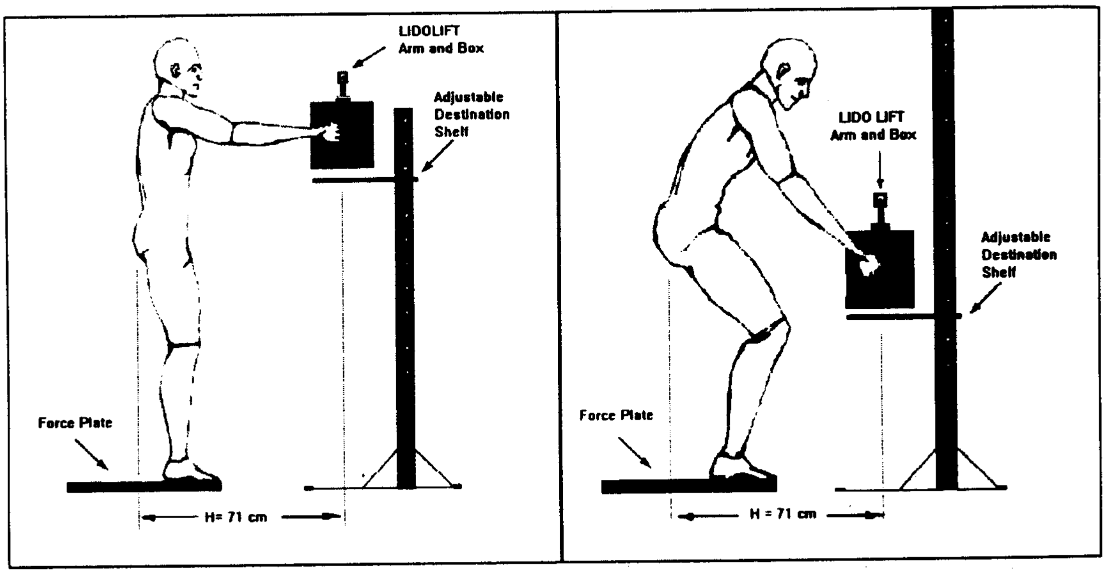
The experimental design was a two-way, within-subjects design. The independent variables were lift range and lift rate. The lift ranges used in the experiment corresponded to floor to knuckle and knuckle to shoulder. These ranges were chosen based on the ranges reported by Snook and Ciriello (1991) and did not vary between participants. For the floor-to-knuckle height lift, the box bottom began at 18 cm and ended at 67.5 cm. During the knuckle-to-shoulder height lift, the box bottom began at 67.5 cm and ended at 128 cm. Figure 1 depicts a participant lifting the box for the two lifting ranges.

The lift rates were chosen to be consistent with previous studies. A fast and slow lift rate were used. The fast rate was set at 4.3 lifts per min (Snook, 1978; Snook & Ciriello, 1991) and the slow rate was set at 1 lift per min (Aghazadeh & Ayoub, 1985; Karwowski & Yates, 1986; Mital, 1987; Mital & Fard, 1986; Mital, Karwowski, Mazouz, & Orsarh, 1986; Snook, 1978; Snook & Ciriello, 1991; Snook & Irvine, 1967; Wu & Hsu, 1993).

The dependent variables were maximum acceptable weight of lift and moment about the lumbar spine. For each of the lifting tasks, each participant's maximum acceptable weight of lift was measured through the LIDOLift™ (Loredan Biomedical, Inc.) lifting simulator. These weights were then compared with those in previous studies. Trunk muscle electromyographic, trunk motion, and force plate information were also collected but are not reported here.

In order to consider the effect of moment on the maximum acceptable weight, the horizontal moment arm length was measured. The moment was calculated by multiplying the load lifted by the maximum moment arm. The moment arm, defined as the horizontal component of the distance separating the box from the participant's lumbar spine, was measured from the center of the lifting box to the approximate location of the participant's lumbar spine. The moment arm was measured in the starting and ending lifting postures for each experimental condition using a tape measure. The average of the maximum moment arm across all participants was used to estimate the moment for each condition.

To simulate the lifts of previous studies, participants were asked to simulate the same lifts,



a.) Knuckle to Shoulder b.) Floor to Knuckle

Figure 1. A schematic view of a subject performing the two lifting conditions (knuckle to shoulder and floor to knuckle) while using the LIDOLift, which was used to eliminate visual feedback from the mass being transferred to and from the lifting box.

except they were permitted to move their feet as they wished (not necessarily staying on the force plate). Psychophysical studies such as that by Snook and Ciriello (1991) allowed participants to take a step to place the load on the shelf. This would allow the maximum external moment to be lower than in our study because the box would probably be closer to the body throughout the lift. This was accomplished after the four conditions were satisfactorily completed with the participant's foot position fixed. The horizontal moment arm distance was remeasured under the conditions used to adjust the MAWL of previous studies.

Apparatus

A LIDOLift lifting simulator was used to perform the expected lift. Its functions simulate isometric, isokinetic, and isoinertial lifting conditions, and it has strain gauges in the arm to measure the vertical force applied at the lifting handles and the three-dimensional position in space. The present experiment utilized the LIDOLift in the isoinertial mode. The shelf can be placed at 10 discrete heights at 15.25-cm intervals. Maximum handle height is limited to 218 cm. In conjunction with the LIDOLift, a force plate (Bertec 4060A) was used to measure the three-dimensional ground reaction forces and moments.

The box used in this experiment had a width of 29 cm, a length of 25 cm, and a depth of 23 cm. The width dimension corresponded to the box width of 34 cm reported by Snook and Ciriello (1991). Similar box sizes have been found in typical material handling tasks (Drury, Law, & Pawensk, 1982). The length was shown not to influence the determination of the MAWL (Snook & Ciriello, 1991). The top of the handles on the box were 18 cm from the bottom of the box.

Procedure

After participants signed a consent form and anthropometry measurements were taken, they were instructed about the procedures of the study by watching a prerecorded videotape (see Appendix). The videotape allowed all participants to receive identical instructions; it has been found that the administration of instructions by different individuals influenced the maximum acceptable weights (Gamberale, 1990). Next, participants were permitted time to become familiar with the LIDOLift and to practice the tasks to be performed. The training session lasted until the participants reported confidence in operation of the LIDOLift and the adjustment procedure, which usually lasted approximately 15 min.

For each condition two 25-min trials were performed, during which the participant was allowed to adjust the weight. He was able to either increase or decrease the weight by a minimum of four units at any time. One unit corresponded to 1 lb (0.45 kg) of weight, which was unknown to the participants. Karwowski et al. (1992) recommended that the adjustment process use incremental weights of at least 1.8 kg (4 lbs). One trial started at a high weight, 467 N (47.6 kg), and the other trial began at a low weight, 67 N (6.8 kg). Starting weights were chosen to correspond to the 5th and 95th percentile weights of the Snook and Ciriello (1991) tables. Additionally, the low weight was chosen to minimize error in the LIDOLift.

A computer-generated tone signaled when the participant was to begin the lift at each frequency. Participants were required to keep their feet fixed on a force plate during each lift. They were permitted to move until the tone signaled again, at which time they were to return to a designated position on the force plate. After completion of the two trials, the results were compared. If the two trials did not result in weights within 15% of each other, the condition was redone on a different day. The experiment was divided into two parts, and each part was performed on a separate day in order to reduce fatigue. All conditions were counterbalanced in reference to starting weight and lifting condition.

Analyses

The experimental maximum acceptable weight limits for each condition were compared with the MAWLs of the Snook and Ciriello (1991) study through the use of a *t*-test. Analysis of variance

(ANOVA) was performed on the dependent variables. For all significant independent variables, post hoc analyses (Tukey test) were performed to determine the source of the significant effects.

RESULTS

The descriptive statistics of the MAWLs for the four lifting conditions are shown in Table 1. In addition, MAWLs for similar conditions from the Snook and Ciriello (1991)tables are displayed. These MAWLs were interpolated from the Snook and Ciriello tables because the vertical distances used in this experiment did not correspond to the exact vertical distances listed. The standard deviations were calculated based on a normal distribution and the corresponding percentile values from Snook and Ciriello (1991).

For all conditions, the MAWLs for the present experiment are quantitatively lower than values found by Snook and Ciriello (1991). However, only the weight for the knuckle-to-shoulder at 4.3 lifts per min (lpm) condition was statistically different from that of Snook and Ciriello (1991), $p \leq .05$. Similar trends between conditions were present in both studies. The ANOVA indicated that height and frequency were both significant influences on MAWL ($p \leq .05$), though their interaction was not significant. Post hoc analyses indicated that the MAWLs (22.3 kg) for the 1 lpm tasks were significantly larger than for the 4.3 lpm task (17.4 kg; $p \leq .05$). Furthermore, the MAWLs for the floor-to-knuckle tasks (21.2 kg) were significantly greater than for the knuckle-to-shoulder MAWL (18.5 kg; $p \leq .05$).

Figure 2 shows the maximum weights acceptable to 10%, 25%, 50%, 75%, and 90% of the populations for this experiment, as compared with the large and small boxes of the Snook and Ciriello (1991) study. This figure indicates that participants in this study consistently selected weights lighter than those reported by Snook and Ciriello for the small box dimensions (width = 34 cm). For the floor-to-knuckle conditions, the MAWLs for this study corresponded fairly well to MAWL values for the large box (width = 75 cm) in the Snook and Ciriello (1991) study. However, for the knuckle-to-shoulder conditions, the results remained lower than the values for the large box.

Estimates of the moment arms for the Snook and Ciriello (1991) data were performed under simulated lifting conditions that permitted participants to move their feet. The difference in the horizontal moment arm was 12.52 cm (*sd* 8.82 cm) and 16.77 cm (*sd* 10.66 cm) for the floor-to-knuckle condition and the knuckle- to-shoulder task, respectively. This difference was statistically significant ($p \leq .05$).

After adjusting for moment arm, the maximum acceptable moment of lift (MAML) for the two studies were found to be virtually identical. No significant difference between the MAMLs of the two studies was found ($p \leq .05$). The MAML percentiles for both studies are shown in Figure 3.

DISCUSSION

This study has shown that the psychophysical method is not significantly affected by visual information about the load value used to determine

TABLE 1

Descriptive Statistics on the MAWLs for All Four Conditions in this Experiment and the Small Box in the Snook and Ciriello (1991) Study

	Experiment		Snook and Ciriello (1991)	
Condition	Mean	Std. Deviation	Mean	Std. Deviation
Floor to knuckle at 1 lpm	23.96	10.04	30.5	11.57
Floor to knuckle at 4.3 lpm	18.45	5.22	23	8.71
Knuckle to shoulder at 1 lpm	20.64	7.13	27	8.32
Knuckle to shoulder at 4.3 lpm	16.31*	5.15	22^A	6.79

* Indicates significant difference at $p \leq .05$.
All weights are in kg. lpm = lifts per minute

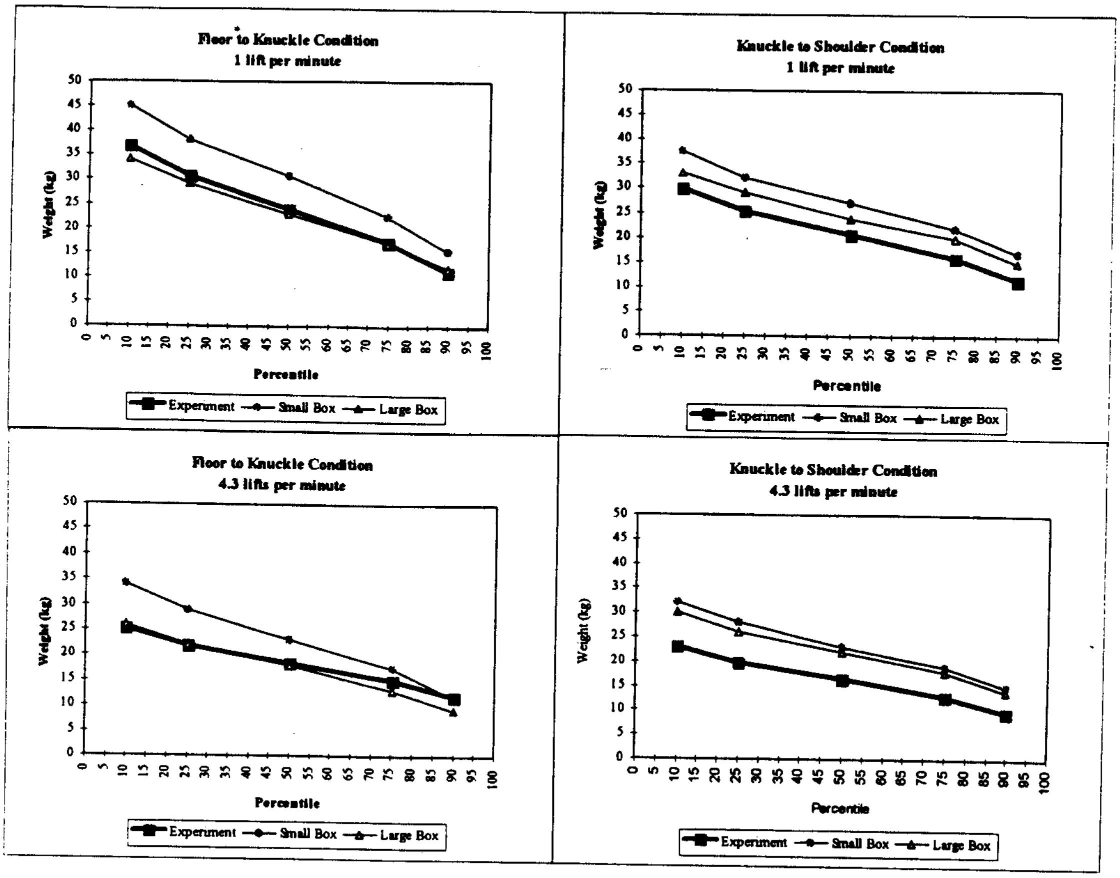


Figure 2. For each condition, the MAWL for the 10th, 25th, 50th, 75th, and 90th percentiles is shown for both this experiment and Snook and Ciriello (1991) data.

MAWL. Some researchers suggested that when a participant rates a weight, his or her expectation of that weight will influence the rating (Luczak & Ge, 1989). For example, if a participant believes that a large box may be heavier than a small box, then he or she will apply more effort. The resulting rating may be lower than expected because the participant perceived less effort than expected. In psychophysical experiments, however, the participant normally lifts the load several times, thus this factor may become negligible as the expected effort approaches the actual need. As a result, visual feedback about the load that normally affects the expectation of a load is much smaller than the experience that is gained during the trial. Because the participant does not make expectations based on visual data that may be erroneous but rather on experience gathered during the trial, visual feedback about the load does not affect the results.

This experiment was designed to be as similar as possible to previous psychophysical studies, with the exception that we did not provide participants with visual feedback about the adjusted load. Comparisons of the present results were made with the findings of Snook and Ciriello (1991) because these data are commonly used in industry. In both studies the fast lift rate had lower average MAWLs than the slow lift rate, and the knuckle-to-shoulder lift range had lower average MAWLs than the floor-to-knuckle lift range across all participants. However, these trends were consistent for only 5 of the 12 participants, which indicates that they had different

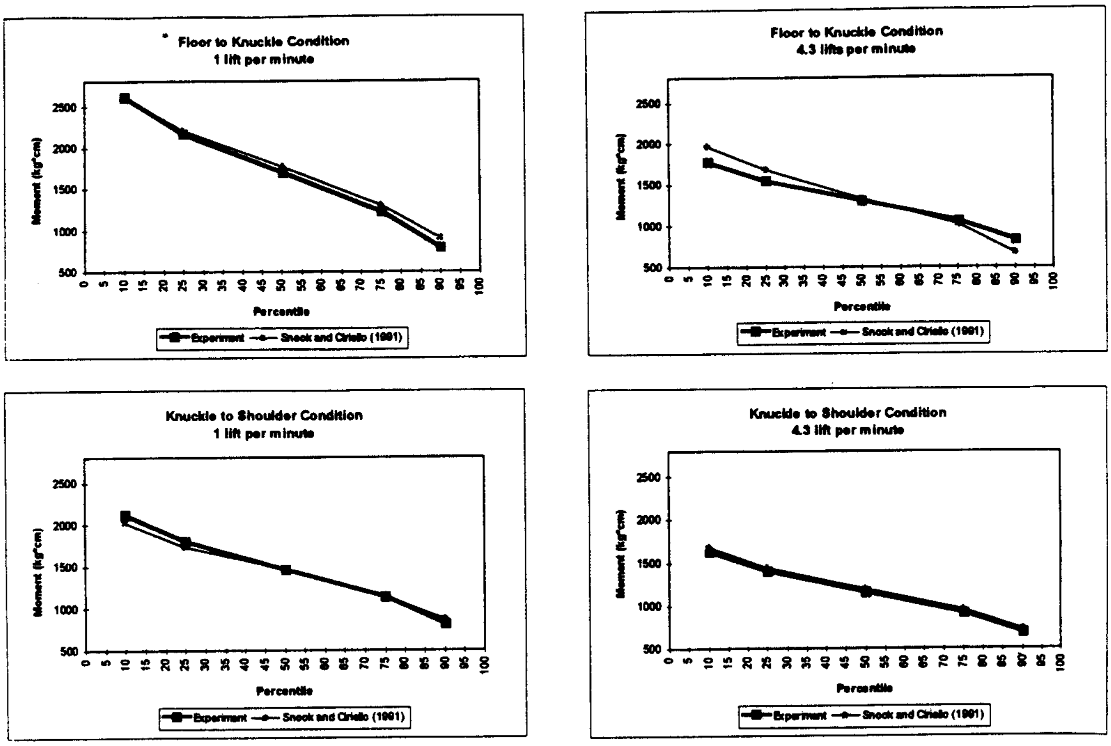


Figure 3. For each condition, the MAML for the 10th, 25th, 50th, 75th, and 90th percentiles is shown for both this experiment and for the small box in the Snook and Ciriello (1991) study.

perceptions as to the relative ranking of the effort needed for each of the conditions. Participants appear to use different triggers for setting the MAWL when performing different tasks. Therefore, one participant may be responding to moment only, whereas another may be responding to heart rate or fatigue. These different limiting factors would certainly have different implications for low back disorders.

Interestingly, when the MAWLs determined by the present experiment were divided into percentile groupings, they were always lower than the MAWLs reported by Snook and Ciriello (1991) for the small box size (width = 34 cm); however, the differences were statistically significant for only one condition. Ciriello, Snook, and Hughes (1993) found that exertions with extended reaching had 48% lower MAWLs than did lifts for which the box remained close to the body. In general, the present study's MAWLs are about 75% of the MAWLs for the small box in the Snook and Ciriello (1991) study. It is tempting to attribute the difference in MAWLs to the lack of visual feedback about the load. However, the disagreement between the studies could possibly be attributed to the differences in moment arm distance between the box and the spine. The current study required participants to perform the tasks at a significant distance away from the destination shelf, whereas the participants in the Snook and Ciriello (1991) study were able to move freely, allowing the weight to remain close to the body. This would result in drastically different postures, ultimately changing the perception of the exertion level.

The importance of the horizontal distance has been found to affect the so-called safe load of a lift (NIOSH, 1981; Waters et al., 1993). Chaffin and Page (1994) found that the horizontal distance influenced the MAWLs during typical psychophysical studies. Similarly, Ciriello, Snook, and Hughes (1993) found that lifts with extended reaches drastically reduced the MAWLs. Therefore, because the horizontal distance is known to be important, it is imperative that it be considered when predicting safe lifting conditions.

One possible method of including the effects of moment arm distance would be to compare the MAWLs of the present study with the MAWLs of the large box (width = 75 cm) in the Snook and Ciriello (1991) study. The results for the large box were similar to this study for the floor-to-knuckle conditions, but the MAWLs for the knuckle-to-shoulder conditions for the present study remained lower. The difference between the studies that remained for the knuckle-to-shoulder conditions may have resulted from the influence of the shoulder joint in the determination of the MAWLs; a correction for moment about the shoulder may bring the studies into closer agreement. Thus the comparison with the large box indicates that when using psychophysical tables, one must consider distance between the box and body, not just box size.

Another method used to control the confounding effects of moment arm distance is to compare the estimated MAMLs for this study with the MAMLs for the small box in the Snook and Ciriello (1991) study. These values were virtually identical for all four conditions. This result corresponds well with the findings of industrial surveillance data, which indicate that moment is highly associated with low back disorders (Marras et al., 1993). By considering horizontal moment arm distance along with weight (moment), many more potential workplace and individual variables can be considered in workplace design. For example, anthropometric differences could have resulted in different moment arms. Taller individuals might have potentially larger moment arms than shorter people. Hence we suggest that a MAML might provide a more meaningful measure of worker capacity than MAWL.

Concerns regarding the psychophysical methodology have stemmed from the fact that the results have not been validated with biomechanical methods (Leamon, 1994). Marras et al. (1993) reported that from the odds ratios associated with 114 reported measures, occupationally related low back disorders were most strongly associated with mechanical moment at the L5/S1 intervertebral disc of the spine. Weight had an odds ratio of 2.76–3.17, but moment was 4.08–5.17. These odds ratios lead to the conclusion that moment might be a better predictor of low back pain risk than weight. Therefore, it might help to prevent low back disorders if psychophysical data directly used moment.

Several possible limitations of this study must be acknowledged. First, because the participants chose the amount of training acceptable to them, familiarity with the apparatus, weights, and procedures might be limited. Although all were given equal opportunity to practice, the individual participants came to the experiment with varying degrees of work experience. Thus the use of students could be affecting the resulting MAWLs. Mital (1987) found a difference between inexperienced and experienced participants. In the present study, this appears not to be the case because the results, when corrected for moment arm distance, are similar to results found in previous psychophysical studies. Furthermore, it is possible that the differences between the MAWLs in the present study and in the Snook and Ciriello (1991) study were attributable to the variations in experimental protocols.

Second, participants' feet were required to be fixed on the force plate, resulting in a constant maximum moment arm distance. This could have resulted in lower MAWLs because the participants were not able to step into the lift. Thus the task was not realistic, and the kinematic characteristics may therefore differ between this study and the previous psychophysical studies.

Third, the present study investigated only one aspect of visual perception. Other researchers have investigated the effects of other perceptual cues. Karwowski and Pongpatana (1989) found that the color of the box influences MAWL. Additional perceptual factors could be found to influence MAWL; this factor was held constant in the present study. The perception of tissue loading or muscle coactivity may be triggering participants' response in determining MAWL. Another study from this laboratory is exploring the issue of coactivity and spinal loading.

CONCLUSION

MAWLs for the present study followed a pattern comparable to other psychophysical studies. MAWLs of the present study were consistently lower than those for boxes of similar sizes, in some cases by 25%. When the MAWLs were compared with values for a larger box, those for the floor-to-knuckle conditions were found to be similar, although for the knuckle-to-shoulder exertions, the differences remained but were smaller. The effect of moment arm distances was further evaluated by computing a maximum acceptable moment limit (MAML), with the results being almost identical to those of previous psychophysical studies. Hence two major conclusions were formed from this experiment.

First, visual feedback about the load does not influence MAWL because the participant's expectations are based on the experience gained during the trial, not expectations based on visual perception. Second, MAML may be a more robust measure of what constitutes an acceptable lifting task. On a practical level, this means that practitioners must exercise caution when applying psychophysical data and be sensitive to not only weight of lift but also moment arm conditions. Ultimately, this means that MAWLs need to be adjusted for the effects of the moment arm distance by using the larger box dimensions in the psychophysical tables, or by computing the resulting MAMLs.

APPENDIX: INSTRUCTIONS FOR ADJUSTING WORKLOAD

We want you to imagine that you are working on a job which requires handling boxes, and you are getting paid for how much load you handle. The job would be conducted over an 8-hour shift that allows you to go home not feeling exhausted. We want you to work as hard as you can without straining yourself, or without becoming unusually tired, overheated, or out of breath.

The task will consist of two lifting frequencies and two types of lifting tasks. One lifting frequency will be fast (4.3 lifts per minute) and one will be slow (1 lift per minute). You will be lifting a box from a given starting height to a position marked on the shelf. The two lifting tasks are (1) lifting from the floor to a shelf at knuckle height and (2) from the knuckle height to a shelf at shoulder height. In both cases, the load will be returned to the original position by the LIDOLift and one of the experimenters. Each task will start with a very heavy or very light load; you will be told beforehand which load you will be starting at.

You will be cued to begin lifting by an audible tone. There will be two tones that you will hear: first, a low tone, and then a few seconds later, there will be a higher tone. The first tone is used to "zero out" the force plate on which you're standing. You need to stand still in an upright posture when you hear this tone with the tip of your shoes lined up along the front edge of the force plate. Try to be consistent in your standing posture when the first tone sounds; in other words, adopt the same posture with your head, hands, and body in the same position each time. The second tone is the signal for you to begin lifting. Lift the box and place it on the shelf between the two tape markers. If, when you begin lifting, you find the box is too heavy, you don't have to complete the lift. Just let it go, and the mechanical arm will support the box. The box will not fall and hurt you. The tones will signal at two different rates, depending on the frequency (fast or slow).

YOU WILL ADJUST THE WEIGHT OF THE BOX AS YOU FEEL APPROPRIATE. Use the arrow keys on the keyboard located on your right. By pressing the "up" arrow, the load will increase proportionally to the number of times the key is pressed — that is, the more times the key is pressed, the larger the increase in load. Similarly, the "down" arrow will decrease the load proportionally. For each adjustment, you must press the key (either "up" or "down" key) at least 4 times, although you may press it more than 4 times. You will have 25 minutes per task to make your adjustments. This part of the task will not be easy. Remember, only you know how you feel.

After each lift, you will need to give a number to the experimenter, indicating how difficult the lift was, compared to how much you could comfortably lift at that frequency for an 8-hour work day. The number assigned to the maximum acceptable load for an 8-hour day is 100. For example, a very heavy load would be given a number greater than 100, and a very light load would be given a number less than 100.

If you feel you are working too hard, reduce the load. But we don't want you loafing either. If you feel you can lift more, increase the load. Don't hurry your lift. Feel free to adjust the load as many times as you feel necessary. Remember, we are not interested in how much you are capable of lifting but rather the maximum amount that you would like to handle if you were actually performing this task at work.

We do have a few requirements to enable us to collect the most accurate data. First, we need you to place your feet on the force plate at shoulder width apart. We need you to keep your feet in place throughout the lift, that is do not take any steps. Second, we need you to keep your shoulders straight back during the entire lift. PLEASE DON'T HUNCH YOUR SHOULDERS.

Again, remember that you can change the load at any time, except when the lift is to be performed, and as many times as you want. Also, you need to work at the pace specified by the computer tone.

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