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Effects of box size, frequency of lifting, and height of lift on maximum acceptable weight of lift and heart rate for male university students in Iran

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Abstract

Introduction: In spite of the widespread use of automation in industry, manual material handling (MMH) is still performed in many occupational settings. The emphasis on ergonomics in MMH tasks is due to the potential risks of workplace accidents and injuries. This study aimed to assess the effect of box size, frequency of lift, and height of lift on maximum acceptable weight of lift (MAWL) on the heart rates of male university students in Iran.

Methods: This experimental study was conducted in 2015 with 15 male students recruited from Tehran University of Medical Sciences. Each participant performed 18 different lifting tasks that involved three lifting frequencies (1lift/min, 4.3 lifts/min and 6.67 lifts/min), three lifting heights (floor to knuckle, knuckle to shoulder, and shoulder to arm reach), and two box sizes. Each set of experiments was conducted during the 20 min work period using the free-style lifting technique. The working heart rates (WHR) were recorded for the entire duration. In this study, we used SPSS version 18 software and descriptive statistical methods, analysis of variance (ANOVA), and the t-test for data analysis.

Results: The results of the ANOVA showed that there was a significant difference between the mean of MAWL in terms of frequencies of lifts ($p = 0.02$). Tukey's post hoc test indicated that there was a significant difference between the frequencies of 1 lift/minute and 6.67 lifts/minute ($p = 0.01$). There was a significant difference between the mean heart rates in terms of frequencies of lifts ($p = 0.006$), and Tukey's post hoc test indicated a significant difference between the frequencies of 1 lift/minute and 6.67 lifts/minute ($p = 0.004$). But, there was no significant difference between the mean of MAWL and the mean heart rate in terms of lifting heights ($p > 0.05$). The results of the t-test showed that there was a significant difference between the mean of MAWL and the mean heart rate in terms of the sizes of the two boxes ($p = 0.000$).

Conclusion: Based on the results of this study, it was concluded that MAWL and heart rate are influenced by the variables of lifting frequency and the size of the boxes.

Keywords: MMH, MAWL, heart rate, psychophysical methodology

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1. Introduction

Although many work activities have been automated to a significant extent, manual material handling (MMH) is still used in many occupational settings, and this can cause significant problems, even with more recently developed industrial activities and technologies (1). Manual handling is defined as any activity that requires a person to exert a force to lift, lower, push, pull, carry, move, hold, or restrain a person or object (2). Because of the risks of workplace accidents and injuries, there is a widespread emphasis on ergonomics in MMH tasks. MMH tasks may lead to work-related low back pain (LBP), which is identified as one of the major types of occupational disabling injuries, and it can have negative effects on the quality of life of industrial workers. As a public health problem, MMH can impose many adverse effects on people. In many industrialized countries and communities, the governments and industries pay significant amounts of money for workman's compensation, and they also are responsible for paying for workers' treatment and employees' insurance claims. Thus, they spend billions of dollars on workers' health, which includes paying for injuries to the back and other musculo-skeletal injuries (3). Many methods have been developed to assess the manual handling of loads, including the National Institute of Occupational Health and Safety's (NIOSH's) carrying of loads equation, 3D Static Strength Prediction Program(3-D SSPP), and Liberty Mutual Insurance Company's maximum acceptable weight of lift (MAWL) tables (4).

The psychophysical MAWL method is commonly used to decrease LBP in the workplace (5, 6). Based on the MAWL method, participants are asked to visualize that they are doing a task for a specified period of time, and, then, they must actually do the task for a fraction of the specified time. In this method, participants typically can control one task variable and they are allowed to change that variable to a desired comfort level (7). The interaction between the weight and frequency of handling first was studied by the Health and Safety Laboratory (HSL) in the late 1990s (8, 9). In 2000, Swei-Pi Wu conducted a study to assess the effect of MAWL on experienced Chinese male workers, and he realized that the MAWL was reduced significantly as the size of the box and frequency of lifting increased, but the mean heart rate increased noticeably (10). In addition, in another study that was conducted in 2003, Wu also studied MAWL for Chinese working women and again he found results similar to those he had already observed in men (11). In 2005, Lee studied the maximum acceptable weight of carriage (MAWC) for different conditions of frequency and different sizes of containers. He conducted his study on young men in Taiwan, and he found that the MAWL decreased as the frequency and the width or length of the container increased; however, the interactive effect of the frequency and the size of the container on MAWL was not significant (12). In 2009, Lee studied the MAWL in a height of Floor to Knuckle for young Taiwanese men and found that the participants' lifting capabilities were significantly different ($p < 0.05$) based on changes in the lifting modes and in the dimensions of the container (13). In 2011, Lee and Cheng conducted a study to determine the MAWL for young Taiwanese men for different sizes of containers, and they found that the size of the container had a significant effect on MAWL, i.e., the MAWL was reduced as the size of the container increased, and the increasing the width of the container decreased both MAWL and MWL to a greater extent than increasing the length of the container (14). In 2003, Ciriello conducted a study to evaluate the effects of box size and lifting frequency on the MAWL in men, and he found that the frequency had a significant effect on MAWL of lifting with a large box (15). In addition, in 2005, Ciriello conducted another study to evaluate the effects of the size of the box and lifting height on the MAWL in women working in industry, and he found that the MAWL values were reduced significantly as the variables of the size of the box and the lifting height increased (16). In 2007, Ciriello conducted another study that showed that the MAWL was affected significantly by the frequency of lifting the large box. Hence, the results obtained in this study were similar to the results of a similar study that was conducted on men (17). According to the results of a study by Maiti & Ray, the increase in vertical lifting distance led to a significant reduction in load weight for Indian female workers (18). In 2012, Jaswinder Singh et al. conducted a study in which they evaluated the MAWL for Indian male industrial workers. They found that the changes in size of the box, lifting height, and frequency had a significant reducing effect on the MAWL (19). The present study was aimed to assess the effect of box size, frequency of lift, and height of lift on MAWL and the heart rate of male university students in Iran.

2. Material and Methods

2.1. Participants

This experimental study was conducted in 2015. Fifteen young male students (20-30 years old) were recruited from the total population of students at Tehran University. The sample size was consistent with those of previous studies (4, 7, 20-22). The students were examined to ensure that they had no serious cardiovascular problems and no previous history of significant low back pain or musculoskeletal problems in their extremities. They participated in training sessions and became familiar with the experimental procedures before the experimental data were collected.

The reason for selecting students as the subjects was their availability in terms of schedule flexibility and the duration of the experiments. For at least two hours prior to the session in which data were collected, the participants were instructed to avoid eating, smoking, and drinking alcoholic beverages or carbonated liquids. They were trained to avoid taking part in any intense physical activity before the experiment and to maintain their normal sleeping patterns. All participants signed an informed consent form and were paid for their participation in the study.

2.2. Equipment

A height adjustable setup, similar to the device used by Snook (1978), was used to simulate the 18 different lifting conditions considered in this study. A stopwatch was used for time measurements and to instruct the subjects to start and end of the test by examiner. Digital weighing equipment was used for measuring and adjusting the weights. Two plastic tote boxes with external handles were used. The external handles were 17.8 cm long and 4.2 cm thick, and they did not have any sharp edges. The small tote box typified a common small industrial carrying box with the following dimensions: “width: 33.4 cm, length: 56.2 cm, depth: 16.0 cm”. The large tote box typified a very large industrial box with the following dimensions: “width: 76.1 cm, length: 56.5 cm, depth: 22.0 cm”. The width and the length show the horizontal distance between hands and the central axis of the body and the distance from the outside edge of the left handle to the outside edge of the right handle, respectively. The handles were placed midway in the width dimension. The dimensions of the box and handles were the same as those used in the Snook and Ciriello MMH lifting tables (1).

2.3. Physiological measurements

The students’ heart rates were measured using a portable heart rate monitor (Breuer Electro Oy, PM70, Germany). The means of the participants’ heart rates (in beats/min) during the 20-min period were used for statistical analysis.

2.4. Experimental design

The experiments were designed to study the effect of independent factors at different levels on response variables, as shown in Table 1. A randomized, complete-block, factorial design was used to collect data. Three different variables were used in this study, i.e., frequency of lifting, height of lifting, and size of the box. These three variables are the major descriptors of manual lifting tasks. Three levels of lifting frequency (1 lift/min, 4.3 lifts/min, 6.67 lifts/min) were used to simulate slow and fast paces of work. Three different lifting heights (floor to knuckle (F-K), knuckle to shoulder (K-S), and shoulder to arm reach (S-A) were specified. Two different box sizes were used (small and large). Thus, the levels of these three task variables (frequency/height/box size) provided 18 combinations of similar basic manual lifting tasks. Each participant performed lifting for all 18 tasks in random order. As a result, a total of 540 experimental lifting trials (15 participants by 3 frequencies by 3 heights by 2 box sizes by repeat) were performed by the subjects. Each subject determined the maximum acceptable weight of lift. A psychophysical methodology was used to approximate the maximum acceptable weight of lift for each lifting combination (6). In random order, the subjects started with either a very light or a very heavy weight (according to 10th percentile and 90th percentile male (Based on Snook Tables) (5), and they were allowed to adjust it to arrive at the maximum acceptable weight of lift. The adjustment took approximately 20 minutes. The adjustment period was similar to that reported in past studies (23-26). The total experimental time for each participant was distributed over a two-month period to minimize the effect of residual fatigue. Heart rates were recorded as response variables. The room temperature was maintained at 22-24 °C, and the relative humidity was 45–55%.

Table 1. MMH task parameters at different levels

No.	Symbol	Factors	Level		
			Level-1	Level-2	Level-3
1	A	Frequency of lift (lifts/min)	1	4.3	6.67
2	B	Box size (cm^3)	Small	Large	-
3	C	Height of lift (cm)	Floor to knuckle height	Knuckle to shoulder height	Shoulder to arm reach

2.5. Study procedure

The psychophysical methodology was used in this experiment (5, 21, and 27). The subjects were trained to adjust the amount of weight or force until it showed the maximum they could handle for 8 h without "exhausting themselves or becoming unusually tired, weakened, overheated, or out of breath." During the experiments, the participants wore normal work clothes and flat-soled sport shoes. Prior to the experiment, the participants were asked to relax for at least 10 min on a seat, and, then, before starting the experimental session, the researcher explained the aim and the procedures of the study to the participants. There was also a 5-min warm-up period before starting each session. During this period, light physical exercise was performed by the participant, including movements of adductions and abductions of the extremities, flexion, extensions, along with rotations of the trunk and neck. After the warm-up period, under the specific experimental conditions, the participant began handling the box. Next, the participant performed one of the 18 possible experimental conditions (three lifting frequencies, three lifting heights, and two box sizes). Each participant was asked to lift the box using a free-style lifting posture. The start of the lift was considered when the box was moved from its original position. The end of the lift was considered to be the time when the box was placed on the shelf. The vertical lifting distances were set according to the subjects' anthropometry results. A periodic sound was generated from a computer to control the frequency of lifting. When the participants heard the sound, they lifted the box and then waited for the next sound. The participants were permitted to add or remove as much weight from the box as desired between the lift trials. During the lifting tasks, the subjects changed the weight of the tote boxes by adding or removing sand bags. The subjects were aware of the sand bags, but they did not know how much they weighed. The weights of the bags were varied randomly. During the next 20 min, the subjects adjusted the weight according to the instructions. The final weight at the end of the period was considered as the MAWL of the combined task for that particular frequency. Each experimental condition was performed twice by each subject (one replication), and the order in which the subject performed the condition was randomized for each set of experiments. For a given lifting task condition, if the participant's MAWL for the second adjustment was within 15% of the first adjustment, the average of the two adjustments was considered as the final MAWL for that lifting condition. Otherwise, the results were discarded and the relevant data were collected the next time the left was performed.

3. Results

The mean (SD) demographic data of the subjects were as follows: age 22.2 (±2.1) years, body weight 67.5 (±7.4) kg, and height 177.7 (±5.3) cm. The mean and standard deviation of maximum acceptable weight of lift (MAWL) for the small box at a frequency of one lift per minute at different heights of F-K height, K-S height, and S-A height, respectively, were 29.93 (± 4.00), 22.33 (± 2.71), and 19.80 (± 2.21) kg, and the mean and standard deviation of heart rate were 98.60 (± 12.15), 114.07 (± 9.34), and 117.07 (± 5.90) beats per minute. The obtained values for the same box at frequencies of 4.3 and 6.67 lifts per minute at the same heights are presented in Tables 2 and 3. In addition, the mean and standard deviation of the MAWL for the large box at a frequency of one lift per minute at different heights of F-K height, K-S height, and S-A height, respectively, were 20.27 (± 2.22), 19.00 (± 1.51), and 16.87 (± 1.50) kg, and the mean and standard deviation of heart rate were 125.93 (± 4.60), 128.40 (± 4.42), and 130.40 (± 4.12) beats per minute. Tables 2 and 3 provide the values obtained for the same box at frequencies of 4.3 and 6.67 lifts per minute at the specified heights.

Table 2. Maximum acceptable weights (kg) of lift for various boxes at different heights and frequencies

F[1]	Floor to knuckle height (F-K)		Knuckle to shoulder height (K-S)		Shoulder to arm reach	
	Small	Large	Small	Large	Small	Large
1	29.93 (4.00)	20.27 (2.22)	22.33 (2.71)	19.00 (1.51)	19.80 (2.21)	16.87 (1.50)
4.3	24.07 (2.74)	17.00 (2.10)	17.67 (1.49)	16.07 (1.28)	17.07 (1.71)	14.33 (1.40)
6.67	18.80 (2.30)	15.00 (2.77)	15.47 (.092)	14.27 (0.96)	14.20 (1.37)	12.73 (1.58)

1: Frequency of lift (per minute)

Table 3. Mean of heart rate (beats/min) for lifting various boxes at different heights and frequencies

F[1]	Floor to knuckle height (F-K)		Knuckle to shoulder height (K-S)		Shoulder to arm reach	
	Small	Large	Small	Large	Small	Large
1	98.60 (12.15)	125.93 (4.60)	114.07 (9.34)	128.40 (4.42)	117.07 (5.90)	130.40 (4.12)
4.3	122.80 (5.63)	131.20 (5.92)	121.67 (7.73)	135.60 (4.38)	129.27 (6.09)	139.07 (4.50)
6.67	132.87 (7.42)	136.67 (6.50)	133.13 (6.42)	147.53 (3.00)	135.87 (6.73)	145.13 (10.80)

1: Frequency of lift (per minute)

Results obtained from the experiments were analyzed using the analysis of variance (ANOVA), which helps to predict the significance of independent factor for any desired response function. It can identify the most influential factor or parameter. The results of the ANOVA showed that there was a significant difference between the mean MAWL in terms of frequencies of lifts ($p = 0.02$). Tukey's post hoc test showed that the mean MAWL did not show a significant difference between the frequencies of 1 lift/minute and 4.3 lifts/minute ($p > 0.05$); however, there was a statistically significant difference between the frequencies of 1 lift/minute and 6.67 lifts/minute ($p = 0.01$). It should be noted that there was no significant difference between the frequencies of 4.3 lifts/minute and 6.67 lifts/minute ($p > 0.05$). As the frequency increased from 1 lift/min to 4.3 lifts/min, the mean MAWL declined by nearly 19%, from approximately 21 kg to 17 kg. A further decline of 17.65% from 17.00 kg to 14.00 kg was observed when the lifting frequency increased to 6.67 lifts/min. The MAWLs of lifting the small and large box in F-K height, K-S height, and S-A height at 6.67 lifts/min were 40%, 31.8% , 26.3%, and 30%, 26.3%, 25% of the MAWL of lifting at a frequency of 1 lift/min, respectively (Table 2). Although our study showed that this frequency was seldom used in industry, the results may help in redesigning tasks, such as loading and off-loading a conveyer at such high frequencies. In addition, the results of the ANOVA test showed that there was a significant difference between the mean heart rates in terms of frequencies of lifts ($p = 0.006$). Tukey's post hoc test showed that the mean heart rates at the frequencies of 1 lift/minute and 4.3 lifts/minute were not significantly different ($p > 0.05$), but there was a statistically significant difference between the frequencies of 1 lift/minute and 6.67 lifts/minute ($p = 0.004$). Note that there was no significant difference between the frequencies of 4.3 lifts/minute and 6.67 lifts/minute ($p > 0.05$). When the frequency of lifting was increased from 1 lift/min to 4.3 lifts/min, the mean heart rate increased by approximately 4.8%, from 119 beats/minute to 130 beats/minute. In addition, by increasing the frequency of lifting to 6.67 lifts/min, the mean heart rate was increased by 6.6%, from 130 beats/minute to 139 beats/minute. The results of ANOVA showed that there was no significant difference between the mean MAWL in terms of lifting heights ($p > 0.05$). In addition, the results of the ANOVA test showed that there was no significant difference between MAWL in terms of lifting heights ($p > 0.05$). The results of the t-test showed that there was a significant difference between the mean MAWL in terms of the sizes of the two boxes ($p = 0.000$). When the size of the box was increased from small to large, the mean MAWL decreased by approximately 20%, from 20.00 to 16.00 kg. This was due to the fact that the subjects preferred lifting more weight when lifting the smaller box than when lifting the larger box. In addition, the results of the t-test showed that there was a significant difference between mean heart rate in terms of the sizes of the two boxes ($p = 0.000$). When the size of the box was increased from small to large, the mean heart rate increased by approximately 10%, from 123 beats/minute to 136 beats/minute. Our findings also showed that the mean maximum acceptable weight of lift had a significant difference in terms of the combined variables of lifting frequency, lifting height, and the size of the box ($p < 0.05$). In addition, the mean heart rate had a significant difference in terms of the combined variables of lifting frequency and the size of the box, as well as the simultaneous effects of variables of lifting frequency, lifting height, and the size of the box ($p < 0.05$). However, the mean heart rate had no significant difference in terms of the combined variables of lifting frequency and lifting height or the lifting height and size of the boxes ($p > 0.05$).

4. Discussion

The MAWL that was obtained in this study was lower than that obtained by Snoock et al. for American men. However, with increase in the size of the box, the frequency, and height of lift, MAWL had a decreasing trend, which was consistent with Snoock et al.'s study. The lower levels obtained in our study may have been due to the anthropometric differences between American men and Iranian men. In this study, the MAWL was reduced due to the increase in the size of the box; this was in good agreement with the results of other studies (12-15, 17, 19). It is due to the fact that the subjects preferred lifting more weights when lifting the smaller box than when lifting the larger box. Frequency was significant in this experiment, and it also has been a significant factor in all of our previous papers for both males and females. Thus, MAWL decreased with an increase in the lifting frequency. Differences in the frequency also led to greater effects than the differences in the size of boxes (10-20). In the present study, it was found that participants lifted more load when there was a lower vertical lifting height (from F-K height). The MAWL was decreased gradually as the vertical lifting height, lifting frequency, and box size increased. These results were consistent with the results reported by previous studies (5, 6). The results on the effects of height on lifting were similar to the results of earlier studies that reported the effects of height on males and females (2, 6, 20), but it was contrary to the results of other studies that found that height had no significant effect on males or females (16, 27). The MAWL decreased with the changes in the frequency, while the physiological costs increased. The increase in physiological costs may be primarily due to increased body weight. In addition, the mean heart rate obtained in this study increased with an increase in the size of the box, lifting height, and the frequency of the lifts, which was in good agreement with the results of other studies (10, 11).

5. Conclusions

This study showed that there was a significant difference between mean MAWL in terms of frequencies of lifts and size of the boxes, but the difference was not significant in terms of lifting height. In addition, there was a significant difference between mean heart rate in terms of frequencies of lifts and size of the boxes; however, it did not show a significant difference in terms of the height of the lift. It is recommended that similar studies be conducted with females. This study was conducted only on students whose ages ranged from 20 to 30, because they were easily available; therefore, it is recommended that similar studies be conducted with workers with a wider age range in order to obtain more accurate standards for the maximum acceptable weight of lift and to reduce the risks of handling weights. Based on the results of this study, it can be concluded that MAWL and heart rate are influenced by the variables of lifting frequency and size of the boxes.

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Conflict of Interest:
There is no conflict of interest to be declared.

Authors' contributions:
All authors contributed to this project and article equally. All authors read and approved the final manuscript.

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