EFFECT OF FLOOR SLOPE ON SUBMAXIMAL LIFTING CAPACITY

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ABSTRACT

In order to reduce injuries due to lifting a box from the floor, maximal acceptable weights of lift (MAWL) have been established for a level surface. However, an inclined surface condition may be encountered on a jobsite. The purpose of this investigation was to determine if facing up or down a sloped surface affects MAWL. After obtaining university-approved informed consent, 20 apparently healthy men (age = 22.4±1.4 yrs) and 20 women (age = 22.0±1.9 yrs) determined floor to knuckle height MAWL using the psychophysical approach. After a familiarization day, two data collection days were completed with the uphill and level (+20, +10 and 0°) or downhill and level (-20, -10 and 0°) lifting capacities determined. A cadence of four lifts/min was used after starting with an unknown load that participants adjusted after each lift. No differences ($p > 0.05$) in level MAWL were found on the downhill day compared to the uphill day. While the men lifted significantly more than the women in every condition ($p<0.001$), no differences were found across the lifting conditions ($p>0.05$). The men averaged a MAWL of 24.7 kg across the five conditions (average standard deviation (SD) = 7.4 kg), the women averaged 14.8 kg (average SD = 3.1 kg). While these findings would suggest no changes in lifting guidelines for a sloped surface within 20° of level, other factors such as lifting technique and the stress placed on the low-back should be examined to assess risk of injury in these different conditions.

INTRODUCTION

Back pain has been described as one of the most common and significant musculoskeletal problems in the United States [1,2]. Its magnitude is so large that even a 1% reduction in the overall prevalence rate would considerably reduce morbidity and save billions of dollars every year [3]. Numerous studies have focused on the relationship between the incidence of back pain and lifting. Investigators have determined that approximately 66% of all lifting tasks are initiated at or below hip level and these tasks are associated with 78% of all back injuries [4]. In the work place, recommendations have been established and equations developed that account for risk factors such as lifting frequency, height of the lift and object size [5,6]. However, all recommendations are on a level surface and consideration has not been given towards the slope of the surface.

For a majority of occupations it is anticipated that lifting is performed from a level surface, however, circumstances do exist at building and construction sites or loading/unloading docks where lifting may occur from a sloped surface. Interestingly, occupations recognized for their unstable terrain and uneven working conditions, such as lumber and building material retailing, have a high prevalence rate for back pain and injury [3]. Although the effects of lifting from a sloped surface have not been documented, it has been established that joint angle may influence maximal strength [7]. Due to the interaction between the lifter and the slope, the ankle joint is expected to be affected by the incline with possible changes to joints on up the kinetic chain.

An additional factor created by the sloped surface that must be considered is the change in lifting height required from the different slope conditions. Facing up the incline with the load in front of the

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person will reduce the distance required to lift the load to knuckle height compared to the level. Similarly, facing down the incline with the load in front of the person will increase the distance required as compared to the level. This factor may also change lifting capacity since the height the box is raised is proportional to the mechanical work (average force x displacement) required from the lifter.

The goal of the present research effort is to determine if either facing up or down a sloped surface influences submaximal lifting capacity as compared to the level surface, thereby altering recommended safe loads for these conditions. Additionally, since women appear to have a higher incidence of back pain and injury than men [2] and since women have slightly different musculoskeletal characteristics than men [8,9], they might be affected differently by the sloped surface. Therefore, both men and women should be examined.

METHODS

Participants: After obtaining university-approved informed consent, 20 men and 20 women between 18-25 years old successfully completed the protocol (men: age = 22.4 ± 1.4 yrs, height = 181.6 ± 7.1 cm, mass = 80.1 ± 7.9 kg; women: age = 22.0 ± 1.9 yrs, height = 167.9 ± 7.0 cm, mass = 64.8 ± 7.8 kg). Participants were apparently healthy, with no history of chronic back pain or injury, or episode of back pain within the last month. Participants were not employed as manual laborers or in jobs where lifting is a primary task, though this has not been found to be necessary [10]. However, all were comfortable with lifting a box from the floor to knuckle height (arms extended near hips).

Experimental Apparatus: Participants performed the prescribed protocol from an adjustable square platform (1.22 x 1.22 m) (Figure 1). Hinged at one end, the platform was capable of varying slopes (from 0 to ~25°) with the aid of two manually operated screw jacks placed 0.33 m fom the front of the platform. A non-skid floor finish additive (Behr Process Corporation, Santa Ana, CA) combined with black latex paint was applied to the surface of the platform to reduce the risk of slipping during the lifting procedure.

(a) (b) (c)

Figure 1: Lifting platform with examples of slope conditions: (a) facing down (negative slope), (b) level, and (c) facing up (positive slope). Slope pictured is at 20° relative to horizontal. Example participant mocked up with reflective markers to see landmarks more clearly.

To replicate actual lifting movements, a standard milk crate was utilized. A wooden box with a false bottom was placed inside the milk crate to prohibit the participant from receiving any visual cues

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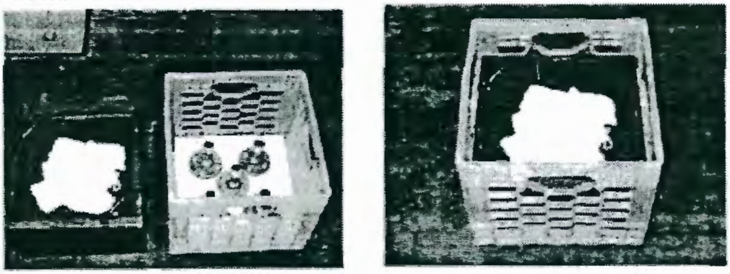
concerning a randomized load within the box (Figure 2). In addition to the weights beneath the false bottom, supplementary packages of lead shot, each with a mass of 0.91 kg, were available to increase or decrease the load.



(a) (b)

Figure 2: Milk crate and false bottom with six bags of lead shot on top: (a) independent of each other with posts exposed where weights are placed to randomly adjust the initial load, and (b) combined together to eliminate visual cues concerning the weight load.

Experimental Protocol: The psychophysical method was utilized to safely determine the submaximal lifting capacity for all the floor conditions based on its reproducibility [11] and validity [12]. The experimental protocol extended over three sessions that were completed by each participant within a seven-day period. The first session was designated as a familiarization day while the second and third days were for data collection. On the second and third days of testing, participants determined any differences in floor-to-knuckle height lifting capacities from the level surface and two levels of sloped surface. Participants were encouraged to utilize the same lifting technique they would use during a typical lifting situation.

After a brief warm-up period, each participant began the lifting protocol with an unknown weight on a randomized surface slope (0□, +/-10□ or +/-20□, + indicating facing up the slope). The participant successfully completed all of the positive (or negative) conditions during the first data collection session. During the second data collection session the participant completed the remaining conditions. Each session had the participant lift from the level surface to ensure that no differences existed from day to day.

Lifting instructions were provided to the participant before the initiation of the first lift for all of the trials. The participant lifted the load from the floor to knuckle height at a frequency of four lifts/min, and then lowered the load back to the starting position after a momentary pause at the top. The participant was able to add or subtract weight as needed between lifts to determine the maximum load they were able to sustain without feeling the onset of fatigue. Besides the initial six bags placed on top of the wooden insert, 18 additional bags were available to the participants to increase the load. With a randomized load hidden from view, participants were not able to judge the amount of weight based on visible bags of shot. The MAWL for each lifting condition was determined within 10 minutes following the initiation of the specific condition or until the subject selected a load that was maintained for eight consecutive lifts [13]. Participants were not informed of the ending criterion.

A mandatory 10-minute rest period was given to the participant following each lifting condition to minimize fatigue throughout the experimental procedure. The starting load was adjusted out of view of the participant. Following the rest period, the participant continued determining their MAWL on the remaining lifting conditions.

Data Analysis: The anthropometric measures recorded on the participants were compared between genders with Student's t-tests. The p-value for significance was set at 0.05 for all analyses based on the exploratory nature of the study and a power analysis of the psychophysical data collected by Aghazadeh and Lu [14] in order to analyze the men and women independently. All analyses were performed using Statistical Package for the Social Sciences, Version 11.5 (SPSS, Inc., Chicago, IL).

In order to ensure that participants performed equally on each data collection day, the level lifting condition results were compared with repeated measures Student's t-tests. No significant differences were found in the level lifting conditions from day-to-day for the men or women (see results below), so the two data sets were averaged to create a single set for comparison with the sloped surface lifting conditions. The effects of gender and slope lifting condition were examined with a 2 x 5 repeated-measures Analysis of Variance.

RESULTS

While the 0.4 year greater average age in the men compared to the women was not significantly different (p= 0.408), height and mass were significantly greater in the men compared to the women (p<0.001).

No significant differences were observed between whole group level lifting capacities between the data collection trials (p=0.170). Whole group level lifting capacity on the downhill day (20.25 ± 8.29 kg) was similar to the capacity determined on the uphill day (19.6 ± 7.37 kg). Independent level lifting capacities for men and women produced similar findings. Values for the men on the downhill day (25.80 ± 8.29 kg) were not significantly different (p=0.058) than the values obtained for the uphill day (24.34 ± 6.81 kg). Likewise, level lifting capacities for the women on the downhill day (14.70 ± 2.72 kg) were not significantly different (p=0.763) than the capacity determined for the uphill day (14.86 ± 4.2 kg). Given the lack of difference among the downhill and uphill session level lifting capacities, as previously described, a single data column comprised of an average of the two sessions for level lifting capacity was established to analyze the effects of gender and slope on these variables.

Surface slope did not have a significant effect on lifting capacity when the men and women were combined (p = 0.191) (Table 1). There was also no significant interaction effect for slope and gender (p = 0.193). However, there was a significant main effect for gender (p < 0.001). For each slope the men lifted significantly more than the women. Since there was a significant difference between the men and women, these sets were then examined separately. Findings were similar to those as a whole group. No significant differences were found across slope for men (p = 0.134) or women (p = 0.806).

DISCUSSION

MAWL values from the level surface compare favorably to the 50^{th} percentile of Snook and Ciriello's [15] revised tables of maximum acceptable weights and forces for a lifting task originating from floor level up to knuckle height at a frequency of four lifts/min. In the current study, male and female participants lifted, on average, 25.1 and 14.8 kg, respectively. Snook and Ciriello's revised tables indicate that half of the male and female industrial population could acceptably lift a load of 24 and 14 kg, respectively, from the floor to knuckle height without injury.

Our findings also compare to MAWL values established by Ciriello *et al.* [12] for a similar lifting task. Ciriello *et al.* determined male and female MAWL values after 40 minutes and compared them to the values after 240 minutes. Interestingly, MAWL values obtained after 40 minutes (29.1 and 12.3 kg for males and females, respectively) were not significantly different than the MAWL values achieved after 240 minutes (27.9 and 11.9 kg for males and females, respectively).

Table 1: Effect of Slope on Lifting Capacity

		Down 20°	Down 10°	Level	Up 10°	Up 20°
Men	Mean	25.1	24.1	25.1	23.8	25.5
[n=20]	*Std Dev*	*8.9*	*7.4*	*7.4*	*6.1*	*7.2*
Women	Mean	14.7*	14.7*	14.8*	15.0*	15.0*
[n=20]	*Std Dev*	*2.9*	*2.8*	*3.3*	*3.6*	*2.7*
Combined	Mean	19.9	19.4	19.9	19.4	20.3
[N=40]	*Std Dev*	*8.4*	*7.3*	*7.7*	*6.7*	*7.6*

All capacities reported in kilograms
* ($p < 0.05$) between men and women

A clear difference between our lifting capacity study and that of Ciriello *et al.* [12] involved the length of the test. All of our participants determined their MAWL values within 10 minutes. This is quite different compared to the 240-minute protocol utilized by Ciriello *et al.* Ten minutes was selected as an appropriate test length due to the fact that most changes occurred in the first few lifts of the adjustment period, followed by minor oscillatory changes [13]. However, this could account for the minor differences between our findings and theirs. The difference could also be attributable to familiarity with the task, where industrial workers lift more often.

Results from the current study support findings from Mital *et al.* [16] indicating gender has a distinct influence on psychophysical lifting capacity. According to their research, a female's lifting strength is, on average, 60-76% of a male's lifting strength. Results from this study demonstrated that female MAWL values were nearly 60% of the male values.

While no other studies have examined the effect of slope on lifting capacity, Aghazadeh and Lu [14] examined the effect of high-heeled shoes. Although lifting with high heels creates an environment similar to lifting while facing down a sloped surface, given that both situations elevate the heel above the toe, visible differences in lift distance exist. Facing down a sloped surface places the object to be lifted at a different height relative to the forefoot. In contrast, lifting with high heels does not alter the object's height relative to the forefoot. Provided that more work is accomplished while lifting from a sloped surface (compared to wearing high heels), greater differences in MAWL values might be expected than when wearing high heels.

Aghazadeh and Lu [14] determined MAWL values for 9 college-aged females (age = 22 ± 1.98 yrs, height = 1.69 ± .1 m, mass = 64.3 ± 12.28 kg) using three different heel conditions (flat, 5 cm, and 7.6 cm). The participants used by Aghazadeh and Lu compared favorably with the female participants used in the current study. The lifting protocol was consistent to the one used in the current study with the exception of the test duration. Each test trial lasted 20 minutes. The heel conditions utilized by Aghazadeh and Lu were similar to the slopes presented to our participants. Considering the average woman's foot is 24.4 cm long [17], a 5 cm and 7.6 cm high-heel would equal 11.8 and 17.9□.

respectively. Although not identical, these conditions compare favorably to the downward facing slopes presented to our participants (10 and 20□).

In contrast to our results, Aghazadeh and Lu [14] discovered noticeable differences in MAWL values between heel conditions. The values obtained from the flat condition were significantly different ($p < 0.001$) than the values obtained from the 7.6 cm heel condition. In fact, participants lifted 21.5% less while wearing the 7.6 cm high heels compared to the flat-heeled shoes. Although no significant difference ($p = 0.078$) was observed between the flat and 5 cm heel condition, it was noticed that the load lifted with 5 cm high heels was 11% less than the load lifted with flats.

Differences in MAWL results between the two studies can be attributed to a number of factors. Both of the lifting capacity studies allowed the participants to lift using any style they wanted (freestyle lifting), with one exception. Participants in our study were instructed to incorporate a stance wider than the width of the box to allow them to stand closer to the box and reduce the chance of back pain and injury. Despite the instructions to use a freestyle lifting technique, all the participants from Aghazadeh and Lu's [14] study used a stoop lifting posture. In contrast, based on qualitative visual observation, our participants preferred the semi-squat style of lifting. Interestingly, Sedgwick and Gormley [18] indicated the semi-squat technique is the most popular method used by males and females to pick up a load from floor level and that stoop lifting should not be used owing to poor adaptability and potential hazards for the lumbar spine.

The duration of each lifting trial could also have influenced the MAWL values obtained from each study. Despite similar lifting protocols, each lifting trial in Aghazadeh and Lu's [14] study lasted 20 minutes. Comparatively, MAWL values were obtained within 10 minutes of testing for nearly all of our participants. Perhaps the additional 10 minutes of lifting experienced by the high-heeled participants was enough to influence the final MAWL value for each condition. However, this is unlikely based upon the level floor MAWL tests that found 10 minutes an adequate time [13].

While it was anticipated that floor slope would have a significant effect on lifting capacity, none was found in this study. Even though it appears that lifting kinematics are altered by the slope, since the ankle must accommodate the altered orientation of the foot created by the slope, and the joint ranges of motion must change in order to pick up a box at a different height relative to the foot with each different slope, these changes do not seem to be of a magnitude great enough to alter MAWL. This leads to the questions, what mechanism is responsible for us to select the appropriate maximum load in a repetitive lifting task and how does this impact the risk of low-back injury. Additional research is needed into these areas before decisive conclusions can be made regarding the effect of floor slope and appropriate recommendations for safe lifting loads.

CONCLUSIONS

While men are capable of lifting significantly more than women, on average, varying the surface slope does not significantly alter submaximal lifting capacity of either gender as measured through the psychophysical approach in spite of noticeable changes in the amount of work accomplished (based on height lifted in different conditions). Further investigation is needed into this finding to determine if posture (joint alignment) plays a role in loads internal to the body and, therefore, risk of injury. As a result, no adjustments to lifting guidelines based on floor slope may be made at this time. Future research is needed to understand how the body is loaded and why submaximal lifting capacity does not change with floor slope.

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