

The effect of floor slope on sub-maximal lifting capacity and technique

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Abstract

Inclined surfaces, where both the lifter and load are on the slope, may be encountered in a jobsite situation. The purpose of this study was to determine if facing up or down a sloped surface (10° and 20°) would affect maximal acceptable weights of lift (MAWL) using a 10 min psychophysical approach with symmetric freestyle technique at 4 lifts/min. Seventeen healthy men and 18 women determined floor to knuckle height MAWL while facing uphill, downhill, and on a level surface. Motion capture was also performed to examine sagittal plane joint angles and foot placement relative to a milk crate. Slope did not alter MAWL ($p > 0.05$) with the men lifting more than the women in every condition ($p < 0.001$) (25 kg vs. 15 kg, respectively). Foot placement relative to the box was altered by slope such that both horizontal position behind and vertical position below the box increased as slope changed from the downhill to uphill conditions (both $p < 0.001$). Forward torso lean as well as hip, knee, and ankle (plantar) flexion generally decreased as slope changed from the downhill to uphill conditions (all $p < 0.001$). Torso and knee motion appeared to be protected compared to the other joints, changing the least. Though trends were the same in both sexes, interactions did exist in vertical foot position and hip angle (both $p \leq 0.001$). In conclusion, the body is highly adaptive to floor slope, maintaining MAWL at least in the short term. However, while slight technique differences exist between men and women, care should be taken by all when facing uphill due to the tendency to stand further from the load horizontally and when facing downhill due to increased torso lean.

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1. Introduction

Back pain is associated with many factors that relate to both the condition of the person (i.e. obesity, physical fitness level, smoking, age, and sex) (Pope et al., 1991) as well as the occupational requirements (i.e. lifting frequency, height of the lift, and object size) (Ayoub et al., 1997). In order to minimize injuries from the occupational requirements, recommendations have been established for maximum acceptable weights of lift (MAWL) (Ciriello et al., 1990, 1993; Ciriello, 2007; Jiang et al., 1986; Snook and Ciriello, 1991). However, all recommendations are based on lifting from a level surface and consideration has not been given towards the slope of the surface where the lift might be performed while facing up or down an incline (Fig. 1).

Sloped surfaces are of interest because of circumstances existing at building and construction sites, loading/unloading docks, or roofs where lifting objects is a necessity in these conditions. Within this list, lumber and building material retailing have a high prevalence rate for back pain and injury (Bureau of Labor Statistics, 2006). Awkward lifting scenarios have been found to increase the risk for injury (Liira et al., 1996), which may be one reason why sloped surfaces suggest caution. Lifting on a sloped surface may alter whole-body stability (balance) and slip potential, which influences lifting technique (Zhao et al., 1987) as well as physiological and psychophysical responses (Li et al., 2007). Lifting technique affects MAWL (Chaffin and Page, 1994) as do the vertical and horizontal distance between the lifter and load (Ciriello et al., 1993; Ciriello, 2007; Snook and Ciriello, 1991, respectively) which may be altered when using a free-style technique. Therefore, it is difficult to predict how lifting capacity recommendations should be altered when on a sloped floor.

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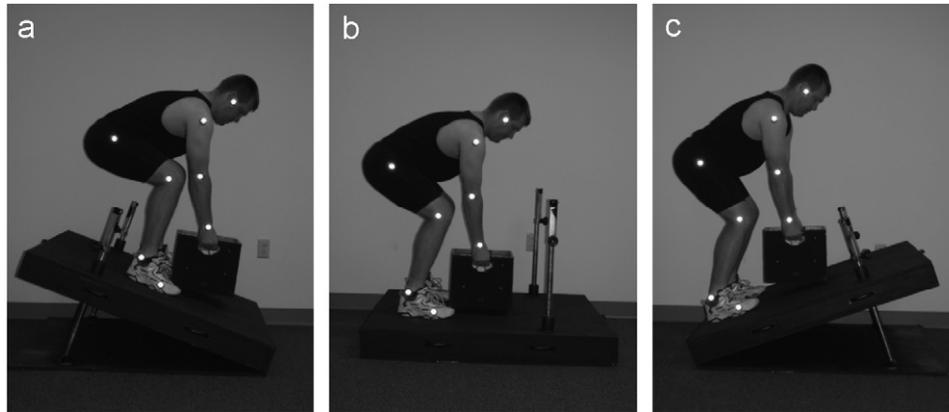


Fig. 1. Demonstration of lifting from the simulated sloped floor condition where person and box both start on the same slope: (a) declined surface relative to the horizontal (-20°), (b) level surface (LVL), and (c) inclined surface relative to the horizontal ($+20^\circ$). Pictures were taken slightly after the box completely left the floor.

Vertical and horizontal foot placement relative to the load at lift off, individually as well as collectively, will affect the distance required to bend over and grasp the load. Bending over incorporates a combination of both spinal flexion and anterior pelvic rotation at the hip (Granata and Sanford, 2000). As the spine flexes the extensor muscles tend to reduce their activity (known as the flexion–relaxation phenomenon), placing greater loads on the passive structures, increasing risk for ligament injury (McGill and Kippers, 1994). As the spine flexes and the natural lordosis of the lumbar region is lost, shear forces on the spine increase along with the risk for disc rupture (Marras et al., 1995; Potvin et al., 1991). There is also a compromised ability to control spinal curvature when bent over, which may lead to increased injury (Wilson and Granata, 2003). In order to limit the amount of spinal flexion, an option may be to increase knee and hip joint motion with a squat technique. However, the knee extensors are not as strong as the low back musculature and are prone to fatigue (Schipplein et al., 1990; Trafimow et al., 1993). Lifting with the legs also significantly increases hip joint loading, which has been implicated in degenerative cartilage wear (Luepingsak et al., 1997). Independently, the horizontal distance between the foot and load will affect the moment arm that the load has relative to the low back. An increased moment arm will increase the torque at L5/S1, potentially increasing the risk for injury while at the same time limiting MAWL (Davis et al., 2000).

At present, the most closely associated research examining floor slope effects on MAWL have only altered foot orientation, leaving the box on a level surface (Aghazadeh and Lu, 1994; Shin and Mirka, 2004). However, their results suggest that MAWL and lifting technique should be altered by floor slope. Therefore, the goal of this research effort is to determine if either facing up or down a sloped surface influences sub-maximal lifting capacity (MAWL) and technique as compared to the level surface. Since women may lift differently than men (Marras et al., 2002) and are affected by horizontal reach differently than men

(Ciriello, 2007), it may not be assumed that both men and women will be affected equally by the sloped surface, so both sexes should be included (Lindbeck and Kjellberg, 2001). From this examination, adjustments to recommended MAWL values for sloped surfaces will be possible as will limited conclusions regarding the risk for injury associated with lifting from a sloped floor.

2. Methods

2.1. Participants

Subjects volunteered from the general college population, limiting age from 18 to 24 years (Table 1). Participants were healthy based on a medical screening, with no history of chronic back pain or injury, or episode of back pain within the last month. Additional exclusions from the study were any condition that prevented them from lifting symmetrically or were formally trained in lifting objects from the floor (e.g. weightlifters and powerlifters). Subjects were not required to be employed as manual laborers or in jobs where lifting was a primary task. However, they were comfortable with the task.

Standing height, right side floor to closed fist knuckle height, and floor to hip (palpated greater trochanter) height measurements were performed on each subject while wearing shoes. Knuckle-to-hip and hip-to-standing height ratios were then calculated by dividing knuckle height by hip height and hip height by standing height, respectively. Both ratios were converted to a percent by multiplying by 100. Body mass was measured while in shorts and t-shirt with shoes.

2.2. Apparatus

After obtaining university-approved informed consent, participants performed the prescribed protocol from an adjustable square platform (1.22×1.22 m) (Fig. 1). Hinged at one end, the platform was capable of varying slopes

Table 1
Summary of anthropometrics

	Age (years)	Mass (kg)	Standing height	Knuckle height	Hip height	K/H ratio (%)	H/SH ratio (%)
Men (<i>n</i> = 17)							
Mean	22.3	81.4	181.7	82.0	97.7	83.9	53.8
S.D.	1.5	7.7	7.6	3.7	4.6	2.3	1.1
Women (<i>n</i> = 18)							
Mean	22.1	65.3*	167.7*	76.7*	94.7	81.0*	56.5*
S.D.	1.8	8.1	7.2	4.1	4.6	2.7	1.0

All heights are reported in centimeters. K/H ratio, knuckle-to-hip ratio. H/SH ratio, hip-to-standing height ratio.

* $p < 0.05$ between men and women.

(from 0° to ~25°). A non-skid floor finish additive (Behr Process Corporation, Santa Ana, CA, USA) combined with black latex paint was applied to the surface of the platform to reduce slip potential.

A standard milk crate measuring 28 × 33 × 33 cm (height × width × depth) with opposing padded handholds located 25 cm from the bottom was lifted. Handholds were padded to minimize discomfort and remove this factor from influencing MAWL. A wooden fixture with a false bottom was placed inside the milk crate to prevent the participant from receiving any visual cues concerning a randomized load placed in the bottom. Together, the crate, wooden fixture, and securing pegs created a system with a mass of 6.25 kg. In addition to the weights held securely 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.

2.3. Experimental design and procedures

The psychophysical method was utilized to determine the lifting capacity for all the floor conditions based on its reproducibility (Snook, 1985) and validity for frequencies at or below 4.3 lifts/min (Ciriello et al., 1990). The experimental protocol extended over three sessions (days) that were completed by each participant within a 7-day period. The first session was for familiarization, during which each participant was exposed to the psychophysical method in three conditions (one level, one facing up, and one facing down an incline) using the same protocol that was utilized during testing.

On the second and third days, participants determined any differences in floor-to-knuckle height lifting capacities from the level surface and two levels of sloped surface. Participants were videotaped in the sagittal plane to quantify technique during all lifting conditions. A single 60 Hz camera (shutter speed = 1/1000 s) was positioned orthogonal to the plane of motion at a distance of ~5 m. All participants were required to wear appropriate clothing (sleeveless shirt and tight fitting shorts) during the experimental protocol, so that joint locations could be quantitatively analyzed. Retro-reflective markers were placed on the skin (or clothing) of the right side of the

body at the temple and approximate joint centers of the shoulder (glenohumeral head), elbow (lateral humeral epicondyle), wrist (lateral side midway between styloid processes of the radius and ulna), hip (greater trochanter), knee (lateral femoral epicondyle), ankle (lateral malleolus), and toe (distal head of fifth metatarsal) as outlined by Winter (2005) (Fig. 1). Participants were allowed to wear whatever shoes they felt comfortable lifting in, as long as they were worn during both data collection sessions.

Subjects were encouraged to utilize the same lifting technique they would use during a typical lifting situation. However, in order to reduce the incidence of back pain or injury from enhanced horizontal distance from the load (Chaffin et al., 1999; Snook, 1978) participants were required to keep their feet wider than the width of the box (roughly shoulder width) so that they could straddle the box with their feet if desired. Slight misalignments of the feet in the fore-aft direction up to 2.5 cm were allowed to ensure as normal/comfortable a lifting style as possible, though not to the extent that a staggered stance was created.

After a brief warm-up period, each participant began the lifting protocol with an unknown weight on a randomized surface slope (0° = LVL, +/−10° or +/−20°; ‘+’ = facing uphill, and ‘−’ = downhill). 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 (either positive or negative). Each session also had the participant lift from the level surface to ensure that no differences existed from day-to-day. The protocol was randomized so that half of the subjects completed the up hill conditions and half completed the down hill conditions on the second day. Then, within each day, the two different inclines and the levels were randomized.

Lifting instructions consistent with those published by Ciriello et al. (1993) and Jiang et al. (1986) were read to the participant before the initiation of the first lift for all of the trials. Subjects were instructed to “work hard without straining yourself or becoming unusually tired, weakened, overheated or out of breath,” establishing the maximum amount of weight they could lift at the prescribed pace indefinitely. A randomized load ranging from 2.27 to 22.73 kg for the men and 0–11.36 kg for the women was placed in the

box out of view of the subject, under the wooden insert. Loads varied across trials for each subject as well as across subjects. Performance during the familiarization session was utilized to assess load range to ensure the initial load was neither excessively light nor heavy. Six bags of lead shot were then placed on top of the wooden insert.

The participant lifted the load from the floor to standing knuckle height at a frequency of 4 lifts/min. Both the participant and the investigator monitored a clock to ensure a consistent lifting frequency, with auditory cues from the investigator as needed to maintain pace. After each lift the participant lowered the load back to the starting position. The participant added or subtracted weight as needed on their own to identify a load they were willing to sustain for the designated surface slope. The MAWL for each lifting condition was determined at 10 min or sooner if the subject selected a load that was maintained for eight consecutive lifts (Davis et al., 2000). Participants were not informed of the second ending criterion. A mandatory 10-min rest period was given to the participant between each lifting condition to minimize fatigue throughout the experimental procedure. In order to reduce the risk of variation between testing sessions, participants were scheduled during the same time of day and encouraged not to perform any strenuous activity during the day prior to the data collection. Participants were monetarily compensated for their involvement in the study.

2.4. Data processing

Lifting technique analysis was based on an average of the last three lifts for each condition. Each of these lifts was automatically digitized from six video frames prior to the first onset of motion starting the countermovement phase of the lift until six frames after the completion of motion at the end of the extension phase of the lift. Coordinate data was then smoothed at 5 Hz using a fourth order, recursive, low-pass Butterworth filter (Motus, Peak Performance Technologies, Inc., Englewood, CO, USA).

The coordinate data was utilized to calculate the sagittal plane torso (shoulder and knee markers relative to positive horizontal axis), hip (shoulder, hip, and knee markers), knee (hip, knee, and ankle markers), and ankle (knee, ankle, and toe markers) angles. Each angle was defined such that it decreased during the countermovement phase and then increased during the extension phase of the lift. The minimum value of each angle was then extracted for analysis. In order to assess how close a person stood to the box, the horizontal and vertical position of the box relative to the foot was calculated by subtracting toe position from wrist position at the start of the lift when first motion of the box was observed.

2.5. Data analysis

Anthropometric measures were compared between sex with independent *t*-tests. The *p*-value for significance was

set at 0.05 for all analyses which were performed using the Statistical Package for the Social Sciences, Version 11.5 (SPSS, Inc., Chicago, IL, USA).

In order to ensure that participants performed equally on each data collection day, the level (LVL) lifting condition results were compared with repeated measures *t*-tests. No significant differences were found between any of the variables when comparing the LVL lifting conditions from day-to-day for the men or women. Therefore, the two data sets were averaged to create a single set for comparison with the results in the sloped surface lifting conditions. Intra-class correlation coefficients were also calculated for the men ($r = 0.970$), women ($r = 0.956$), and whole group ($r = 0.985$) to verify the internal consistency of the subjects.

The effects of sex and slope lifting condition were examined with a 2×5 repeated measures analysis of variance (ANOVA). If the interaction between the sex and condition was found to be significant, then simple main effects were analyzed to determine the differences between sex and conditions. If differences were found across condition for each sex, then a post-hoc, one-way repeated measures ANOVA with Bonferroni confidence interval adjustments were conducted to determine where the differences existed.

If the interaction between sex and condition was not found to be significant, but the main effect for condition was significant, then a post-hoc one-way repeated measures ANOVA with Bonferroni confidence level adjustment was conducted to investigate the location of the differences in the whole group. Regardless of the significance of the interaction between sex and slope, if the main effect for sex was found to be significant, simple main effects were conducted to determine the condition(s) where differences occurred.

3. Results

3.1. Subjects

Seventeen men and 18 women successfully completed the protocol. The men and women were not significantly different in age ($p = 0.744$) or standing hip height ($p = 0.060$). However, the remainder of the general characteristics was significantly different between the men and women ($p \leq 0.001$). The men were significantly heavier, taller, had greater standing knuckle height as well as a greater knuckle-to-hip ratio, while the shoulder-to-hip ratio was less in the men compared to the women (Table 1).

3.2. Maximal acceptable weight of lift (MAWL)

There was no significant interaction between sex and lifting condition in MAWL ($p = 0.427$), nor was there a main effect for condition ($p = 0.200$). However, there was a significant main effect for sex ($p < 0.001$), with the men

lifting significantly more than the women in every condition (Table 2).

3.3. Foot placement

There was an interaction between sex and lifting condition for the vertical distance between the box (wrist) and toe at the start of the lift ($p < 0.001$). The main effect for sex was also significant ($p < 0.001$) with the men significantly further away in both down hill conditions and the LVL condition. The simple main effect for lifting condition of each sex was also significant ($p < 0.001$), with a trend for an increase in vertical distance as lifting condition progressed from the -20° to $+20^\circ$ lifting condition (Fig. 2a). While the women possessed a significant increase in every lifting condition, the men were not significantly different from the -20° to -10° lifting condition.

In the horizontal direction there was no interaction between sex and lifting condition for distance between box and toe at the start of the lift ($p = 0.522$). However, there was a main effect for both sex ($p = 0.002$) and lifting condition ($p < 0.001$). The men were significantly closer than the women in all conditions except the $+10^\circ$ lifting condition. The main effect for lifting condition was significant ($p < 0.001$) with the trend for an increase in horizontal distance as floor slope increased from the -20° to $+20^\circ$ lifting condition (Fig. 2b). Even though this trend existed, there was a leveling off at both 20° conditions such that the down hill conditions were not different and the up hill conditions were not different from each other.

3.4. Joint kinematics

There was no interaction between sex and lifting condition for minimum torso angle ($p = 0.058$), nor was there a main effect for sex ($p = 0.925$). There was a main effect for condition ($p < 0.001$) with an increase in minimum torso angle (less bending over) as floor slope increased from the -20° to $+20^\circ$ condition (Fig. 3a). While this trend existed, there was a leveling off in the up hill conditions such that the LVL was not different from the -10° and both of the up hill conditions, and both up hill conditions were not different from each other.

Table 2
Effect of slope on lifting capacity (MAWL)

	-20°	-10°	LVL	$+10^\circ$	$+20^\circ$
Men ($n = 17$)					
Mean	24.6	23.8	24.9	23.9	25.3
S.D.	6.6	6.3	6.1	5.9	6.0
Women* ($n = 18$)					
Mean	14.5	14.5	14.6	14.8	14.9
S.D.	2.7	2.4	3.2	3.3	2.6

All capacities are reported in kilograms.

* $p < 0.05$ between men and women in every condition.

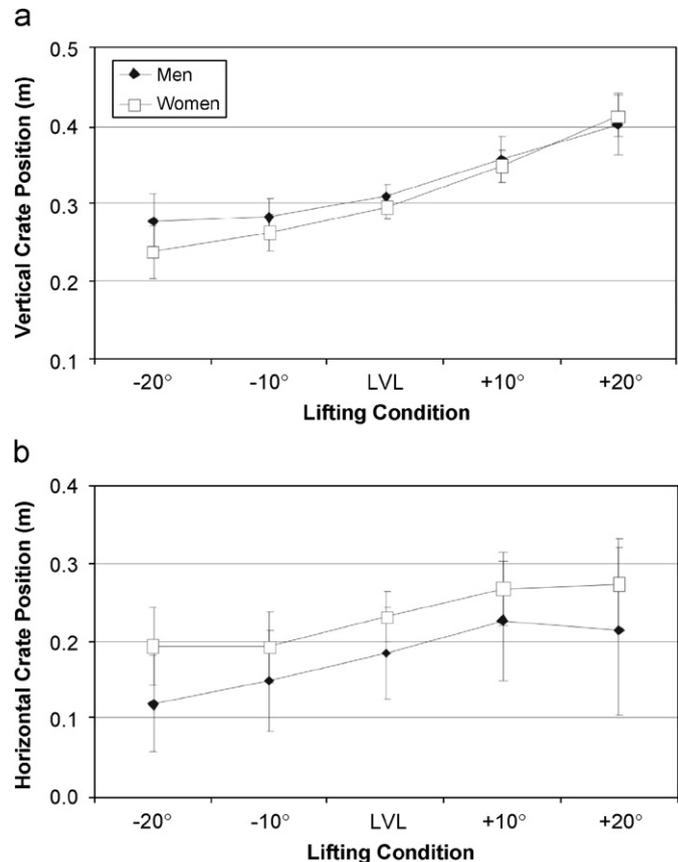


Fig. 2. Position of the crate (wrist) relative to the toe at the start of the lifting phase in the (a) vertical and (b) horizontal directions. Error bars indicate 1 S.D.

An interaction existed between sex and lifting condition for minimum hip angle ($p = 0.001$), yet within the range of slopes examined there was no main effect for sex ($p = 0.168$). The main effect for condition was significant for both the men and women (both $p < 0.001$) with the minimum hip angle of the women increasing slightly more than the men (less flexion) as slope increased from the -20° to $+20^\circ$ lift condition (Fig. 3b). For both the men and women there was a significant difference in hip angle at every lift condition.

There was no interaction between sex and lifting condition for minimum knee angle ($p = 0.676$), nor was there a main effect for sex ($p = 0.653$). There was a main effect for condition ($p < 0.001$) with a slight decrease in knee angle (more flexion) as slope increased from the -20° to LVL lift condition followed by an increase in knee angle (less flexion) from the LVL to $+20^\circ$ lift condition (Fig. 3c). While this trend was apparent, the only significant differences were with the $+20^\circ$ condition relative to both the LVL and $+10^\circ$ conditions.

There was no interaction between sex and lifting condition for minimum ankle angle ($p = 0.891$), nor was there a main effect for sex ($p = 0.229$). There was a main effect for condition ($p < 0.001$) with a general decline in ankle angle (less plantar flexion) as slope increased from

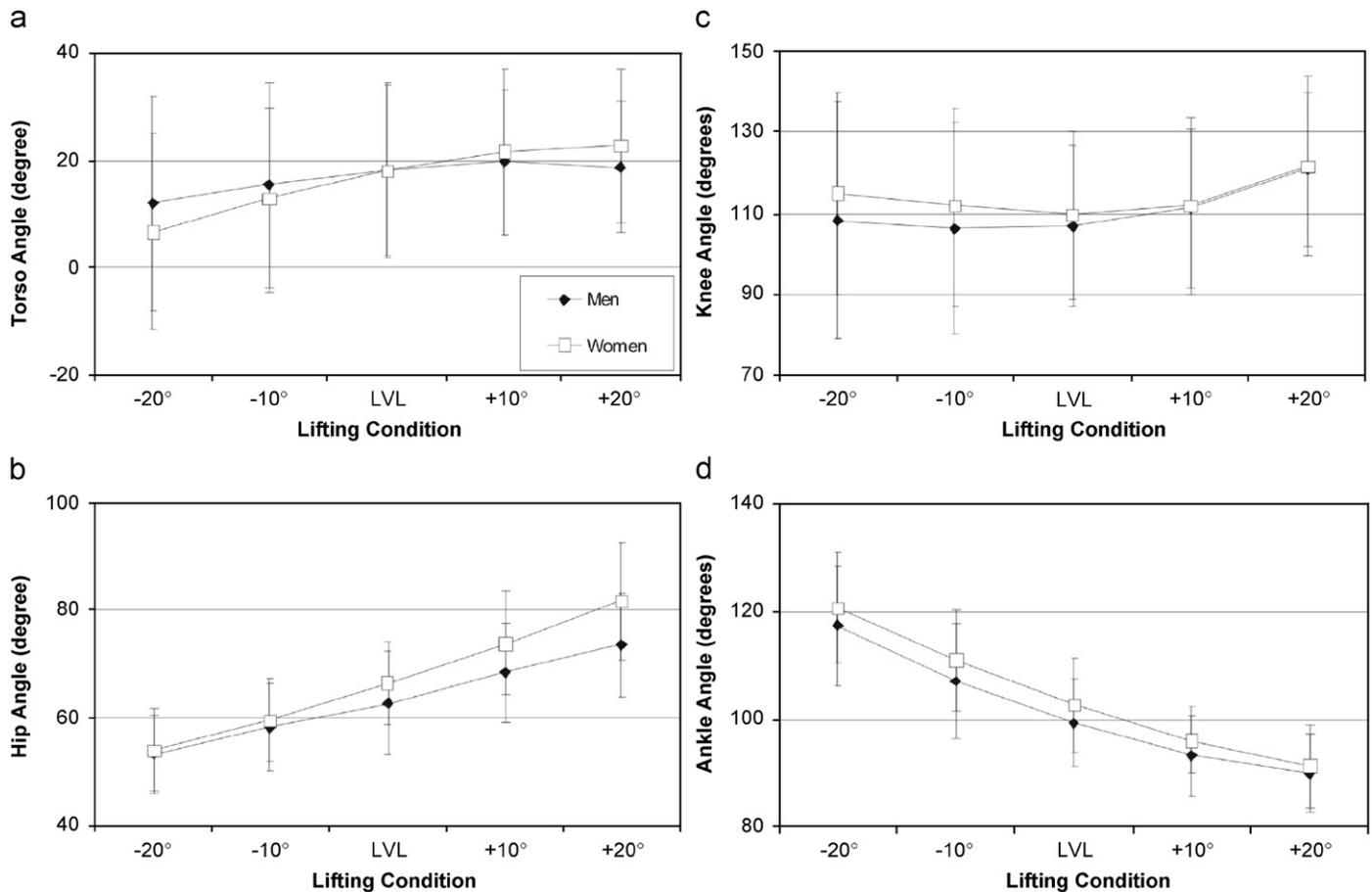


Fig. 3. (a) Minimum torso, (b) hip, (c) knee, and (c) ankle angles during the course of the lift. Error bars indicate 1 S.D.

the -20° to $+20^\circ$ lift condition (Fig. 3d). There was a significant difference in ankle angle at every lift condition.

4. Discussion

Consistent with the experimental design, the men and women were of similar ages, and consistent with normative data, the men were heavier, taller, and possessed greater knuckle heights than the women (Tilley, 2002). With an increase in total mass there is an expected increase in muscle leading to greater strength. This, combined with the fact that men generally have slightly less body fat as a percent of bodyweight than women (Bennell, 2001), points to our finding that the men lifted more weight than the women in every condition. While not employed in jobs that required excessive manual material handling, based on the work by Mital (1986) the results from the population studied should be highly generalizable.

It is anticipated that the anthropometric differences in heights, lengths, and when combined as ratios between the men and women, contributed to the differences in the observed joint angles and relative foot placements to the box. Since the box has the same dimensions for both sexes, and the women were shorter than the men, the women would not have to bend over as far to pick up the box and

most likely contributed to the significant interactions between sex and lifting condition that existed in several variables. However, trends were in the same direction for all variables across lifting conditions. Therefore, it appears that both the men and women are influenced by floor slope in much the same way, even though the magnitude of the effect may differ.

MAWL values from the level surface are comparable to values from other studies using a similar lifting protocol. Snook and Ciriello's (1991) revised tables indicate that the 50th percentile of the male and female industrial population could acceptably lift a load of 24 and 14 kg, respectively, from the floor to knuckle height at a frequency of 4 lifts/min. Our findings also compare favorably to MAWL values established by Ciriello et al. (1990) for a similar lifting task after 40 min (men = 29.1 kg and women = 12.3 kg). However, floor slope induces some relatively dramatic changes in lifting technique that might not be noticeable in MAWL until after 10 min. This may be one of the reasons why Aghazadeh and Lu (1994) found MAWL differences with foot orientation changes associated with the wearing of high-heels in their 20-min tests compared to the current 10-min tests.

Aghazadeh and Lu (1994) suggest that the instability of the ankle joint partially explained the reduced lifting

capacity observed by their participants in high heels. Comparing to the sloped floor, distinct differences in heel stability are apparent. However, this difference, similar to the test duration difference, most likely only partially explains the difference in findings. The freedom to adjust both horizontal and vertical position (though linked) is probably more responsible for the differences. Our participants chose to stand closest to the box in the -20° lifting condition with a continuous increase in toe-to-box distance through the $+20^\circ$ condition, as expressed by straight line distance between the toe and wrist marker at lift off. This adjustment affected the vertical foot placement such that there was a general increase with slope that was most noticeable in the up hill conditions. The adjustments in foot placement made by the subjects also made noticeable changes in the horizontal direction, where a trend was present to increase the horizontal distance as slope increased from the -20° to $+20^\circ$ lifting condition with a leveling at each extreme.

Both Aghazadeh and Lu (1994) and the current study allowed the participants to lift using any style they wanted (freestyle lifting). However, all the participants from Aghazadeh and Lu's (1994) study used a stoop lifting posture. In contrast, based on joint angles our study indicated the semi-squat approach was the preferred style of lifting, potentially adding to the reasons for differences in results. While preferred lifting style could be population dependent, it could also be due to the comfort level obtained in the lifting situation and an attempt to keep forces in the low back consistent from slope to slope (Davis et al., 2000; Mirka et al., 1998). It is possible that the horizontal and vertical manipulations of foot placement relative to the box allowed the subjects of this study to adopt a semi-squat lifting technique in each condition that was more comfortable than any stoop technique. This is consistent with previous findings observed when lifting a box from a level surface while foot orientation was altered, where the loading response changed when a different lifting technique was adopted (Shin and Mirka, 2004).

In addition to the ability to keep muscle stress constant from lift condition to lift condition as a plausible reason that there was no difference in MAWL as slope was altered (Davis et al., 2000), other possibilities must be considered. As mentioned previously, whole-body stability (balance) and slip potential may play a role (Zhao et al., 1987). Anecdotally, it was observed from comments by the subjects that it was more difficult to maintain balance when facing down hill. However, usually after a couple of lifts the subjects were able to settle in on a foot placement and lifting technique where balance no longer seemed to be a concern. Slip potential was minimized by allowing the participants to wear shoes they were comfortable with and coating the floor surface with a non-slip additive. Therefore, balance but not slip potential may have played a role in the MAWL selected.

The foot placement chosen by the subjects relative to the box was such that the vertical position created a scenario

where the person would have to bend less to pick up the box as slope changed from the -20° to 20° lifting condition while the horizontal foot position created the exact opposite trend. Therefore, depending on the magnitude of each foot placement effect, a situation may be created where only minor differences in joint angles were needed from condition to condition, balance was maintained, and the forces in the low back kept relatively constant.

As it turned out, subjects bent over slightly less ($\sim 10^\circ$) at the torso as slope changed from the -20° to 20° lifting condition. The minimum hip angle responded by increasing ($\sim 25^\circ$) over the same span of lifting conditions so that the hip was less flexed as slope increased. The response of the minimum knee angle was less predictable, decreasing slightly and then increasing again over the span from the -20° to 20° lifting condition, though the maximum difference between any two conditions was only $\sim 10^\circ$. Finally, as expected by the foot being placed on the platform, the minimum ankle angle continuously declined as floor slope increased from the -20° to $+20^\circ$ lifting condition. The change in the ankle angle across conditions was only $\sim 30^\circ$ while the total change in sloped floor was 40° . This discrepancy is due to subjects allowing the heel to rise off the floor, reducing the need for such a large range of motion from the ankle joint, and also minimizing the effect of the floor slope on the rest of the body.

Based on this response it appears that the body is relatively protective of the torso and knee angles. One note of caution with the torso angle is that it represents the sum of all pelvic, spinal, and shoulder girdle motion relative to the hip, since the second marker is on the shoulder joint. Therefore, it is hard to interpret how this affects the curvature of the low back, though the tendency would be to expect a reduction in low-back lordosis as maximum torso angle increased (Granata and Sanford, 2000). This suggests that the damaging forces in the low back associated with the flexion-relaxation phenomenon (McGill and Kippers, 1994) and lumbar spine flattening (Marras et al., 1995; Potvin et al., 1991) might be reduced as slope increases from downhill to uphill conditions. However, since the horizontal foot position increases with increasing slope, an increased torque will be present when facing up hill due to the increased moment arm that the box places on the low back.

The fact that the minimum knee joint angle was relatively protected by changes in slope is supported by the literature examining knee extensor contributions and fatigue during lifting (Schipplein et al., 1990; Trafimow et al., 1993). The body appears to protect the knee joint at the expense of the ankle and hip, with these joints not being fully exposed to extreme changes in range of motion by spinal, shoulder girdle, and raising the heels off the ground (when appropriate). These kinematic interpretations of how slope affects low back and lifting technique is limited and should be followed by a more thorough investigation that includes detailed lumbar motion with calculation of

the loads in the low back region and other joints of the lower extremities.

The other existing limitations also suggest additional research is needed into the effects of floor slope on lifting kinematics and kinetics. While Mital (1986) found that experienced workers were not required to gain valid results from the psychophysical method, the subjects only lifted from a level surface. Experience working on a sloped surface may cause specific adaptations which should be elucidated. Furthermore, this experimental design required a symmetric foot placement with a semi-squat lifting technique. Future research should examine if a staggered stance or slightly different technique may be more appropriate on a sloped surface. There should also be consideration of foot placement relative to the box to determine if standing closer when facing up the incline actually reduces the lumbar moment caused by the load. The altered joint ranges of motion suggest that fatigue rates might be affected by floor slope. While this was not apparent in the 10 min duration of this investigation, longer duration studies should be considered. Finally, since balance and joint range of motion are altered by slope, effects of load magnitude should also be considered in future investigations.

5. Conclusions

While men and women lift different amounts, and slight kinematic differences in lifting technique exist, lifting capacity is not affected in either sex over the short term by floor slope. When lifting a box from a sloped floor, foot placement is adjusted to minimize the effect of the slope and maintain balance in combination with minor adjustments in joint ranges of motion. Foot placement is such that both horizontal and vertical distance is increased relative to the crate as slope increases from the -20° to $+20^\circ$ lifting condition. This translates to an increased moment arm for the box relative to the low back that may increase risk for injury when facing up a slope. Therefore, care should be taken to stand as close to the box as possible when facing up a hill. Concerns when facing down hill are that people tend to bend forward more at the waist, which may reduce the natural lordosis of the lower back, increasing risk for injury (Marras et al., 1995; McGill and Kippers, 1994; Potvin et al., 1991). Facing down a hill should also be avoided if the box is awkwardly shaped or excessively heavy, since balance is more difficult in this condition, especially in the first couple of repetitions.

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