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Effect of load distance on self-selected manual lifting technique

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Abstract

The aim of this research is to determine the effects of constraining the horizontal distance of the feet from the load on the posture adopted at the start of the lift. Kinematic data were collected while each of 24 subjects lifted 3, 6, and 9 kg loads from a starting height 18 cm above the ground. The position of the feet was controlled relative to the load such that the horizontal distance from the hand to the ankle at the start of extension was either 20, 40, or 60 cm. Subjects performed 20 trials in each of six combinations of load and ankle–load distance chosen to provide three sets of equivilent load moment pairs. The initial horizontal distance from the load to the ankle had a large influence on the posture adopted to lift the load. Ankle and knee flexion, in particular, were reduced when the ankle–load distance was smaller, and particularly so when the distance was reduced to 20 cm. Hip flexion was reduced to a smaller extent, while lumbar vertebral flexion remained relatively unchanged. The inclination of the trunk at the start of the lift was unchanged when the ankle–load distance was 60 or 40 cm, but was 10° greater when the load was 20 cm from the ankles, indicating that subjects adopted a posture closer to a stoop when the ankle–load distance was small. Comparison of conditions of equal load moment (but different load mass and ankle–load distance) revealed differences which mirrored the effects of ankle–load distance alone, suggesting that the effects of ankle–load distance on the posture adopted at the start of extension were largely independent of the load moment. While the forces and torques required to lift a load must be to some extent dependent on the load moment, rather than load or ankle–load distance per se, the posture adopted to lift the load is not.

Relevance to industry

Reducing the distance of the load from the body reduces trunk inclination as well as the load moment. The finding re-emphasises the importance of reducing the distance of loads from the body, as well as the mass of loads to be lifted.

Keywords: Manual handling; Lifting; Technique; Moment

1. Introduction

The forces and torques required to lift a load are, in part, determined by the load moment (the product of load mass and distance from the body), and consequently it is expected that engineering

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controls which reduce load moment will reduce the potential for injury. The question of whether subjects alter the posture adopted to lift loads in response to changes in load moment is thus of interest. The effects of changes in load mass on the posture adopted at the start of lifting has been described previously (Burgess-Limerick et al., 1995). When subjects were asked to lift loads using a self-selected technique the average overall effect of increases in load mass from 2.5 to 10.5 kg (distance remaining constant, and hence load moment increasing with mass) was to slightly increase the flexion of the knee, hip, and lumbar vertebral joints at the start of the lift.

In this previous experiment, the placement of the subjects' feet relative to the load to be lifted was uncontrolled, simulating the common situation encountered in an occupational setting in which the lifter has more or less freedom to self-select the placement of the feet. (The ankle–load distances chosen ranged from 240 to 400 cm [mean = 320 cm] and were uncorrelated with load mass.) However, in some occupational situations the task characteristics, such as size or nature of the load, or structure of the environment, restrict the placement of the lifter's feet relative to the load. Bulky loads, e.g., may increase the minimum horizontal distance possible between hands and feet at the start of the lift. Conversely, if a load was elevated, such that the lifter could place their feet under the load, then adoption of a position very close to the load would be possible.

In addition to changing the load moment, changes in the ankle–load distance also have a geometric influence on the joint configurations which can be adopted to grasp the load. The aim of the research reported here is to examine the effect of manipulating the placement of the feet relative to the load on the posture adopted at the start of the lift, and to deconfound the geometric influence of horizontal load distance from the effect due to load moment by examining conditions of equal load moment but different ankle–load distance.

2. Methods

Angular motion in the sagittal plane of ankle, knee, hip, and lumbar vertebral joints was estimated from two-dimensional video images while each of 24 untrained subjects (11 female and 13 male) performed 120 symmetric bimanual lifts. Each trial involved flexing from a normal standing position to lift one of three loads (3, 6 or 9 kg) from a starting height of 18 cm. The position of the feet was controlled relative to the load such that the horizontal distance from the hand to the ankle at the start of extension was either 20, 40 or 60 cm. The load mass and foot position variables were manipulated to form six conditions in which load moment (mass x distance) was either 120, 180 or 360 kg cm. The six conditions were: (i) 3 kg, 40 cm; (ii) 3 kg, 60 cm; (iii) 6 kg, 60 cm; (iv) 6 kg, 20 cm; (v) 9 kg, 20 cm; (vi) 9 kg, 40 cm. The trials were performed in blocks of five trials in each condition, and this 30 trial series was performed four times.

Subjects were given a brief standardised explanation of the purpose of the experiment. The standardised instructions given to the subjects emphasised that they were to lift the load in "the way you would normally do the task, i.e., the most comfortable way for you". The subjects were instructed to adopt a normal standing posture facing the load, with feet approximately parallel and an equal distance from the load.

Ten spherical reflective markers (30 mm diameter) were placed on the right side of each subject on the following anatomical locations: (i) head of the fifth metatarsal; (ii) lateral malleolus; (iii) lateral surface of the shank on a line joining the lateral malleolus to the knee joint centre; (iv) lateral surface of the thigh on a line joining the knee joint centre with the greater trochanter; (v) superior point of the greater trochanter; (vi) posterior superior iliac spine; (vii) anterior superior iliac spine; (viii) spinous process of the first thoracic vertebra; (ix) head of the radius; and (x) dorsal surface of the hand.

These markers defined lumbar vertebral, hip, knee, and ankle angles (Fig. 1). All were defined as included angles which increased when the joint extended or, in the case of the ankle, plantar-flexed. Lumbar vertebral angle was defined as the anterior angle subtended by lines joining the first thoracic vertebra, posterior superior iliac spine, and anterior superior iliac spine markers. Hip angle was defined as the anterior angle subtended between the line

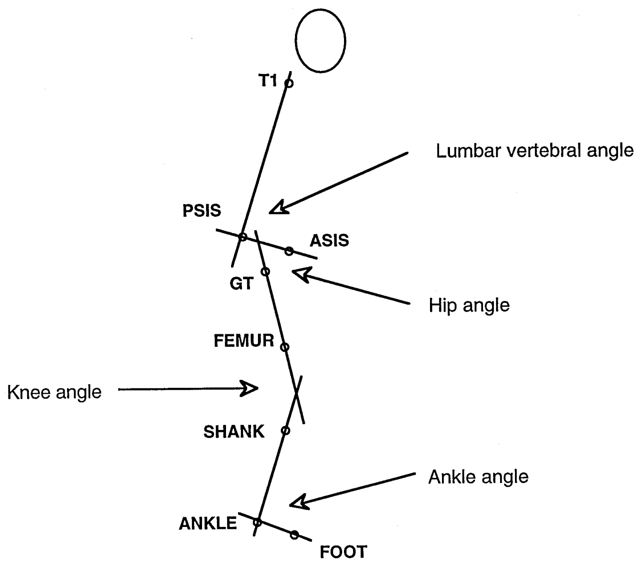

Fig. 1. Definition of joint angles.

joining posterior superior iliac spine and anterior superior iliac spine and the extrapolated line of the femur (as defined by thigh and greater trochanter markers). This angle became negative in extreme hip flexion. Knee angle was defined as the posterior angle subtended by the extrapolated line of the femur and the extrapolated line of the shank (as defined by shank and ankle markers). The ankle angle was defined as the anterior angle subtended by the shank, ankle, and foot markers.

The start of each lift was defined as the time at which the hand marker reached minimum in its vertical displacement. The range of flexion from normal standing at each joint at this time was determined. Subject mean dependent variables for each condition were calculated from the last 15 trials performed in each condition (i.e., trials 31–120). These mean values were submitted to nine planned comparisons for each dependent variable. The effect of load mass was examined by comparing three pairs of constant distance conditions (3 kg, 60 cm and 6 kg, 60 cm; 6 kg, 20 cm and 9 kg, 20 cm; 3 kg, 40 cm and 9 kg, 40 cm), the effect of starting height was assessed by comparing three pairs of constant load mass conditions (9 kg, 20 cm and 9 kg, 40 cm; 3 kg, 40 cm and 3 kg, 60 cm; 6 kg, 20 cm and 6 kg, 60 cm), and three pairs of constant load moment conditions (3 kg, 40 cm and 6 kg, 20 cm; 3 kg, 60 cm and 9 kg, 20 cm; 6 kg, 60 cm and 9 kg, 40 cm) were compared to deconfound the geometric influence of horizontal load distance from the effect due to load moment. A bonferroni correction was employed in that a critical probability of 0.001 was adopted to restrict the overall type one error rate to less than 0.05. The coefficient of determination (r^2) was calculated as a measure of effect size.

3. Results and discussion

Load mass had a small and inconsistent effect on ankle position at the start of extension ($r^2 < 0.03$), however, the manipulation of ankle–load distance had a much larger effect (Fig. 2). Increases in the ankle–load distance were associated with large increases in the flexion of the ankle from normal standing at the start of extension, particularly when the distance increased from 20 to 40 cm ($r^2 = 0.70$, $p < 0.001$). These differences remained when comparisons of constant moment conditions were made, suggesting that the effect of ankle–load distance is independent of changes in load moment.

The tight coupling between ankle and knee is reflected in the similarity of the results obtained for these joints (Fig. 3). When the ankle–load distance

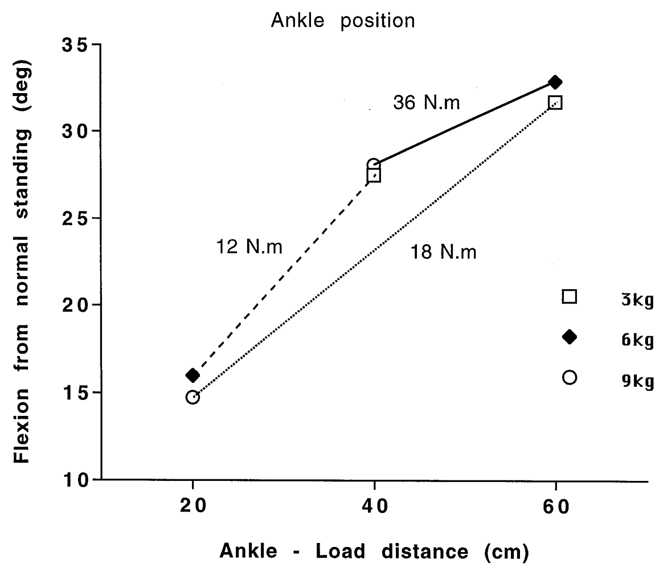

Fig. 2. Ankle position at the start of extension as a function of ankle–load distance and load mass. Lines join conditions of equal load moment.

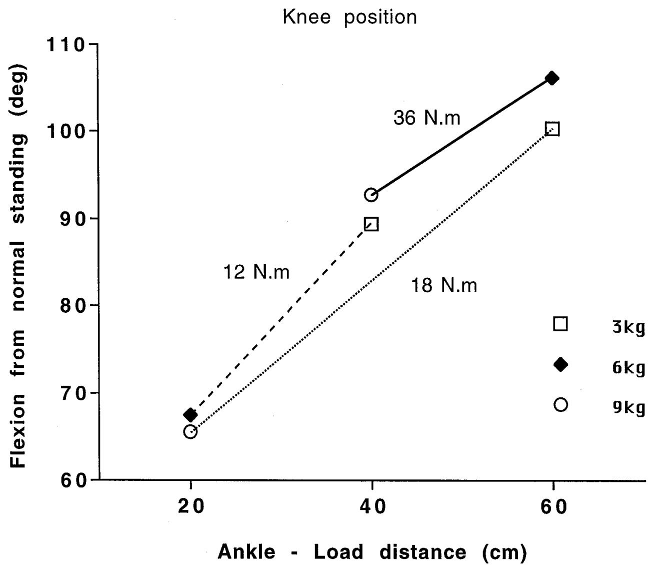

Fig. 3. Knee position at the start of extension as a function of ankle–load distance and load mass.

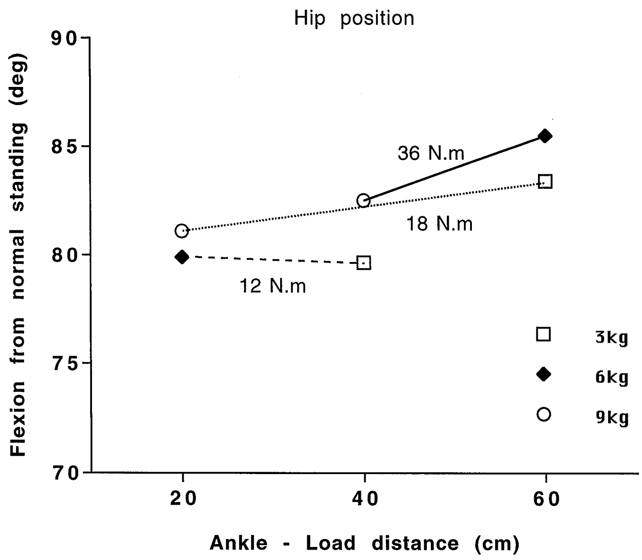

Fig. 4. Hip position at the start of extension as a function of ankle–load distance and load mass.

was 40 or 60 cm the effect of increased load was to increase flexion of the knee at the start of extension, while the effect was reversed when the ankle–load distance was 20 cm. Again, however, load mass accounts for only a very small proportion of the variance in knee positions ($r^2 < 0.02$). Changes in ankle–load distance, and especially a change from 20 to 40 cm, had a much larger effect on the posture adopted at the start of extension ($r^2 = 0.62$, $p < 0.001$). In each case, an increase in ankle–load distance was associated with increased flexion of the knee at the start of extension, and comparison of constant moment conditions revealed that the effect of ankle–load distance was independent of load moment per se.

In contrast to the ankle and knee, the effect of load mass on the position of the hip at the start of extension was consistent across ankle–load distance conditions (Fig. 4). In all cases, increases in load mass while ankle–load distance remained constant were associated with increases in the flexion of the hip at the start of extension, although the proportion of the variance accounted for was small ($r^2 < 0.04$). Increases in ankle–load distance while load mass remained constant were similarly associated with increases in hip flexion ($r^2 = 0.13$). Comparison of conditions of equal load moment suggests that the effect of increasing ankle–load distance from 20–40 cm on hip flexion is a consequence of the increased load moment, while an additional effect was evident when the distance increased from 40 to 60 cm.

Lumbar vertebral flexion at the start of extension was generally increased by increases in load mass while ankle–load distance remains constant, although the effect was only significant ($p < 0.001$) when the ankle–load distance was 60 cm (Fig. 5). Reduction of the ankle–load distance below 40 cm did not have a reliable effect on lumbar vertebral position at the start of extension, however increasing the ankle–load distance from 40 to 60 cm caused lumbar vertebral flexion to be increased slightly ($r^2 = 0.02$, $p < 0.001$). Comparison of the 40 and 60 cm distance conditions in which load moment remained constant suggests that the effect of this change in ankle–load distance on lumbar vertebral position at the start of extension was independent of load moment.

Changes in load mass did not cause changes in trunk inclination at the start of extension when the ankle–load distance was 40 or 60 cm, but increasing the load from 6 to 9 kg when the ankle–load distance was 20 cm caused a small but reliable increase in trunk inclination ($p < 0.001$; Fig. 6).

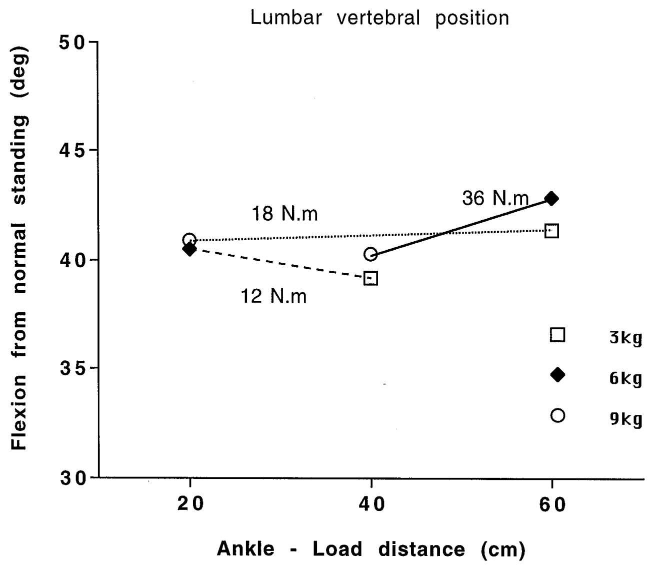

Fig. 5. Lumbar vertebral position at the start of extension as a function of ankle–load distance and load mass.

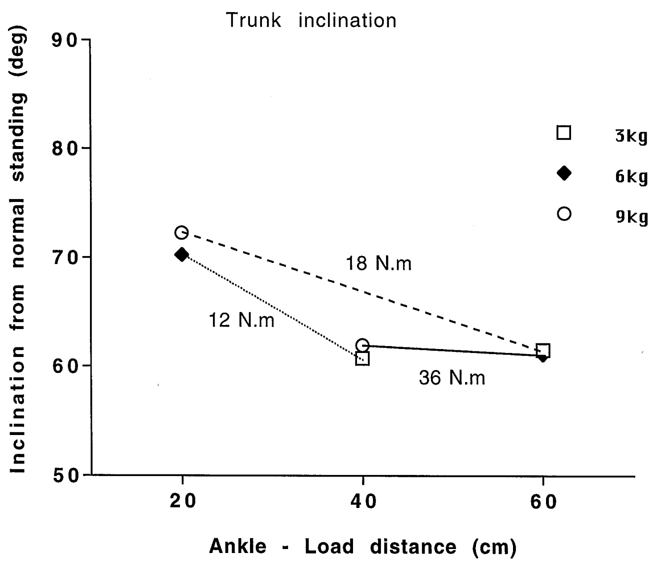

Fig. 6. Trunk inclination at the start of extension as a function of ankle–load distance and load mass.

Similarly, changes in ankle–load distance between 40 and 60 cm were not associated with changes in trunk inclination, while increasing ankle–load distance from 20 to 40 cm was associated with a increase in trunk inclination at the start of extension of the order of 10° ($r^2 = 0.27$, $p < 0.001$). Comparison of trunk inclination at these distances in conditions of constant moment reveals that the effect of ankle–load distance is independent of load moment.

The effect of ankle–load distance on trunk inclination reflects a consistent tendency, when the ankle–load distance was 20 cm, for subjects to adopt a posture at the start of extension in which the knee joints were less flexed relative to the flexion of the hip and lumbar vertebral joints. A consequence is that the inclination of the trunk forward from the vertical was increased on average by 10° in these conditions regardless of the load mass lifted from this location.

Lifting from such a relatively stooped posture reduces the vertical distance through which the body centre of gravity is moved, and thus reduces the mechanical work required. It might be suggested that when the load moment becomes relatively small, minimum work criteria become more important in reducing muscular energy expenditure than optimising joint coordination. However, the current results show clearly that load moment has less influence than the position of the load relative to the body, although this influence is not determinsitic, in that a posture with flexed knees can be adopted to lift a load very close to the body.

4. Conclusions

In general, the effects of load mass on posture were small (accounting for 3% of the variance or less), and the directions of these effects was in some cases dependent on the ankle–load horizontal distance at which the comparison was made. In contrast, the initial horizontal distance from the load to the ankle had a large influence on the posture adopted to lift the load. Ankle and knee flexion, in particular, were reduced when the ankle–load distance was smaller, and particularly when the distance was 20 cm. Hip flexion was reduced to a smaller extent, while lumbar vertebral flexion remained relatively unchanged. The inclination of the trunk at the start of the lift was unchanged when the ankle–load distance was decreased from 60 to 40 cm, but increased by 10° when the load was moved to 20 cm from the ankles, indicating that subjects adopted a posture closer to a stoop when the ankle–load distance was small.

Comparison of conditions of equal load moment (but different load mass and ankle–load distance) revealed differences which mirrored the effects of ankle–load distance alone, suggesting that the effects of ankle–load distance on the posture adopted at the start of extension were independent of the load moment. While the forces and torques required to lift a load must be largely dependent on the load moment, rather than load or ankle–load distance, the posture adopted to lift the load is not.

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