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Short communication

Qualitatively different modes of manual lifting

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Abstract

The question of whether qualitatively different modes of manual lifting exist is addressed via an ideographic analysis of data from an experiment in which 39 subjects lifted loads of varying mass. Angular motion in the sagittal plane of ankle, knee, hip, and lumbar vertebral joints was estimated from video images collected while each subject performed 100 lifts. Bimodality in the frequency distribution of postures adopted at the start of lifting was evident in the data from 4 subjects. While semi-squat postures were usually adopted at the start of lifting, on some trials a stooped posture was observed. The likelihood of a stooped posture being adopted at the start of lifting was related to load mass. Both postures were observed when the load mass was relatively light, while only the semi-squat posture was observed when the load mass was increased. Subjects who adopted stooped postures on some or all trials were also, on average, taller, heavier, and stronger.

Relevance to industry

The observation of qualitatively different modes of lifting, and the influence of task characteristics on the techniques adopted, has implications for manual handling training.

Keywords: Lifting; Manual handling

1. Introduction

The posture adopted immediately prior to lifting, and particularly the position of the knee joint at this time, has been commonly used in the past to differentiate between different lifting techniques (e.g., Bendix and Eid, 1983; Trafimow et al., 1993). A distinction is typically made between techniques involving a posture at the start of the lift in which the knee joints are flexed only slightly, if at all, and the trunk inclined substantially (a stooped posture), and a technique involving substantial knee flexion at the start of the lift and less trunk inclination (a squat or semi-squat posture).

However, it is not known whether these different techniques represent qualitatively different modes of manual lifting, or points on a continuum. In this paper the data gathered in a previous experiment (Burgess-Limerick et al., 1995) are reexamined to determine whether any evidence of qualitatively different modes of lifting exists. The existence of qualitatively different modes of lifting would be indicated by: (i) discontinuous changes in the posture adopted at the start of extension for sequential trials; and consequently, (ii) a bi-modal distribution when measures describing this posture are presented as a frequency distribution.

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An analysis of individual subject data is necessary because any understanding of the control of manual lifting must encompass not only the average, or most common patterns (as revealed by the previous analysis), but also the complete range of behaviour. In this way, individual differences may frequently be more informative for theory development than a knowledge of the average behaviour.

2. Method

The methods employed have been previously described (Burgess-Limerick et al., 1993, 1995). Angular motion in the sagittal plane of ankle, knee, hip, and lumbar vertebral joints was estimated from two dimensional video images while each of 39 untrained subjects (20 female, 19 male, aged 18 to 26) performed 100 symmetric bimanual lifts of a load from 9 cm above floor height.

Subjects were given a brief standardised explanation of the purpose of the experiment and no deception was involved. The standardised instructions given to the subjects emphasised that they were to lift the load in "the way you would normally do the task, that is, 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. The distance of the feet from the load was self-selected and subjects were allowed to vary this distance between trials as desired with the restriction that the horizontal location of the feet did not move during each trial.

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. 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. The use of these markers to estimate lumbar vertebral movements has been radiographically verified (Kippers and Parker, 1989). Hip angle was defined as the anterior angle subtended between the line 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 mass of the load varied from 2.5 to 10.5 kg in 2 kg increments. A total of 100 trials were performed in blocks of five lifts of each mass in ascending series. Five seconds elapsed between trials and 30 s between blocks. The 25-trial series was repeated four times. Data were collected at 100 Hz using a NAC video camera and recorder.

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 plotted as a function of trials and as a frequency distribution for each subject. Sudden changes in the posture adopted at the start of extension during sequential trials, accompanied by bi-modality in the frequency distribution, were considered indicative of the existence of qualitatively different lifting patterns. The relationship between load mass and modality was examined by inspecting the frequency distributions of postural data for each load mass.

2.1. Anthropometry

Subjects returned for anthropometric testing at the conclusion of lifting data collection. [1] The subjects

[1] One male subject was unavailable at the time of anthropometric testing.

had not eaten for two hours prior to the testing nor partaken of vigorous exercise, caffeine, alcohol, or cigarettes on the day of testing. Medication taken during the 24 hour period prior to testing was recorded. No subject reported being unwell at the time of testing.

2.1.1. Protocol

The subjects' heights and masses were taken without footwear using a stadiometer (Model 40-79, Novel products, U.S.A.) and electronic weighing scales (Mercury, AD-4316, Queensland Weighing Machines, Brisbane). Subischial height was determined using a Holtain bench (Crymych, UK) and tibial length using an anthropometer (Model 1214, Takei, Japan). Following these measures the subjects replaced their footwear and warmed up on a bicycle ergometer at a self-selected pace for five minutes. Bilateral measures of knee and hip extension strength at angular velocities of $1.05 \cdot \mathrm{rad} \cdot \mathrm{s}^{-1}$ and $0.52 \cdot \mathrm{rad} \cdot \mathrm{s}^{-1}$ respectively were then taken using a Cybex 340 isokinetic dynamometer (Lumex, New York). A measure of isometric trunk extension strength was also made using a load cell (Model STC 250, Sartek, Brisbane) and meter (Model 210G/B, Barlo, Brisbane) interfaced with an A-D board and personal computer.

The average values for variables describing the posture adopted at the start of the lift (horizontal distance from load to ankles, joint angles relative to normal standing, and trunk inclination) were calculated for the last fifteen trials performed in the 6.5 kg load condition for each subject. The anthropometric data from those subjects who exhibited stooped postures at the start of extension were compared to the other subjects using ANOVA.

3. Results

An examination of the frequency distribution of joint angles at the start of each lift for each subject revealed unimodal distributions for 35 subjects. While the typical pattern of coordination involved moderate flexion of all joints (knee flexion from normal standing > 40°, see Burgess-Limerick et al., 1995), one of these subjects adopted a posture at the start of every lift which involved knee flexion from

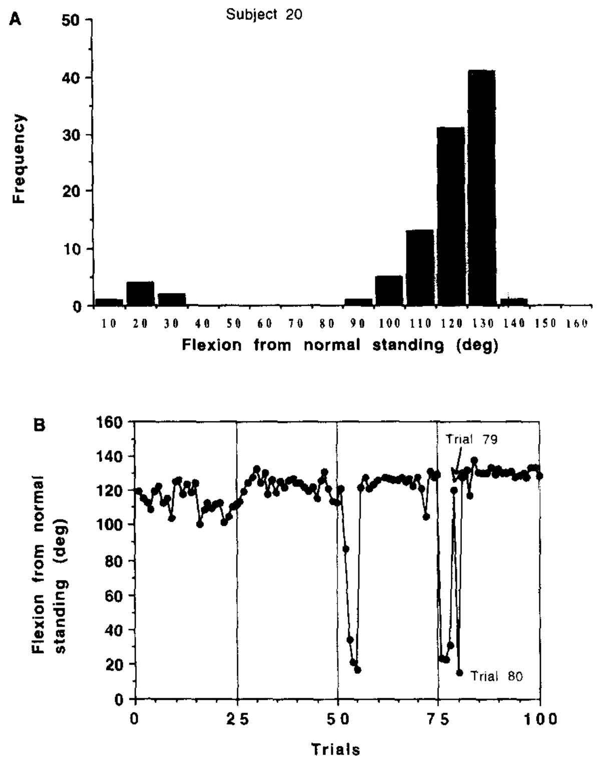

Fig. 1. Knee position at the start of extension during each lift for subject 20, (A) as a frequency distribution and (B) as a function of trials. The mass of the load varied from 2.5 to 10.5 kg in 2 kg increments. A total of 100 trials were performed in four blocks of 25 trials, each block consisting of five lifts of each mass in ascending series.

normal standing of 20 to 30°, trunk inclination of 120° from vertical, and which would typically be described as stooped. The postural data gathered from the remaining four subjects contained load dependent deviations from unimodal distributions.

Such load deviations from uni-modal behaviour were evident in the data gathered from subject 20. An inspection of the knee angular position at the start of extension plotted as function of trials, and the frequency distribution of these trials (Fig. 1), indicates that in most trials this subject adopted a posture, immediately prior to lifting the load, in which the knee joints were substantially flexed (110 to 130° flexion from normal standing). However, in seven trials the range of knee movement involved was substantially reduced and a stooped posture was adopted. Further, an examination of the frequency distribution of knee flexion at the start of the lift for trials in each load condition (Fig. 2) illustrates that

Table 1
Anthropometric comparison between subjects who adopted a stooped posture at the start of the lift on some or all trials, and those who did not.

Anthropometric measure	Mean of stooping subjects ($n = 5$)	sd	Mean of other subjects ($n = 33$)	sd	F	p	r
Mass (kg)	79.7	10.4	66.3	11.8	5.74	= 0.022	0.37
Height (cm)	182.3	6.3	173.2	9.2	4.5	= 0.041	0.33
Knee extension strength (N · m)	102.3	19.1	71.8	25.5	6.5	= 0.015	0.39
Hip extension strength (N · m)	149.8	29.0	120.1	45.0	1.99	= 0.167	0.23
Trunk extension strength (N · m)	22.9	2.0	15.5	5.8	8.0	= 0.008	0.43

Note: Stooping subjects are those who adopted a stooped posture at the start of extension for some or all trials [$df = (1,36)$].

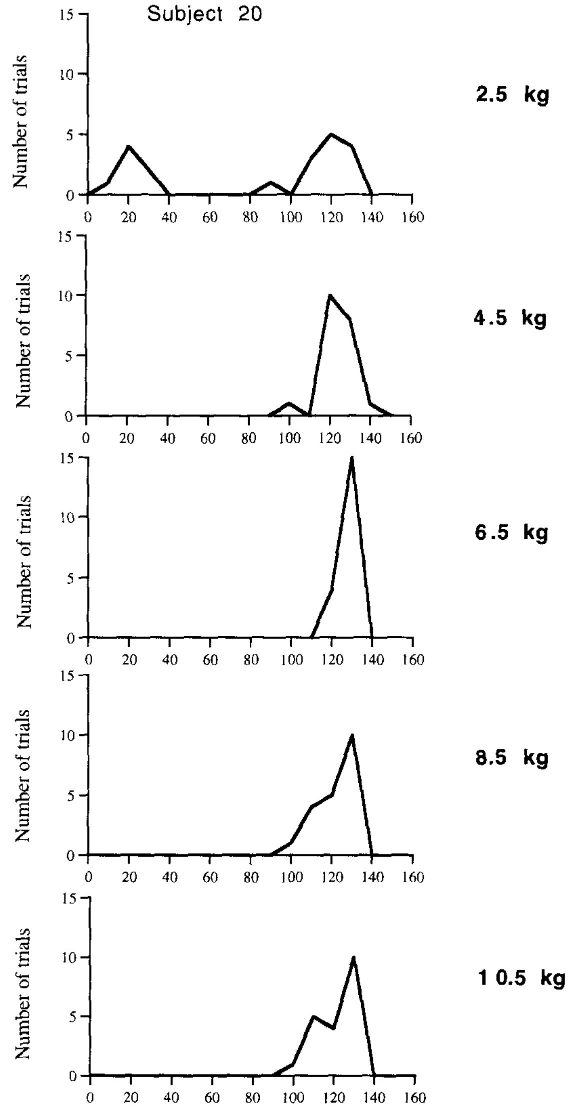

Fig. 2. Frequency distribution of knee position at the start of the lift for each trial as a function of load mass for subject 20.

the seven trials in which a stooped posture was adopted at the start of the lift were all trials in which the lightest load (2.5 kg) was lifted, and thus that the modality was load dependent.

Data containing similar patterns were obtained from three other subjects. For all four, a pattern of movement involving a semi-squat posture was observed in the majority of trials, while a stooped posture was adopted at the start of the lift in other trials. The probability of different patterns occurring was related to the load mass, although not deterministically. When the load mass was heavy (relative to the other loads studied here), only patterns involving a semi-squat posture at the start of extension were observed. However, when the load mass was light, both stooped and semi-squat patterns occurred.

Four subjects adopted stooped postures at the start of the lift on some trials, while one subject adopted a stooped posture for all trials. These 5 subjects were all male, and an examination of anthropometric variables revealed that they were heavier, taller and stronger on average than the remaining subjects (Table 1), although the relationship is not deterministic (i.e., some equally tall, heavy, and strong subjects did not adopt stooped postures at the start of the lift on any trials).

4. Discussion

The posture adopted at the start of the lift influences the pattern of subsequent interjoint coordination by determining the range of movement available at each joint. The previous analysis (Burgess-Limerick et al., 1995) revealed that adopting a posture involving substantial knee flexion at the start of the lift allows an interjoint coordination to occur which reduces muscular effort. Knee extension typically occurred rapidly and commenced early in the lifting movement relative to extension of the hip. The onset of rapid lumbar vertebral extension was delayed substantially after the start of the lift. Estimation of the length changes of the biarticular hamstring muscles revealed that the coordination between knee and hip joints has the consequence of delaying rapid shortening of the hamstrings until after maximum vertical load acceleration. The consequence of the biarticular hamstrings not shortening rapidly during the initial phase of the lift is that the monoarticular quadriceps are able to contribute to hip extension through a tendinous action of the hamstrings. The delay before rapid lumbar vertebral extension also delays rapid shortening of the erector spinae.

A different pattern of coordination occurs when stooped postures are adopted at the start of extension. The large range of hip flexion and small range of knee flexion (or even slight extension) means that the biarticular hamstrings are lengthened further (and are thus stronger isometrically) than if a semi-squat posture were adopted. A stooped posture also has the advantage of lowering the centre of gravity less than a semi-squat and thus less work is done to lift the body during each lift. However, during lifting the hamstrings immediately shorten rapidly because the knee is unable to extend rapidly. This counteracts to some extent the strength advantage which accrues as a consequence of the increased hamstring length. Rapid shortening of the hamstrings also prevents the monoarticular quadriceps from contributing to hip extension.

This trade-off between the costs and benefits of different movement patterns is likely to be the source of the deviations from uni-modal behaviour. For some subjects, in some situations (some strong subjects lifting light loads), the patterns of movement involving semi-squat and stooped postures at the start of extension may be equally sustainable in terms of the variables which determine the postures adopted to lift loads (presumably involving muscular effort). In other situations only one pattern is observed because of the increased muscular effort required.

For four relatively tall, heavy, and strong subjects, a pattern of movement involving a semi-squat posture at the start of the lift was observed in the majority of trials, while a stooped posture was adopted at in other trials. The probability of different patterns occurring was related to, but not determined exclusively by, the mass of the load. When the load mass was heavy (relative to the other loads studied here), only patterns involving a semi-squat posture at the start of extension were observed. However, when the load mass was light, both stooped and semi-squat patterns occurred.

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