HUMAN FACTORS, 1983, 25(5), 517–525

A Comparison of Intraabdominal Pressure Increases, Hip Torque, and Lumbar Vertebral Compression in Different Lifting Techniques

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Intraabdominal pressure (IAP), movements of the body in the sagittal plane, and the forces applied to the load were recorded while 10 male subjects lifted or lowered a 15-kg box using six different lifting techniques and two lowering techniques. IAP data were compared with calculated peak values of lifting velocity, lumbosacral compression and hip torque, and with the integral of lumbosacral compression over time. No consistent relationship between IAP increases and any one of these values emerged. The variation in peak IAPs was considerable. Nonetheless, there were significant differences in IAP between different lifting and lowering techniques. IAP was, in general, less when the trunk was flexed for lifting and lowering than when it was used in a posture nearer to the vertical.

INTRODUCTION

Increases in intra-abdominal pressure (IAP) are normal accompaniments of short-term truncal stress, and their role in supporting the spine and aiding the extensor mechanism is well recognized (Bartelink, 1957; Davis, 1956; Morris, Lucas, and Bresler, 1961). In lifting, acceleration of the load is commonly preceded by glottal closure and contraction of the muscles of the abdominal wall and pelvis, with resulting increases in intrathoracic and intraabdominal pressure. When breathing resumes, or in the case of the glottis having remained open, the diaphragm also contracts so that pressure increases then affect the abdominal cavity alone. The amount of pressure increase is related to the magnitude of the load lifted or, for a given weight, to the speed of lift (Davis, 1959), and similar relationships apply to pushing and pulling as well as to lifting (Davis and Troup, 1964). These results were broadly confirmed by Andersson, Örtengren, and Nachemson (1977) in studies of intradiscal pressure and myoelectric activity of the back muscles, IAP being related to both.

Moreover, there is an association between occupations in which the incidence of reportable back injuries is high and those in which IAP increases commonly exceed 100 mmHg (13.3 kPa) (Davis and Sheppard, 1980; Nicholson, Davis and Sheppard, 1981; Stubbs, 1981). On this basis, Davis and Stubbs (1980) undertook measurements of IAP in males up to the age of 60 during static exertions of

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lifting force in various postures. They expressed their results as a series of contour maps showing the limits of force that could be exerted without incurring IAPs of more than 90 mmHg (12.0 kPa) at different distances from the body. These limits are based on the averages of the population sampled and therefore provide a useful guide for ergonomic application.

What remains an unknown factor is the variation in IAP increases for a given weight of lift, not only in the individual but also within subgroups of the population. Thus it may be difficult to draw a clear deduction from any given difference between IAP increases. One source of variation is back pain: Fairbank, O'Brien, and Davis (1980) found higher IAPs for given lifting exertions in patients with back pain than in controls.

Grew (1980) related IAP measurements during isometric exertions to the forces exerted and to the calculated torques on the trunk: flexor, extensor, and lateral flexor. The relationships were generally linear, but when he compared lifting forces exerted with the trunk upright and flexed, IAPs were relatively lower when flexed for a given extensor torque. Thus the posture of the trunk appeared to influence the relationship between IAP and lumbosacral stress and thus the potential relieving effect of IAP in aiding the extensor mechanism. This is in line with the proposal that IAP acted at a greater mechanical advantage with the lumbar spine flexed than when it was extended (Davis and Troup, 1965). When the spine is extended, the anteroposterior diameter of the trunk is narrower, and the IAP vector is closer to the vertebral axis. In addition, the passive tension in the trunk flexor muscles is increased, thus negating any aid to the extensor mechanism.

Most of the reports that have been cited concern the association between IAP increases and static exertions of force. The relationship between IAP and lumbosacral stress during dynamic lifting is a comparatively unexplored topic. The interpretation of isolated IAP results when comparing lifting techniques is therefore less than simple. In order to throw some light on these problems, IAP was recorded and the results compared with computed values for hip torque and lumbosacral compression using a simple dynamic sagittal-plane model (Leskinen, Stålhammar, Kuorinka, and Troup, 1983).

MATERIALS AND METHODS

Subjects

Ten male subjects, none with significant lumbar spinal disability, took part in the experiments. Table 1 shows the data on age, stature, body weight, and isometric lifting strength based on the averaged maximal force exerted over a 3-s period in the crouched position with knees flexed and trunk straight with the handle at ankle height. Subjects wore trousers and low-heeled shoes but no shirts.

Handling Techniques

For all observations, subjects either lifted or lowered a 15-kg box, with dimensions of 30 × 30 × 30 cm, and with handles 12 cm above the base. Eight techniques were studied. The six lifting techniques were:

(1) The *back lift* (BL) from a stooping position with knees straight and the trunk flexed.

TABLE 1

The Means, Standard Deviations and Ranges for the Age, Body Weight, Stature, and Isometric Lifting Strength for the 10 Male Subjects

	Mean	*S.D.*	*Range*
Age (years)	33.2	6.8	25–44
Bodyweight (kg)	72.5	9.0	64–96
Stature (cm)	178.3	5.1	169–184
Isometric lifting strength (N)	1086	150	835–1370

(2) The *leg lift* (LL) from a crouched position with the knees flexed and one foot in front of the other, the trunk being nearly erect and with no increase in forward flexion in the course of the lift.
(3) The *load kinetic lift* (LKL) from the crouched position with the box 40 cm in front of the feet so that it had first to be pulled towards the body and then swung upwards, keeping the trunk upright as in the LL.
(4) The *trunk kinetic lift* (TKL) from the crouched position but with the hips being raised before the box to simulate an attempt at the LL in a subject with inadequate knee-extensor strength.
(5) The *forward kinetic lift* (FKL) from the crouched position but giving the body horizontal motion prior to lift-off so that the box was swung forward and up. In this lift, subjects took a pace forward as the box reached knuckle height.
(6) The *two-stage leg lift* (2SLL) from the crouched position in which, first, the box was lifted up so that its weight was taken via the forearms onto the thighs and so held close to the body; and secondly, the box was raised vertically with the body as in the leg lift.

The two lowering techniques were:

(1) *Lowering* (LLO) the box using the leg lift technique in reverse.
(2) *Lowering* (BLO) the box using the back lift technique in reverse.

In the six lifts, the box was raised from the floor to knuckle height and held there.

Subjects were trained in these techniques before any observations were recorded to ensure that the characteristic patterns of movement were performed distinctly as described. The kinematic differences between them are shown in Figure. 1.

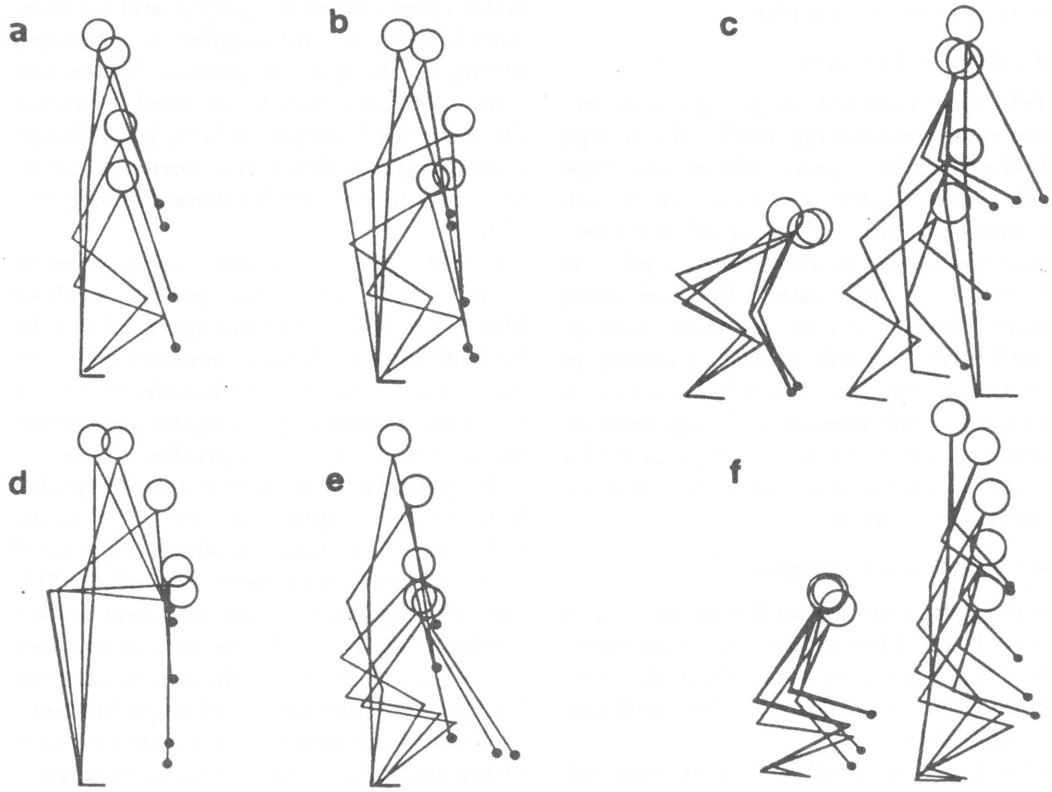

Figure 1. *The six lifting techniques: (a) leg lift, (b) trunk kinetic lift, (c) forward kinetic lift, (d) back lift, (e) load kinetic lift, (f) two-stage leg lift.*

Body Movements

A Selspot monitoring system was used. Four infrared light-emitting diodes were affixed to the knuckle of the middle finger, shoulder, hip, and ankle on the right side. The Selspot camera with optoelectronic sensor was placed on the coronal axis of the body so that movements in the sagittal plane could be recorded. For each channel a second-order Butterworth low-pass filter was used with 20 Hz cutoff frequency. The movements of the load were assumed to coincide with those of the knuckle-marker.

Forces Applied to the Load

Strain-gauge force transducers with bridge amplifiers were fitted to the handles of the box to record the forces applied to it in the horizontal and vertical planes.

Intraabdominal Pressure

IAPs were recorded using a pressure-sensitive radio-transmitting pill (Rigel Ltd, type 7014) and radio-receiver (Rigel Ltd, type 7040) (Davis, Stubbs, and Ridd, 1977) with an aerial strapped to the subject's abdomen. Before the subject swallowed it, the pill was calibrated in a water-bath at 38°C. Before the observation of each lift, subjects were required to remain still, breathing quietly in order to obtain a base-line from which to measure the IAP increase. Readings were delayed if necessary to await the passage of a peristaltic wave that would otherwise invalidate the observation.

Data Collection and Analysis

The signals were sampled at a rate of 100/s with a 12-bit A/D converter and were transferred to a floppy disc for analysis. A microcomputer was used for collection and processing of data.

Means and standard deviations were calculated for (1) peak vertical velocity of the load, (2) peak lumbosacral compression, (3) integral of lumbosacral compression over time, (4) peak hip torque, and, (5) peak intraabdominal pressure.

For Variables 2, 3 and 4, a biomechanical sagittal-plane model was used to estimate the compressive load at lumbosacral (L_5/S_1) level and the torque at the hip joints (Leskinen et al., 1983). The model is based on the free-body-diagram technique, using only two body segments: the upper limbs and trunk, including head and neck, as a whole (i.e., all parts of the body above the level of the hip joints) for Variable 4, but for Variables 2 and 3 above the level of L_5/S_1.

The analysis takes into account the external vertical and horizontal forces applied by the hands to the load, the internal forces and torques caused by gravity, and the horizontal, vertical, and angular accelerations acting on the body segments. The tensile force in the back muscles required to balance the calculated torque at L_5/S_1 is combined with the gravitational and inertial forces at this level to give the lumbosacral compression.

In this study, the model was modified to permit correction for foot position in those lifts in which the feet were apart (all but the back lift and back lower). Moreover, direct recording of the force at the handles of the box was used instead of deriving it from acceleration, as was done in the previous study.

The period for calculation of the integral of lumbosacral compression over time was determined by the time for which the vertical forces on the box exceeded its weight. This was not applicable to the two-stage leg lift in which the lift was divided into two phases.

The significance of differences between lifting techniques was tested using Student's *t* values for paired observations: i.e., each lifting technique was compared separately with all other techniques.

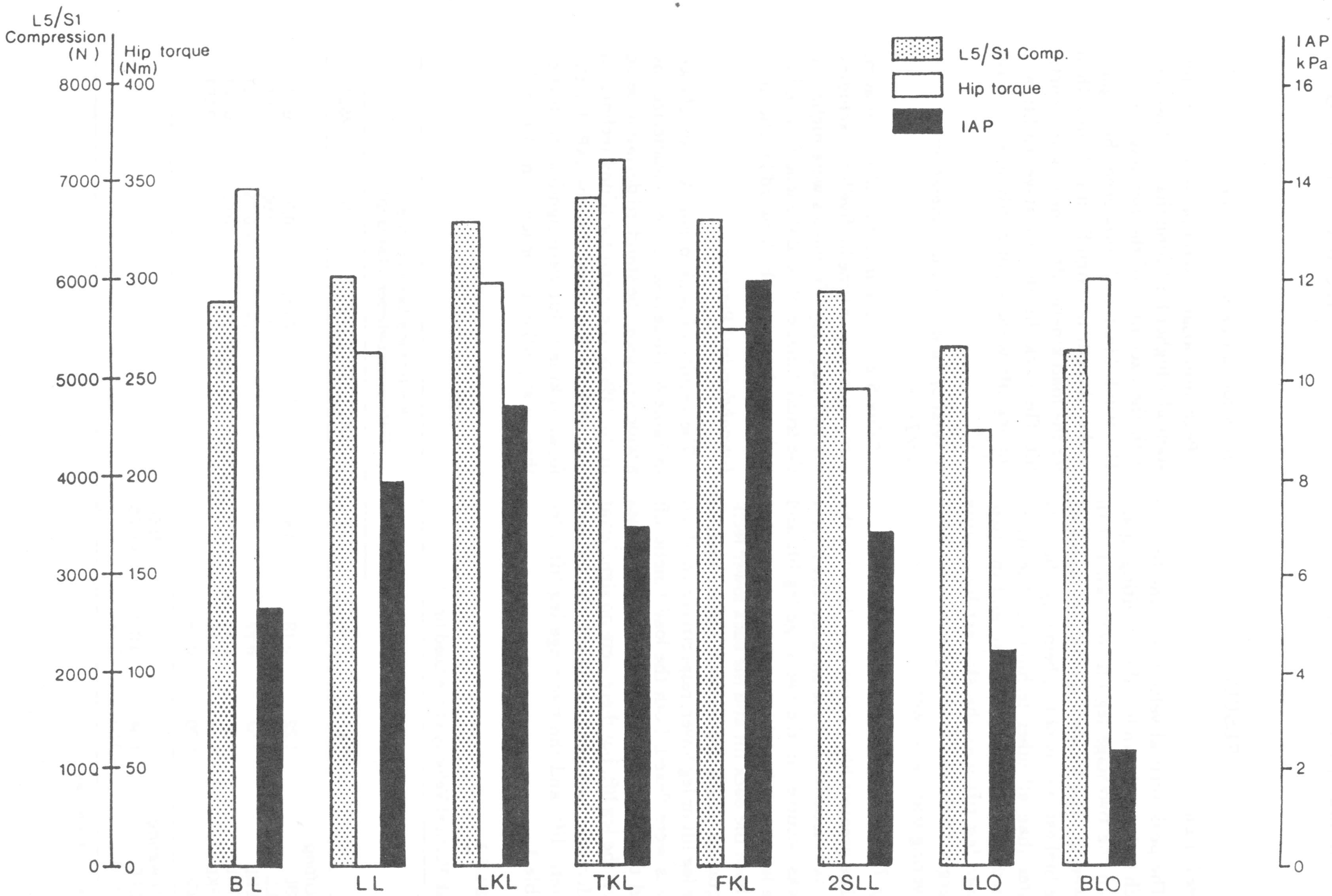

Figure 2. *Histograms for the six lifting and two lowering techniques. Mean peak values for the 10 subjects are given for L_5/S_1 compression (shaded), hip torque (open), and intraabdominal pressure (black).*

RESULTS

Speed of Lift

The peak vertical velocities of the box for each task are shown in Table 2. Lifting, apart from the two-stage leg lift, was faster than lowering. The forward kinetic lift produced the highest speeds of lift, being significantly faster than all other techniques. The trunk kinetic lift was second fastest, and the two-stage leg lift was the slowest by a wide margin. Of the two lowering techniques, back lowering was the slower.

Hip Torque

The greatest hip torques were found in the trunk kinetic lift and the back lift. The lowest peaks occurred in the two-stage leg lift and the leg lower. Peak hip torques were greater in both the back lift and the back lower technique, in which trunks were flexed, than in the leg lift or leg lower, respectively, in which knees were flexed. Both the load kinetic lift and the trunk kinetic lift gave higher values than the leg lift, but there were no significant differences between the leg lift, the forward kinetic lift, and the two-stage leg lift. (See Table 3.)

Lumbosacral Compression—Peaks

Peak lumbosacral compression was substantially higher for lifting than for lowering, with the exception of the two-stage leg lift. The trunk kinetic lift produced the highest peaks, though not significantly higher than for the load kinetic lift or the forward kinetic lift. The back lift, the two-stage leg lift, and the leg lift were significantly less. (See Table 4.)

Integral of Lumbosacral Compression over Time

Table 5 gives the integrals of lumbosacral compression over time for five lifts, excluding the two-stage leg lift. Values were highest in the trunk kinetic lift and the load kinetic lift, and were lowest in the forward kinetic lift.

Intraabdominal Pressure

The results of peak mean IAPs are shown in Table 6. These results are characterized by a wide variance, the standard deviation being up to 73% of the mean for lifting techniques and 86% for lowering. Yet the IAPs for the forward kinetic lift were significantly higher than in any other lift or lower, next in order

TABLE 2

Peak Vertical Velocity of the Load (mls)

			Significance Levels of the Difference between Means (p)				
	Mean	*S.D.*	*LL*	*LKL*	*TKL*	*FKL*	*2SLL*
Lifting							
BL	1.22	0.19	n.s.	n.s.	<0.05	<0.001	<0.01
LL	1.22	0.17		n.s.	<0.05	<0.001	<0.01
LKL	1.34	0.22			n.s.	<0.05	<0.001
TKL	1.37	0.18				<0.05	<0.001
FKL	1.48	0.15					<0.001
2SLL	1.00	0.09					
Lowering			*BLO*				
LLO	−1.04	0.09	<0.05				
BLO	−0.94	0.12					

n.s. = not significant.

TABLE 3

Peak Hip Torque (nm)

	Mean	S.D.	Significance Levels of the Difference between Means (p)						
			LL	LKL	TKL	FKL	2SLL	LLO	BLO
BL	346	108	<0.01	<0.05	n.s.	<0.01	<0.001	<0.001	<0.05
LL	263	77		<0.01	<0.001	n.s.	n.s.	<0.01	<0.01
LKL	295	90			<0.01	n.s.	<0.01	<0.001	n.s.
TKL	360	117				<0.01	<0.001	<0.001	<0.01
FKL	275	88					<0.01	<0.01	n.s.
2SLL	243	85						<0.05	<0.01
LLO	224	65							<0.001
BLO	299	73							

n.s. = not significant.

being the load kinetic lift. Lowering produced the smallest IAP peaks, although for the back lower they were significantly less than for the leg lower. For the lifts, the back lift gave the lowest values. IAPs were not clearly related to the other variables.

DISCUSSION

The results for lumbosacral compression recorded during the first four lifts (back lift, leg lift, load kinetic lift, and trunk kinetic lift) are broadly similar to those reported earlier (Leskinen et al., 1983), except that the apparent advantage of the leg lift over the back lift in terms of peak compression was reversed in the current series despite similar lifting velocities. In the earlier study, the authors pointed out that it required only a small increase in the horizontal distance between the load and the body for the advantages of the leg lift to be lost. The results of this study confirm that judgment, because there were in fact two differences in lifting technique in the two studies. In the present study lifting was from the floor, whereas in the earlier study lifting was from a shelf 10 cm above the floor. Furthermore, except for the back lift and the

TABLE 4

Peak Lumbosacral Compressive Forces (N)

	Mean	S.D.	Significance Levels of the Difference between Means (p)						
			LL	LKL	TKL	FKL	2SLL	LLO	BLO
BL	5765	871	n.s.	<0.01	<0.001	<0.05	n.s.	<0.05	<0.05
LL	6039	1087		<0.05	<0.01	n.s.	n.s.	<0.05	<0.05
LKL	6647	1072			n.s.	n.s.	<0.01	<0.001	<0.001
TKL	6815	996				n.s.	<0.01	<0.001	<0.001
FKL	6534	1394					<0.01	<0.01	<0.01
2SLL	5867	1184						<0.05	n.s.
LLO	5317	663							n.s.
BLO	5290	497							

n.s. = not significant.

TABLE 5

Integral of Lumbosacral Compression over Time (Ns)

	Mean	S.D.	Significance Levels of the Difference between Means (p) LL	LKL	TKL	FKL
BL	2386	509	n.s.	n.s.	<0.05	n.s.
LL	2554	655		n.s.	<0.05	n.s.
LKL	2996	898			n.s.	<0.05
TKL	3041	865				<0.05
FKL	2314	433				

n.s. = not significant.

back lower, the present lifts were made with one foot in front of the other. These differences have led, among others, to small differences in horizontal load-body distance, which would account for the reversal in the leg lift versus the back lift effect.

Comparison of peak L_5/S_1 compression and peak hip torque reveals an apparent discrepancy. In the back lift, peak compression was relatively low, whereas hip torque was notably high, almost as high as for the trunk kinetic lift. In part, this may have arisen from the length of the lever arm from the load and upper trunk to the hip: this is longer in both the back lift and the trunk kinetic lift than for the leg lift. But the length of the lever arm from the load to the L_5/S_1 disc does not differ as much in that case as between the back lift and the leg lift. The position of the L_5/S_1 disc in relation to the hips and shoulders is influenced by the amount of lumbar flexion.

However, both previous and present results are at one in identifying the trunk kinetic lift as the lift with the highest values for compression and hip torque. Of all the lifting techniques observed, the lowest overall values were shown by the two-stage leg lift. Because the load was divided into two stages and was allowed to be lifted close to the body, this was a predictable result. In contrast, the forward kinetic lift rated fairly high in terms of compressive stress. This may have arisen partly because of the speed with which the lift was completed. Forward kinetic lift is comparable to the lifting technique taught by Anderson (1951), the chief proponent of what has come to be known as "kinetic" lifting. However, the forward kinetic lift led, by a wide margin, to the highest IAPs: again, perhaps, due to the speed of lift, alternatively to the direction of the lifting effort, which differed from the other lifts.

IAPs for the back lift were the lowest for all lifting techniques, and in this lift, the trunk is flexed most nearly to the horizontal. The

TABLE 6

Peak Intraabdominal Pressures (kPa)

	Mean	S.D.	Significance Levels of the Difference between Means (p) LL	LKL	TKL	FKL	2SLL	LLO	BLO
BL	5.3	3.4	<0.001	<0.001	n.s.	<0.001	<0.05	n.s.	<0.01
LL	7.9	4.5		<0.05	n.s.	<0.001	n.s.	<0.001	<0.001
LKL	9.5	3.5			<0.05	<0.05	<0.01	<0.001	<0.001
TKL	7.0	5.1				<0.001	n.s.	<0.01	<0.01
FKL	12.0	5.0					<0.001	<0.001	<0.001
2SLL	6.9	4.8						<0.01	<0.01
LLO	4.4	3.8							<0.05
BLO	2.4	1.9							

n.s. = not significant.

next lowest scores for IAPs arose in the two-stage leg lift and the trunk kinetic lift. The trunk kinetic lift simulated the lifting pattern of the individual whose knee extensors are insufficient to raise load and body together without initial knee extension and thus converting a leg lift into an ordinary back lift. Thus, the back lift and the latter part of the trunk kinetic lift differ from the others, first in terms of the inclination of the trunk at the moment the load is accelerated, but also in that the lumbar spine is then more flexed than it is in the crouched position (Troup, Hood, and Chapman, 1968). Therefore the distance of the IAP vector from the vertebral axis will be greater when stooped: hence the mechanical advantage of maximizing lumbar flexion and increasing the AP diameter of the trunk (Davis and Troup, 1965). In this respect, these results are in line with those of Grew (1980).

The major findings of this study are as follows.

(1) Lifting was faster than lowering.
(2) Peak hip torques were greater when the trunk was flexed than when the knees were flexed.
(3) Peak lumbosacral compressions were, in general, substantially higher for lifting than for lowering.
(4) Peak compression and hip torques did not always occur together in all of the techniques. The length of the lever arm creates high hip torques in techniques that require trunk flexion.
(5) IAPs were less when the trunk was flexed than when the trunk was erect.
(6) There was no other pattern explaining the relationship between the IAP and lifting velocity, lumbosacral compression, and hip torque.

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