The effect of inertial factors on spinal stress when lifting

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Biomechanical models used for the evaluation of spinal stress have mostly been static: they reveal the postural stress caused by gravity but ignore the inertial forces and torques induced by the accelerations of body segments and the load handled. In this study both static and dynamic models for determining lumbosacral compression were used, and the results from different models were compared.

Twenty subjects lifted a 15 kg box from a 10 cm high shelf to knuckle height with four lifting techniques: the conventional back and leg lifts and two 'kinetic' lifts with which the subjects gave kinetic energy either to the horizontally moving load or to the vertically moving body before lifting the load itself vertically.

The results showed that the inertial factors increase the spinal load considerably. Comparison between the lifting techniques showed that the dynamic peak stress was clearly smaller in the leg lift than in the back lift, although the static peak stress was smaller in the back lift. The L5/S1–compression × time integral, describing the total stress of a lift, was smallest in the back lift with both models.

Introduction

Lumbosacral compression induced by manual materials handling has been evaluated using biomechanical models based on the analysis of forces and torques acting on the musculoskeletal system of a human body. Hitherto, most such models have been static (e.g., Martin and Chaffin, 1972, Schultz *et al.*, 1982), thus revealing the postural stress due to gravity, but ignoring the inertial forces and torques induced by the accelerations of the load and body segments. Ayoub and El-Bassoussi (1978) introduced a dynamic element in their model by using a mathematical simulation of acceleration. A simple dynamic sagittal plane model employing direct recording of the movements of the body, the acceleration of the load and the force at the feet was presented by Leskinen *et al.* (1983). The aim of this paper is to describe the effects of dynamic factors on the spinal stress when lifting.

Materials and Methods

The study was undertaken with 20 male subjects in the age range 20–42 years (mean 28.3), of heights from 164 to 187 cm (mean 179), and weights from 60 to 94 kg (mean 72.4). The subjects lifted a box from a shelf, 10 cm high, to knuckle height. The total weight of the box was 15 kg and its handles were set 12 cm from the base.

All subjects lifted the box using four lifting techniques illustrated in Fig. 1: back lift (BL), leg lift (LL), load kinetic lift (LKL), and trunk kinetic lift (TKL). BL was carried out with straight knees, flexed hips and bent back. LL was performed with flexed knees and hips, and straight back. In LKL the box was pulled horizontally towards the body and then swung upwards. In TKL the hips were first moved vertically by extending the knees, followed by trunk extension and raising of the load. The subjects practised each lifting technique until they performed the lifts precisely as instructed and only after that were the lifts recorded for the analysis.

To record the movements of the body an optoelectronic Selspot system was used with four infra-red light-emitting diode markers attached on the knuckle of the middle finger, shoulder, hip, and ankle. The velocities and accelerations were computed by differentiating the position signals once or twice, respectively. The movements of the centre of mass of the load were assumed to coincide with that of the knuckle.

The acceleration of the load was recorded with two tri-axial accelerometers, one attached on the front and the other on the rear of the box to be lifted.

The vertical force at the feet was recorded using a force platform, 60 × 60 cm.

An ABC 80 microcomputer with 32 kbytes program memory was used for the collection and processing of data. When recording at the rate of 100 samples/s, the available memory limited the recording time to 2.5s, which is adequate for one lift.

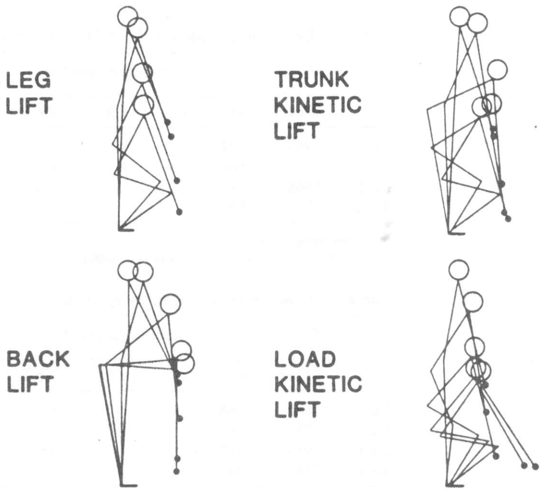

Fig. 1. Lifting techniques of the study

Table 1. Peak vertical acceleration and peak vertical velocity of the load

	Acceleration (ms^{-2})		Significant level[a]			Velocity (ms^{-1})		Significant level[a]		
	Mean	sd	LL	LKL	TKL	Mean	sd	LL	LKL	TKL
BL	6.09	2.26	NS	*	*	1.28	0.14	NS	NS	NS
LL	6.29	1.82		**	***	1.28	0.15		NS	NS
LKL	5.17	0.94			NS	1.25	0.15			NS
TKL	4.94	1.73				1.29	0.21			

[a] NS non-significant
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 2. Peak inertial forces at the feet and the inertial force × time integrals

	Peak (N)		Significant level[a]			Integral (Ns)		Significant level[a]		
	Mean	sd	LL	LKL	TKL	Mean	sd	LL	LKL	TKL
BL	244	68	***	NS	NS	62	13	***	***	**
LL	362	105		***	***	119	24		NS	***
LKL	255	43			NS	112	26			***
TKL	258	145				82	28			

[a] NS non-significant
** $p < 0.01$; *** $p < 0.001$

The dynamic analysis of biomechanical forces and torques leading to the compression at the L5/S1 disc was done using a link-segment model described elsewhere (Leskinen *et al.*, 1983). For the static analysis the same model was used, but all the accelerations were set to zero. In fact the static analysis includes the effects of gravity, and the dynamic analysis adds the effects of inertia.

Two parameters of the L5/S1 compression were studied: the peak compression during a lift, and the compression × time integral for the period when the recorded vertical acceleration of the load was positive.

The inertial force at the feet was obtained by subtracting the weights of the subject and the load from the force platform signal. The peak force and the force × time integral for the positive force period were the parameters detected.

The statistical analysis was based on one recording of each lifting technique from each subject. The results of each technique were compared to the three others in pairs using the paired t-test. The same lifts were used both in the static and the dynamic analyses.

Results

Load velocity and acceleration

The mean vertical peak velocities and accelerations are presented in Table 1. The acceleration was smaller in the kinetic lifts than in the conventional 'non-kinetic' lifts, but there were no significant differences in the peak velocity.

Inertial force at the feet

Table 2 presents the peak inertial forces at the feet and the inertial force × time integrals. Both parameters were highest in LL and lowest in BL.

L5/S1 compression

Table 3 presents the peak compressions at the L5/S1 disc both with static and dynamic analyses. Table 4 presents the compression × time integrals. The static compression peaks were smallest in BL, although the difference to LL was negligible, but the dynamic peaks of BL were

Table 3. Peak compression at L5/S1 (N) computed with static and dynamic models

	Static		Significant level[a]			Dynamic		Significant level[a]			Dynamic increase
	Mean	sd	LL	LKL	TKL	Mean	sd	LL	LKL	TKL	(%)
BL	3989	372	NS	***	***	6365	824	**	*	NS	59.5
LL	4033	544		***	***	5866	807		NS	***	45.4
LKL	4548	581			NS	6042	868			**	32.8
TKL	4650	537				6629	867				42.5

[a] NS non-significant
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 4. Compression × time integral at L5/S1 (Ns) computed with static and dynamic models

	Static		Significant level[a]			Dynamic		Significant level[a]			Dynamic increase
	Mean	sd	LL	LKL	TKL	Mean	sd	LL	LKL	TKL	(%)
BL	1666	296	**	**	***	2268	360	*	*	***	36.1
LL	1884	363		NS	***	2417	425		NS	***	28.2
LKL	1918	319			**	2451	390			***	27.7
TKL	2145	362				2770	443				29.1

[a] NS non-significant
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

clearly greater than those of LL and LKL. The integral was smallest in BL with both static and dynamic models.

Discussion

The magnitude of the acceleration of the load, on average more than g/2, indicates the importance of dynamic aspects when analyzing lifting biomechanically. However, the lower peak accelerations and the smaller forces at the feet in the kinetic lifts than in the leg lift are not reflected in the peak compressive loads at L5/S1, which is higher in the TKL than the BL of LL and higher in LKL than LL. Though in the LKL the dynamic component of compression is clearly less the static component has been increased by the addition of horizontal motion of the load. And the same increase in the static component appears to be produced when a lift which begins as a LL is converted in effect into a BL.

The dynamic component of spinal compression is biggest in the back lift which probably arises from the relatively high angular acceleration of the trunk. Though the smaller dynamic components of compression may appear to lend favour to the two kinetic lifts, in these experiments the advantage was probably lost because subjects were not able to perform these lifts with the box as close to the body as in the non-kinetic lifts.

Conclusion

The dynamic factors should be taken into account in biomechanical models of lumbosacral compression, since the results calculated with dynamic and static models differed clearly from each other. These differences illustrate the importance of analysing both inertial and postural factors when studying lifting technique.

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