International Journal of Industrial Ergonomics, 1 (1987) 219–229
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

QUANTITATIVE TRUNK MUSCLE ELECTROMYOGRAPHY DURING LIFTING AT DIFFERENT SPEEDS

J.Y. Kim and W.S. Marras

Industrial and Systems Engineering Department, The Ohio State University, Columbus, OH 43210 (U.S.A.)

(Received July 28, 1986; accepted October 30, 1986)

ABSTRACT

This study was designed to investigate the effects of trunk motion under lifting conditions described by the Work Practices Guide for Manual Lifting (NIOSH, 1981). Eight male volunteers were used as subjects in this study. Three independent variables; lift style, load location and subjective lift velocity, were controlled under sagittally symmetric lifting conditions. Dependent variables consisted of trunk muscle electromyographic (EMG) activity, actual trunk velocity and load acceleration. There was no effect of lift style. However, as the trunk velocity increased, EMG activity increased within the lastissimus dorsi and rectus abdominus muscles but not within the erector spinae muscles. The erector spinae muscles, unlike the other muscles, was also unaffected by load location and load acceleration. These findings suggest ways in which lifting guides should be adjusted to account for the effects of dynamic motion.

INTRODUCTION

The relationship between Manual Materials Handling (MMH) and the risk of low back disorder (LBD) has been well established by many researchers (Stubbs, 1981; Strachan, 1978; Andersson, 1981; Magora, 1970; Troup, 1981; Magora, 1974; Kelsey, 1975). Recently, Bigos (1986) has shown that MMH was much more commonly considered the cause of injury compared with other types of causes. Bigos also found that MMH was the most common type of injury irrespective of the severity of the injury. In fact, Bigos found that 64% of all low cost (less than $10 000) injuries were due to MMH whereas 56% of all high cost (over $10 000) were due to MMH causes. Hence, MMH is a factor which needs to be controlled in the workplace.

One control measure often used to minimize the risk of LBD due to MMH is the Work Practice Guide for Manual Lifting (WPGML) (NIOSH, 1981). This guide proposes two limits, the action limit (AL) and the maximum permissible limit (MPL) which are based upon the loading (compression) at the lumbro-sacral junction (L5/S1). The AL is the weight in a given lifting situation which could be safely handled by almost all of the population. The MPL, on the other hand, is the weight level, for the same lifting situation,

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which only a few lifters could handle safely. These limits are based upon a static biomechanical model and the strength characteristics of a population of subjects tested under static testing positions.* However, virtually all lifting situations involve dynamic components. The guide addresses these concerns by assuming the worker is performing the MMH task under a slow, smooth lifting condition. However, no investigations are reported in the literature which investigate the effects of lifting speed upon the activity of the supporting structures of the low back. This study monitored the motion parameters of a lift which were quantifiable by the NIOSH guide and observed the reaction of the trunk musculature to motion parameter changes.

The reaction of several trunk muscles was observed in this experiment. The trunk musculature represent the internal supporting structures of the low back which contributes the major portion of spine loading during a lifting task. This is due to the proximity of these supporting structures to the spine compared with the external load being lifted (see Marras et al., 1986). Hence, if the activity of the trunk muscles is monitored, the biomechanical loading of the low back can be appreciated under a given lifting condition.

No direct means exist to monitor the force exerted by a particular muscle under normal lifting conditions. However, electromyography (EMG) is often used as a measure of muscle activity. Under certain conditions, the integrated EMG activity is linearly related to muscle force. For instance, the quantifying proportionality factor for integrated EMG has been established for the special cases of isometric contractions (Inman et al., 1952) and constant load contractions at constant velocity (Bigland and Lippold, 1954). An accurate biomechanical assessment of EMG activity generated by the trunk muscles during free dynamic motion has been difficult to obtain. However, increased EMG activity is present during increased velocity of a muscle as well as during increased loading of a muscle. Since force is a product of mass and acceleration, increases in integrated EMG under dynamic conditions should indicate some form of increased loading of the muscle. Hence, in this study, integrated EMG activity was used as an indicator of muscle activity level, and thus, internal structure activation in the trunk.

The objective of this study was to investigate the effects of trunk motion under lifting conditions described by the WPGML. Several subjective lifting velocities were examined, and the trunk muscle activity and load acceleration characteristics were observed. All the assumptions of the WPGML were met except for the motion assumption and this factor was permitted to vary. The results of this experiment were expected to provide information of how the biomechanical model used by the WPGML should be adjusted to account for the velocity component of a lift.

METHOD

Subject

Eight male students were recruited as subjects for the experiment. All of them were students whose ages ranged from 24 to 31 years. Their mean height was 172.9 cm (S.D. = 3.6 cm) and their mean weight was 68.6 kg (S.D. = 5.6 kg). They were all in good health and had no previous history of back injuries or significant back pain. All subjects were volunteers.

Experimental design

Three independent variables were defined in this experiment. These variables consisted of lift style, load location, and lift velocity.

Generally, lift styles can be categorized according to the involvement of leg bending during the lifting phase of the task. If there is no significant leg bend, the lift style can be categorized as a stooped lift. If the knees are bent, the lift style can be categorized as a squat. In this study, each subject was asked to lift in both the stooped and squat positions. Subjects were trained in the different lift methods. All lifts were also video taped to ensure compliance with the lift method chosen for each trial.

Load location was defined according to WPGML. This guide assumes that all lifts occur in the sagittal plane. Load location refers to the vertical and horizontal location of the load from the floor and center line of the worker, respectively. The two different vertical locations relative to the load destination consisted of 75 cm (knuckle height) and 120 cm (shoulder height). The two horizontal load destination locations consisted of 60 and 75 cm. The inital load location as well as the four destination positions of the load are shown in Fig. 1.

The final independent variable consisted of the velocity of lift. Subjects were asked to lift at velocities which they considered slow, medium and fast. Subjects were permitted at most 5, 4, and 3 seconds, respectively, to perform the lifting tasks. The object of this subjective velocity estimation was to determine the acceptable velocity range under which workers actually lift. This measure also provides a measure which could be compared to the assumptions set forth by the WPGML.

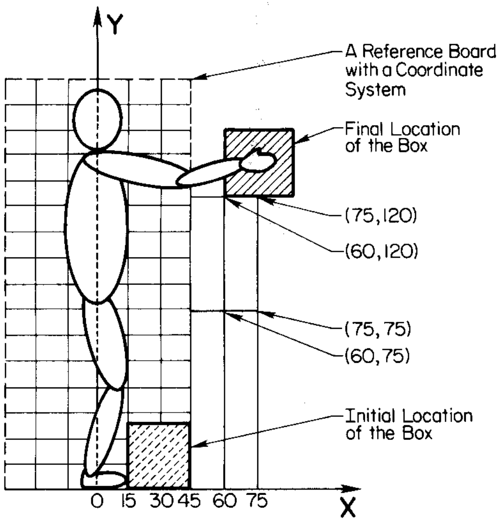

Fig. 1. Load locations for experimental tasks.

The load weight was determined for each load destination location relative to the trunk loading estimates set forth in the WPGML. Under all lifting location conditions, the load was adjusted so that it corresponded to 90% of the MPL.

Several dependent measures were monitored during the experiment. First, the activity of the trunk muscles was monitored. The muscles which were monitored were those which would be active during lifting in a sagittally symmetric position. The transverse plane technique of Schultz and Andersson (1981) was used to identify the muscles which support the trunk in a sagittally symmetric lift. According to this method if the trunk is cut with an imaginary plane at the third lumbar level, the muscles which support the trunk would be identifiable. In a sagittally symmetric exertion the muscles active along this plane would consist of the right latissimus dorsi (LATR), left latissimus dorsi (LATL), right erector spinae (ERSR), left erector spinae (ERSL), right rectus abdominus (RCAR) and left rectus abdominus (RCAL). The activity of these muscles was represented by the "integrated" (RMS value) of the EMG signal of each muscle. The muscle activity was normalized by comparing the activity to the maximum activity for each muscle. Maximum activity was determined during a maximal static effort extension and flexion pretest.

Next, the acceleration characteristics of the load were monitored as a dependent measure under all conditions. An accelerometer was attached to the load and monitored simultaneously with the other dependent measures.

The final dependent measure consisted of actual trunk velocity. A lumbar motion monitor (LMM) was attached to the lumbar region of the back and continuously monitored the angle and angular velocity of trunk bend. The

LMM and its use was described by Marras and Wongsam (1986). All dependent measures were monitored simultaneously and continuously throughout each experimental trial.

Apparatus

Surface electrodes were attached to the skin at the muscle sites. The electrode locations and attachments were prepared according to standard procedures (Basmajian, 1978). At each muscle location two small (1-cm-diameter) Beckman electrodes were attached to the skin at a separation distance of 3 cm. The erector spinae signals were recorded at a point 4 cm lateral to the third lumbar vertebrae. Even though the latissimus dorsi muscles overlay the erector spinae at this location, the latissimus dorsi consists of connective fascia at this point which is electrically silent. Therefore, the erector spinae signal is isolated at this location. The latissimus dorsi muscles were isolated at the most lateral point at the tenth thoracic vertebrae level. This muscle was located by asking the subject to pull the arm down against upward resistance when the upper arm was held directly in front of the body (perpendicular to the midline) with the elbow at a right angle. Comparisons between intramuscular and surface electrodes have shown that the muscle may be isolated at this point. The rectus abdominus muscles were recorded at a point 4 cm lateral to the midline of the body, at a point 2 cm above the line joining the anterior superior spine of the pelvis. These muscles were also palpated while the subject performed a valsalva maneuver. Pilot tests have also shown that these muscles are isolated at this location. The electrode locations were verified by asking the subject to contract the muscle of interest while observing the electrical reaction. Further details regarding muscle identification and isolation may be found in Marras (1982).

The electrodes were attached to small light weight preamplifiers which were attached via velcro to a belt around the subject's waist. This procedure assured that the electrodes were in close proximity to the preamplifiers which significantly reduced noise in the EMG signal. The EMG signal was conditioned with high and low pass filters and "integrated" by a hardware RMS procedure.

The six EMG signals, the accelerometer signal and the LMM signal were all monitored by an ISSAC 2000 data acquisition system. This device uses a microprocessor to convert analog signals to digital form according to the specifications of the experimenter. After each experimental trial the data were transferred to a microcomputer where the data were observed on a graphics display. This process ensured that all signals were active throughout the experiment. The data were then stored for further analysis.

Analysis of the experimental data was achieved by first generating a hard copy of the data using a plotter. This plot was used to locate the points of interest of each signal. These points consisted of time windows throughout which a muscle was active. The points were used as input to a computer program which calculated the mean, standard deviation, starting time, end time, peak and minimum of each signal as well as velocity for the LMM. The data was then transferred via modum to the University main frame computer for statistical hypothesis testing. The experimental apparatus is represented schematically in Fig. 2.

A box with handles was used as a load for liftings. A weight was loaded in the box, and its total weight was adjusted according to the 90% of calculated MPL under the proposed lifting conditions. Dimensions of the box and handle were determined based on previous studies (Ciriello and Snook, 1983; Drury, 1983). The width, length and height were 30 cm each. A handle with 30 mm diameter, 100 mm length and 50 mm clearance was used. A

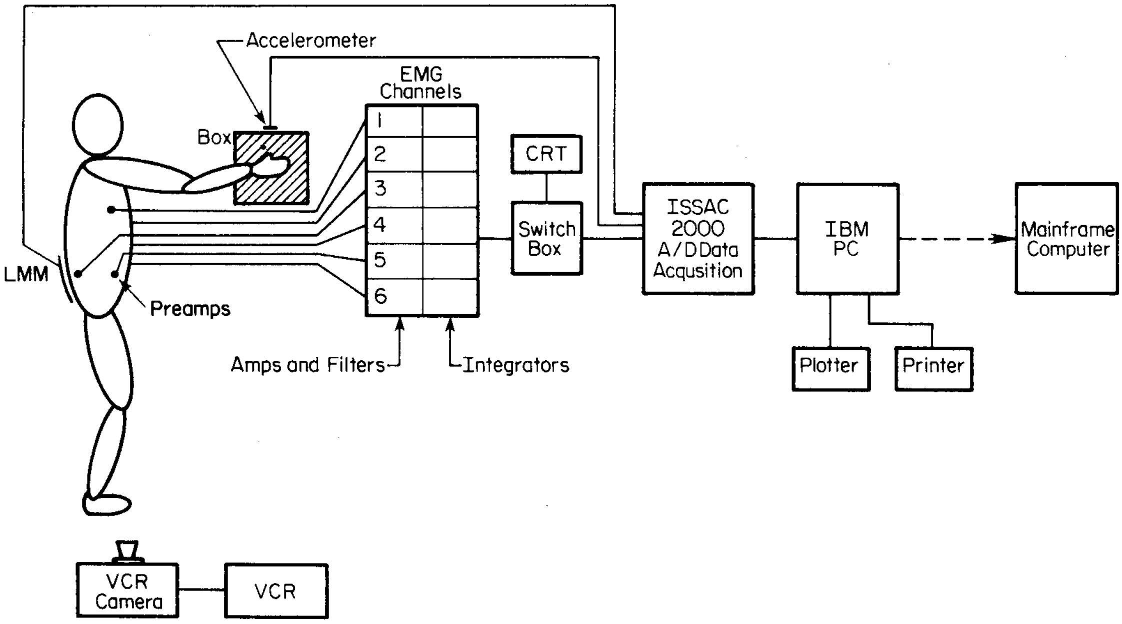

Fig. 2. Configuration of experimental apparatus.

single axis accelerometer oriented in the vertical plane was attached on top of the box. This device revealed the upward acceleration which was believed to be the major acceleration component of the box in this task. A video camera and reference board with a coordinate system (Fig. 1) were used to analyze lifting postures.

Experimental task

Lifting tasks were performed with two-handed, sagittally symmetric postures directly in front of the body without any twisting of the trunk. The room temperature was between 70° and 75°F. The origin of the horizontal location was at the ankle midpoint, and the origin of the vertical location was the center of the gravity of the box. The frequency of lifting was limited to fewer than twice per minute according to the recommendation of Snook (1978). The initial box location was 30 cm forward from the ankle midpoint. The subject was simply asked to lift the box at a specified subjective velocity to a predetermined destination (see Fig. 1).

Procedure

The subjects were asked to warm up by bending and stretching before beginning the lifting tasks. The surface electrodes were attached to the subject's skin. Skin resistance was measured with an ohm meter attached to the electrodes to verify the conductivity of the electrode–skin attachment. Six pairs of electrodes and one ground electrode were connected to the EMG amplifiers. Each channel was examined visually on an oscilloscope to determine whether the EMG signals were of sufficient quality. Quality criteria consisted of (1) low noise when muscles were inactive (2) an absence of a heart beat artifact in the EMG signal (3) an electrical response to a muscle contraction and (4) no cross talk between muscles. Next the LMM was attached. When everything was ready, the pretest (maximum flexion and extension) was conducted. Next, subjects were asked to lift the box using either the squat or stooped position under the various velocity conditions. Presentation order was randomized.

TABLE 1

Angular velocity of trunk movement (deg/s). Each value represents a 4 lift average

subject	slow	medium	fast
DA01	21.74	25.79	34.57
YS02	6.04	8.88	16.33
SH03	10.69	13.01	21.23
JL04	16.35	21.81	33.02
CL05	16.05	21.97	32.01
SP06	13.24	22.57	26.21
YS07	18.45	21.36	31.71
WC08	17.19	19.74	29.75
Mean	14.97	19.40	28.10
S.D.	4.88	5.59	6.40

RESULTS

Lift velocity

The trunk angular velocity exhibited by each subject under the experimental conditions is shown in Table 1. Even though each subject was allowed to choose subjectively his own lift speed, most subjects employed trunk velocities which were fairly similar regardless of lift style or load location within each velocity condition (slow, medium or fast). This table also shows that changes in lift speed resulted in changes in trunk velocities as opposed to only change in arm and leg velocities. The difference between the lift velocities were statistically significant ($F = 13.17$, $p < 0.001$). These trunk velocities compare favorably with those observed by Marras and Wongsam (1986).

Trunk muscle activities

Analysis of variance (ANOVA) techniques were used to determine if the muscle activities differed significantly as a function of lift style, lift velocity or lift location. Table 2 summarizes the results of these tests when the mean value of the trunk muscle activity was considered. These results indicate that there was no significant difference in the mean trunk muscle activities between stooped and squat lift postures.

When lift velocity was evaluated, signifi-

TABLE 2

ANOVA results summary (significant F values) of mean muscle activity (** indicates that a significant difference exists when $p < 0.05$, and * indicates that a significant difference exists when $p < 0.1$)

hypothesis		muscle						
		Overall	LATR	LATL	ERSR	ERSL	RCAR	RCAL
lift type	squat vs stooped							
lift velocity	slow vs med. vs fast	14.50 **	10.67 **	25.71 **			53.26 **	22.98 **
	slow vs med.							
	med. vs fast	21.25 **	20.16 **	47.21 **			88.75 **	33.20 **
	slow vs fast	22.24 **	10.18 **	27.17 **			69.91 **	35.69 **
lift location	60 h vs 75 h			7.11 **				
	75 v vs 120 v	4.48 *					9.72 **	

TABLE 3

ANOVA results summary (significant F values) of maximum muscle activity (** indicates that a significant difference exists when $p < 0.05$, and * indicates that a significant difference exists when $p < 0.1$)

hypothesis		muscle						
		Overall	LATR	LATL	ERSR	ERSL	RCAR	RCAL
lift type	squat vs stooped							
lift velocity	slow vs med. vs fast	2.88 *	9.71 **	3.62 *		3.84 *	3.13 *	6.25 *
	slow vs med.		7.57 *					
	med. vs fast					5.99 *		10.77 **
	slow vs fast		18.98 **	7.10 *				7.44 **
lift location	60 h vs 75 h		4.72 *	10.45 **				
	75 v vs 120 v	4.58 *					5.56 *	4.56 *

cant reactions of the mean trunk muscle activities resulted. These differences were apparent for all lift velocities comparisons except between slow and medium lift speeds. Furthermore, the difference in trunk muscle activity was apparent primarily in the latissimus dorsi and rectus abdominus muscle groups. No significant changes were observed in the erector spinae response to lift velocity.

Finally, lift destination location effects were evaluated. The analysis of mean trunk activity revealed that the LATL responded significantly to horizontal location changes whereas the RCAR responded significantly to vertical position changes.

The peak trunk muscle activities were also evaluated as a function of the experimental conditions. These results are summarized in

TABLE 4

Summary of significant ($p < 0.05$) correlations between acceleration and the EMG

acceleration	muscle					
	LATR	LATL	ERSR	ERSL	RCAR	RCAL
at all speeds	0.338	0.297			0.186	0.424
at fast speed		0.302			−0.328	
at 60 h	0.331					0.424
at 75 h	0.338	0.428				0.445
at 75 v	0.320					0.404
at 120v	0.366	0.345				0.410

Table 3. As with the mean EMG activity analysis, no significant differences were noted in lift style. When peak activity was evaluated as a function of lift velocities differences were noted in the LATR, LATL and RCAL when slow and fast velocities were compared. Finally, peak muscle activities of both the latissimus dorsi and rectus abdominus muscles responded to changes in the horizontal and vertical load destination respectively.

Acceleration

The correlation between load peak acceleration and trunk muscle activity was investigated as a function of the lift velocity and load destination factors. Table 4 summarizes the results of this analysis. Low but significant correlations ($p < 0.05$) associated with lift velocity occurred primarily at the fast speed within the latissimus dorsi and rectus abdominus muscles. Significant correlations between EMG activity and acceleration were also found within these same muscles and the horizontal and vertical load destination position. Of particular interest was the lack of significant acceleration-EMG correlation within the erector spinae muscles. The lack of strong correlations between trunk muscles and load acceleration may indicate that most load acceleration is generated by other muscle groups such as the biceps. However, an increase in trunk muscle activity and thus spine loading did occur as lift velocity increased.

DISCUSSION

This study has been able to quantify many of the changes that occur during free dynamic lifting. Furthermore, many of the adjustments necessary to adapt the WPGML to free dynamic lifting in the sagittal plane have been investigated.

One of the more interesting findings of this study was that style of lift had no significant influence on trunk muscle activity. This finding supports the assumptions stated in the WPGML that the limits apply to unrestricted lifting postures. This is true since the factors which determine the AL and MPL are L5/S1 compression. This compression is a function of the moments imposed about the spine and should not be affected by configuration of the body as long as the location of L5/S1 is known. It is significant to note that this principle also applies under free dynamic lifting conditions.

The findings of this study regarding load destination location indicates the WPGML may underestimate the effects of load destination. The assumptions of the WPGML were based on static exertions of subjects relative to load location. Since the load weight in this experiment was adjusted so that the MPL would be constant under all load-location conditions, no difference in EMG activity under the experimental conditions would be expected. Hence, it is significant to note that increases in trunk muscle activity occur under dynamic lifting conditions. Duncan post-hoc analyses showed that the farther away the load was from L5/S1, the greater the activity in the latissimus dorsi and rectus abdominus muscles. However, no significant changes in EMG activity were found in the erector spinae muscle groups. Since the biomechanical model employed by the WPGML does not consider the action of the latissimus dorsi and rectus abdominis muscles, it appears that inclusion of these muscle groups in the calculation of L5/S1 compression would enhance the predictive power of the model especially under realistic lifting conditions.

When lifting velocity was considered, more significant differences were noted. As with load location, the significant difference in trunk muscle resposes were seen in the latissimus dorsi and rectus abdominus muscle groups. Duncan post-hoc analyses indicated that the activity of these muscle groups increased under fast lifting conditions and the

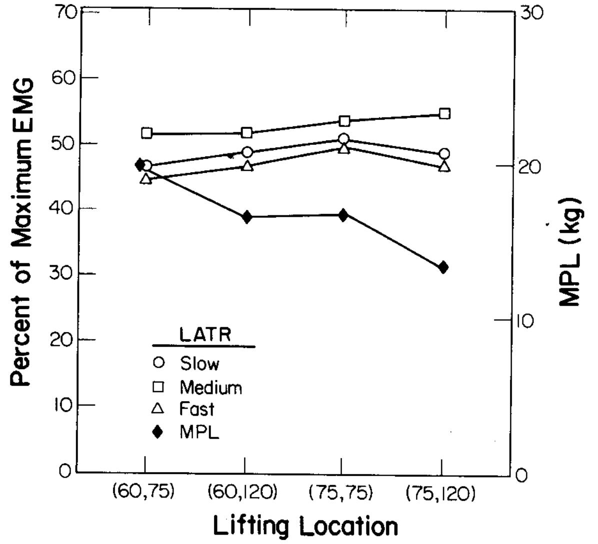

Fig. 3. Mean EMG activities of the right latissimus dorsi muscle compared with MPL level and lift location.

activities of these muscles were indistinguishable between slow and medium lifting velocities. The erector spinae muscles exhibited no increase in activity as would be expected according to the assumptions of the WPGML.

These results indicate that if slow lifting is indeed comparable to static lifting then the predictions set forth by the WPGML would hold for all but fast velocities. However, in order to test this hypothesis, slow lifting EMG activity should be compared with static lifting EMG activity. This testing comparison would be difficult since static evaluation would be necessary throughout the entire range of postures and comparison of static and dynamic signals would be questionable.

These results also point to a specificity of muscle function. As noted earlier, the latissimus dorsi and rectus abdominus muscles were responsive to increases in velocity and increases in load destination distance. Furthermore, the latissimus dorsi responded uniquely to horizontal load locations, whereas the rectus abdominus responded uniquely to vertical load location. The fact that only the right rectus abdominus mean signal responded significantly to vertical load position may indicate a dominant side response of the body. However, further research is needed to interpret this finding correctly. The correlational analyses also indicated that these same muscles were significantly correlated with load acceleration under velocity and load destination conditions. These findings suggest that these muscle groups may play a large role in dynamic load transport whereas the erector spinae muscles respond consistently and provide a stable base of support for the biomechanical system. If such a specificity of muscle function does exist, it should be incorporated into the L5/S1 loading function in biomechanical models.

The correlation coefficient values observed in Table 4 were not impressive. However, they were statistically significant and indicate that at least some of the variability in load acceleration may be explained by the muscle activities. The fact that these correlations were not greater is also not surprising. It may be the case that load acceleration was generated in muscles other than the trunk muscles (i.e. arm muscles). However, this study does show that trunk muscle activity is indeed influenced by trunk velocity and, thus, the dynamic action of the trunk can influence significantly the loading of the spine.

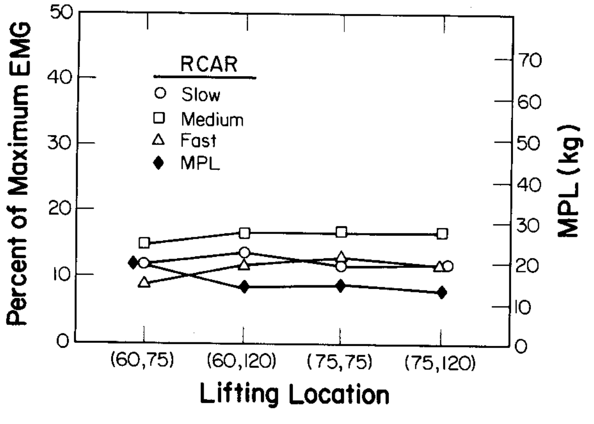

Fig. 4. Mean EMG activities of the right rectus abdominus muscle compared with MPL level and lift location.

The effects of these results upon the estimation of the AL and MPL should also be discussed. The mean activities of the LATR and RCAR muscles are shown in Figs. 3 and 4, respectively, as a function of load location and lifting speed. The MPL axis was scaled so that the slow velocity lift at position (60,75) corresponded with the slow velocity EMG at the same postition. This procedure permitted relative comparisons between conditions. These figures are shown as an example of the class of latissimus dorsi and rectus abdominus muscles. If the WPGML was reactive to dynamic lifting, one would expect the slow, medium and fast curves to remain horizontal and fall on top of each other. These figures show that as velocity increases these muscles must increase their activities. This is probably due to the co-activation function of these muscles which is to accelerate the load at the beginning of the lift and stop the trunk motion near the end of the lift. If these activities were included in the calculation of L5/S1 compression their effects would result in an increase in L5/S1 compression values. Hence, under slow dynamic conditions, the WPGML may predict a L5/S1 loading which is within the AL or MPL limit. However, if the lift velocity is rapid, the L5/S1 loading may actually exceed these limits due to the activity of the latissimus dorsi and rectus abdominis muscles. Therefore, adjustments to the WPGML should be considered.

CONCLUSION

The conclusion of this study may be summarized by the following points:

(1) There is no difference in trunk muscle activity as a function of lift style.

(2) The latissimus dorsi and rectus abdominus muscles responded significantly different to changes in load destination even when load level is adjusted according to the WPGML.

(3) The latissimus dorsi and rectus abdominus muscles increase their activity under fast lifting conditions.

(4) The erector spinae muscles are unaffected by adjusted load location, lift velocity, or load acceleration.

(5) These findings indicate that the WPGML could be adjusted for dynamic lifting in the sagittal plane by including L5/S1 compression due to the latissimus dorsi and rectus abdominus muscles. These would provide a more reasonable comparision with the AL and MPL values.

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