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The Effect of Complex Dynamic Lifting and Lowering Characteristics on Trunk Muscles Recruitment

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A better understanding of how the neuromuscular spinal system behaves during lifting and lowering could provide more insight about potential causes of occupational low back disorders (LBDs), and could help in the prevention and rehabilitation process of these disorders. The purpose of this study was to quantify trunk muscle activities under various whole-body free-dynamic symmetric and asymmetric complex lifting and lowering tasks. Eleven male subjects with no prior history of LBDs participated in the study. Electromyographic activities of ten trunk muscles were monitored while subjects either symmetrically or asymmetrically lifted and lowered a box under three different speeds and three weights. The results showed that all ten muscles were responsive to various experimental conditions with the erector spinae and internal oblique muscles showing the greatest response. Substantial electromyographic activities were observed in muscles that were on the contralateral side of the load. Lowering conditions yielded consistently lower muscular activities than their corresponding lifting conditions. These results show that it is essential to consider multiple trunk muscles in modeling efforts of quantifying spinal loading, as well as for back rehabilitation research purposes.

KEY WORDS: electromyography; lifting; lowering; muscle activity; asymmetry.

INTRODUCTION

Low back disorders (LBDs) in occupational settings have been considered the most significant musculoskeletal disorders in terms of both cost and prevalence (1,2). Manual materials handling (MMH) in general, and lifting activities in particular, have been implicated most often in relation to the risk of occupationally-related LBDs (3,4). A better understanding of how the internal structures of the body behave during lifting and lowering could provide more insight about potential

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causes of occupational LBDs, and could help in the prevention and rehabilitation process of these disorders.

When compared to the moment arm of the external load imposed on the body, trunk muscle reactive moment arms are very small. For example when lifting a box in front of the body, the distance between the center of the load and the center of the spine (external load moment arm) could be as high as 75 cm; whereas, trunk muscle moment arms are usually under 10 cm. This large disadvantage of internal moment arms as compared to external moment arms requires the trunk muscles to generate forces that are several times higher than the external load in order to maintain equilibrium conditions. These large muscle forces load the spine in the form of compressive and shear forces and have been implicated as having a link to low back disorders (5–10). Assessing the roles of different trunk muscles and their relative contribution to total spinal loading provides information about the response of the neuromuscular system and the contribution of the potential risk factors present during MMH tasks and implicated by epidemiological studies.

When assessing trunk muscle activity, it is essential to include both agonist and antagonist muscle groups. Originally, several researchers have investigated spinal loading through the use of one equivalent extensor muscle (11, 12). This type of analysis assumes there are no antagonistic activities present. Also, several optimization-based linear models of spinal loading assumed null values for all antagonistic muscles when minimizing the compression forces on the spine (9, 12–15). Although the exact origin of this observed coactivation between agonists and antagonists is poorly understood, ignoring coactive muscles can result in the extreme underestimation of the resultant spinal loading, especially the shear forces (16–18). These types of loads have been implicated in increased strain imposed on the intervertebral disk fibers, subjecting the structure to greater risk of failure (10, 19, 20). McGill *et al.* (21) have emphasized the role of coactive muscles and suggested that their effect could be incorporated even into simple 2-D models by reducing the effective moment arms of single equivalent muscles.

Several studies have investigated muscle coactivity under either simple isometric or controlled isokinetic conditions (17, 22–26). These studies have demonstrated that the antagonistic muscles had significant levels of activity under several experimental conditions. However, few studies investigated, in detail, trunk muscle activity under *free-dynamic lifting* conditions (16, 27, 28). These studies emphasized the role of antagonistic muscles under different upper-body free-dynamic lifting conditions. These types of conditions would better match a realistic lifting condition than isometric or isokinetic conditions, since the trunk was allowed to move freely in an asymmetric or sagittally symmetric plane. To date, researchers have been able to describe muscular response and the corresponding spinal loading during isolated trunk motion. However, it is important to expand the current knowledge and consider complex *whole-body* free-dynamic (unconstrained) conditions.

Whole-body free-dynamic symmetric and asymmetric (complex) lifting conditions provide situations that more closely match realistic industrial tasks. Fathallah *et al.* (29) have shown how complex lifting conditions (simultaneously occurring complex high trunk velocities and positions) could distinguish patterns in groups at increased risk levels of LBD. It is of interest to further investigate how the body's neuromuscular system responds under these conditions, and to identify the recruitment patterns of trunk muscles during symmetric and asymmetric lifting and lowering tasks that have not yet been delineated. It should be noted that although other studies have qualitatively investigated muscle activities under unconstrained asymmetric conditions, few, if any, have used normalization which enables the comparison and contrast of muscle activities across levels of independent variables as well as across various trunk muscles. Hence, the main objective of this study was to quantify normalized trunk muscle activities under various whole-body free-dynamic symmetric and asymmetric complex lifting and lowering.

METHOD

Subjects

Eleven healthy male subjects volunteered to participate in this experiment [average age was 28.2 years (4.4 SD); average height was 180.7 cm (3.7 SD); and average weight was 78.6 kg (10.8 SD)]. A questionnaire was administered to each subject to ensure that there was no significant history of back disorders and to screen subjects with current back-related discomforts.

Experimental Design

The experiment was a four-way within-subject design. The independent variables included: (1) task, (2) speed of lifting/lowering, (3) weight handled, and (4) task symmetry. The task variable consisted of two levels: lifting and lowering. Speed of lift/lower (heretofore referred to as speed) had three levels: low (2 s per lift), medium (1.5 s per lift) and high (1 s per lift). These speed levels were chosen to represent varying speeds similar to those observed in industry (30). Three weight levels were considered: low (22 N), medium (67 N), and high (156 N) (these levels correspond to 5, 15, and 35 lb). The weight levels were determined based on the distribution of weights observed in industrial tasks (30). The low weight level corresponded to a value between the 25th and the 50th percentile, the medium level between the 50th and 75th, and the third level between the 75th and 100th percentile of the weight distribution. Lastly, task symmetry had two levels: symmetric and asymmetric lifting/lowering. The asymmetric tasks are considered *complex* tasks since they require simultaneous motions in more than one anatomical plane of motion (usually all three planes: sagittal, frontal, and transverse); whereas the symmetric tasks require motion in only one plane of motion (sagittally symmetric plane).

The dependent variables considered were average normalized electromyographic activity (NEMG) of ten trunk muscles. The ten muscles included the right and left Latissimus Dorsi (LTR and LTL), Erector Spinae (ESR and ESL), Rectus Abdominus (ABR and ABL), External Obliques (EXR and EXL), and the Internal Obliques (INR and INL). These muscles are commonly considered in three-dimensional modeling of "internal" spinal loading since they constitute the *main* musculature system supporting the trunk at the lumbar cross-sectional region (6,7,9,28).

Apparatus

An electromyography (EMG) system collected signals from ten pairs of bipolar silver–silver/chloride surface electrodes affixed over the specific locations of the ten muscles of interest (Fig. 1). The electrode locations were: (1) LAR and LAL: most lateral portion of the muscle about the T9 spinal level, (2) ESR and ESL: at the L3 level, 4 cm from the spinal midline, (3) ABR and ABL: 2 cm from the umbilicus level, 3 cm from the abdomen midline, (4) EXR and EXL: 10 cm from the abdomen midline at 45 deg, 4 cm above the iliac crest, and (5) INR and INL: 3 cm above the posterior superior iliac spine, 10–12 cm from the spinal midline at 45 degree angle (lumbar triangle) (17,26).

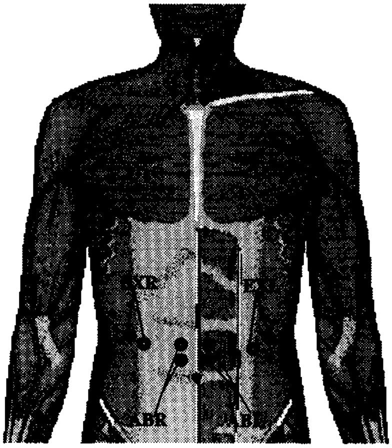
The EMG signals were first amplified 1000× by preamplifiers placed at short distances from the muscle sites (less than 25 cm). The signals were then sent via shielded cables to the EMG system for further processing. The signals were further amplified in the main amplifier between 30× to 55×, depending on the muscle and the subject under consideration. Also, to eliminate undesired signal artifacts, the signals were low pass filtered at 1000 Hz. The filtered signals were rectified and processed via a 20 ms moving average window (integration constant). The ten rectified and filtered EMG signals were collected at a sampling rate of 100 Hz using a 12-bit 32-channel analog-to-digital (A/D) converter connected to a 386-based microcomputer.

Static maximum voluntary contractions (MVCs) were obtained using an Asymmetric Reference Frame (ARF) structure (17, 26). The structure allows the subject's legs, hips, and trunk to be secured while performing a given MVC exertion.

The experimental protocol required the subject to lift a wooden box that was loaded with the proper weight of the prescribed condition. The box was a 30.5 cm × 30.5 cm × 23 cm with two handles (3.8 cm diameter and 11.4 cm length) centered at its sides. For each condition, the subject was provided with an auditory signal (loud tone) indicating the start and end of each lifting/lowering trial. This tone was necessary to control the speeds (durations). Figure 2 shows a subject performing a typical symmetric lift (2a) and a typical asymmetric lift (2b), respectively.

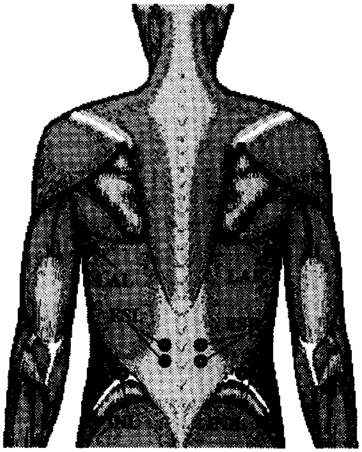
Experimental Procedure

Initially, each subject consented to volunteer in the experiment and answered a "history of LBD" questionnaire. Muscle sites of interest were identified, the skin was shaved (if needed) and thoroughly cleaned with alcohol, then lightly abraded to remove possibly interfering dead skin tissue. Each pair of surface electrodes were filled with an electrolyte gel and placed at 3 cm apart (center to center) in their appropriate locations. The integrity of the EMG signals were visually checked via an oscilloscope and on-line monitoring on the computer screen. Written instructions were given to the subject detailing the six *static* MVCs he was about to undertake.



EXR = Right External Obliques
ABR = Right Rectus Abdominus
EXL = Left External Obliques
ABL = Left Rectus Abdominus

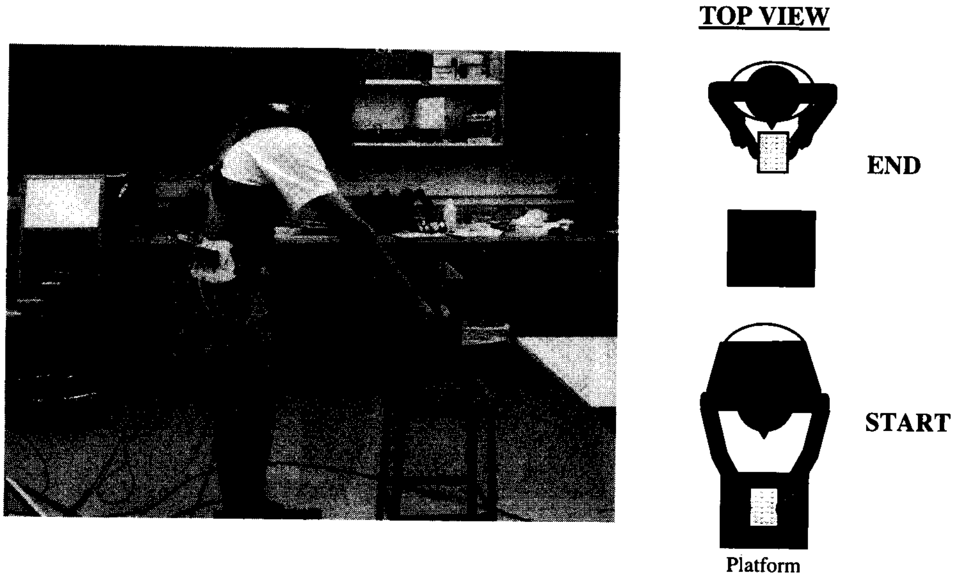
(a) Frontal view



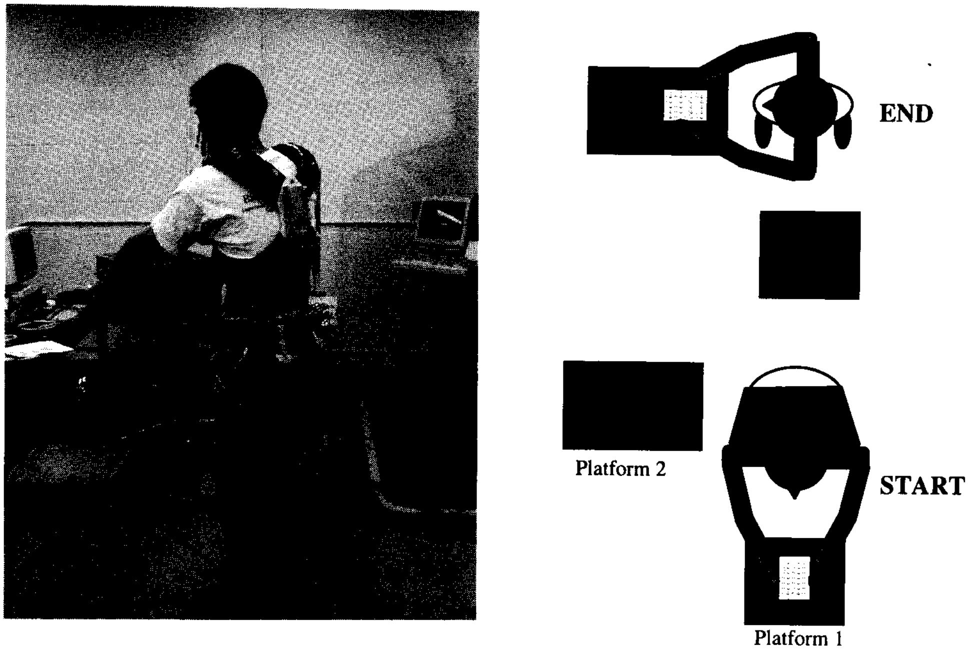
LAL = Left Latissimus Dorsi
ESL = Left Erector Spinae
INL = Left Internal Obliques
LAR = Right Latissimus Dorsi
ESR = Right Erector Spinae
INR = Right Internal Obliques

(b) Back view

Fig. 1. Locations of the bipolar surface electrodes for each of the ten monitored muscles. (a) Frontal view of the body, and (b) a back view of the body.



(a) Symmetric lift.



(b) Asymmetric lift.

Fig. 2. A subject performing a typical symmetric lift (a), and an asymmetric lift (b).

Prior to any testing, the experimenter ensured that the subject understood the nature of the exertions. The subject's legs, hips, and trunk were secured in the ARF at 22.5 deg of sagittal flexion. The subject was then asked to perform six exertions in random order. The six MVCs consisted of right and left lateral bends, flexion, extension, and right and left twisting exertions.

Each experimental trial consisted of two lifts and one lower with tones indicating the start and end of each task. Two types of conditions were administered: symmetric and asymmetric lifting/lowering. In the symmetric condition, the box (weight) was placed on a platform in front of the subject slightly above knee height, and at a horizontal distance from the spine to the center of the load equals to his arm length (distance between the center of the shoulder joint and tip of the middle finger). At the onset of the tone, the subject was asked to lift the box from its location to a position as close as possible to the body, while maintaining straight legs and arms (see Fig. 2a). A second tone was given to indicate the end of the lift. The subject paused for half a second while holding the box then, at the tone, he started lowering the box and setting it back to its origin on the platform. Again, a tone signaled the end of the lowering part. Another half a second pause was given before the subject repeated the lifting part. This concluded a typical symmetric condition.

For the asymmetric conditions, the box was placed in front of the subject in the same manner as the symmetric condition; however, in this case the subject was asked to set the box down at another platform placed to his right at an angle perpendicular to the midsagittal plane at the start of the lift (see Fig. 2b). The platform height was set even with the subject's iliac crest height and was placed at about arm's length horizontal distance. Similar to the symmetric conditions, the subject was again asked to perform two lifts and a lower with tones marking the start and end of each phase. To minimize fatigue, the subject was given at least a 60 s rest period between exertions. The subjects were also instructed to take an additional rest period whenever they desired to do so.

Prior to each experimental condition, the task was demonstrated and the subject was allotted time to practice the lift/lower. During the experiment, the experimenter ensured that the subject was performing the task as instructed, especially starting and ending the task at the onset of the two auditory tones; otherwise, the trial was repeated.

Within a given speed, the type of symmetry was randomized. Also, within a given symmetry level (symmetric or asymmetric), the three weights handled were presented in random order. However, the subject was not asked to alternate between speeds nor between symmetric and asymmetric conditions. This was necessary in order to ensure consistency in lifting/lowering speeds and styles.

Data Conditioning and Analysis

For each subject, each muscle's continuous EMG values were normalized with respect to the muscle's maximum EMG value obtained from the static MVCs part of the experiment. This will be referred to as normalized EMG (NEMG). For each lifting/lowering trial, the average NEMG of each of the ten muscles was assessed. Multivariate analysis of variance (MANOVA) was used to investigate the change in average NEMGs due to different experimental conditions. This is an appropriate type of analysis since it is desirable to test the combined effect of all muscles' NEMGs under various experimental conditions. Subsequent analysis of variances (ANOVAs) were performed on each of the ten dependent variables (average NEMGs).

In addition, to investigate the role of muscle coactivity under various experimental conditions, the relative contribution of the flexor muscles with respect to the extensor muscles ("coactivity ratio") was determined as follows:

[SUM Flexors average NEMG/(SUM Extensors + Flexors average NEMG)] * 100 Where Flexors = ABR, ABL, EXR, EXL muscles, Extensors = LAR, LAR, ESR, ESL, INR, INL muscles.

Graphical representation and statistical testing (ANOVA and *post hoc*) will be presented to explore, in detail, how the *average* "coactivity ratio" changed in response to different conditions. Statistical analyses were performed using SAS GLM procedure (31). Graphical results were generated with STATISTICA statistical software (32).

RESULTS

Table I represents a summary of the muscles that reacted differently to various experimental lifting conditions and their interactions. The first column shows the MANOVA results, followed by the individual ANOVAs of each muscle. At the multivariate level, there was a significant two-way interaction between task (lifting/lowering) and weight, task and speed, as well as weight and symmetry ($p < 0.05$). This type of higher level interaction makes it less useful to independently present the main effects involved in these interaction terms, since a given main effect may not be correctly interpreted without considering the interacting variable. To explore such interactive patterns among factors, graphical representation of the ten muscle responses (NEMG) under each task by weight by symmetry combination are shown in Fig. 3, and for the task by speed combinations in Fig. 4.

Given the rather large number of possible paired comparisons that could be performed on various experimental combinations presented in Figs. 3 and 4, only general significant trends are discussed. For all muscles and each weight level, the muscle activity for asymmetric lifts/lowers were substantially higher than their corresponding symmetric lifts/lowers (see Fig. 3). In addition, lowering tasks seem to elicit less NEMG activity than lifting especially from the major extensor muscles (erector spinae and internal obliques). Furthermore, under asymmetric conditions, muscles on the left side of the body (contralateral muscles) showed considerably higher NEMG than the right side, especially under lowering tasks. Note that the erector spinae muscle under lifting tasks did not show significant difference in NEMG between the left and right sides.

Table I. Significance Summary (*F* Ratios) of Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA) for Average NEMG of All Ten Trunk Muscles

Condition	*df*[a]	MANOVA (*F*)	ANOVA(*F*) RLAT	LLAT	RERS	LERS	RABD	LABD	REXTO	LEXTO	RINTO	LINTO
TASK (T)	1,10	10.6	12.5**	37.2**	48.7**	22.4**	0.1	0.2	0.1	2.6	32.8**	48.5**
WEIGHT (W)	2,20	11.8**	36.4**	90.8**	173.8**	747.5**	43.0**	42.7**	25.7**	79.6**	143.8**	149.3**
SPEED (S)	2,20	1.9	3.5*	0.9	0.7	0.4	4.84*	7.2**	10.6**	9.1**	11.8**	13.4**
SYMMETRY (SM)	1,10	17.7	28.6**	96.8**	14.8**	18.8**	19.4**	37.2**	32.5**	90.3**	18.3**	75.2**
T×W	2,20	3.4**	6.7**	13.9**	0.7	8.7**	1.5	3.0	2.1	2.2	9.0**	0.7
T×S	2,20	2.4*	4.8*	8.1**	3.5**	2.5	2.5	2.5	11.3**	6.8**	8.8**	6.7**
T×SM	1,10	12.8	13.27**	6.2*	14.4**	13.7**	4.0	4.2	17.0**	0.4	4.1	2.6
W×S	4,40	1.0	0.8	0.7	1.4	0.7	1.1	0.4	1.3	0.8	0.9	1.4
W×SM	2,20	7.6**	9.2**	39.0**	0.5	13.1**	14.4**	20.6**	7.3**	119.4**	6.1**	34.2**
S×SM	2,20	1.7	1.3	3.9	1.5*	1.6	2.2	2.5	1.7	3.3	0.4	0.7
T×W×S	4,40	0.9	1.2	0.6	2.5	4.4**	1.1	2.1	2.2	1.2	2.7	2.7*
T×W×SM	2,20	1.6	4.6*	0.4	9.9**	0.4	4.2	1.0	1.4	1.7	4.7*	0.1
T×S×SM	2,20	1.1	0.7	0.7	0.3	0.2	0.1	1.0	3.8*	1.9	3.2	1.6
W×S×SM	4,40	1.2	1.2	1.4	1.1	0.4	1.5	0.8	0.1	0.2	3.7*	1.0
T×W×S×SM	4,40	0.8	1.7	0.8	0.4	0.6	0.3	0.8	2.7*	0.3	1.0	1.1

[a] *df* = Degrees of freedom: Effect, Error.

*Significant at $\alpha < 0.05$.

**Significant at $\alpha < 0.01$.

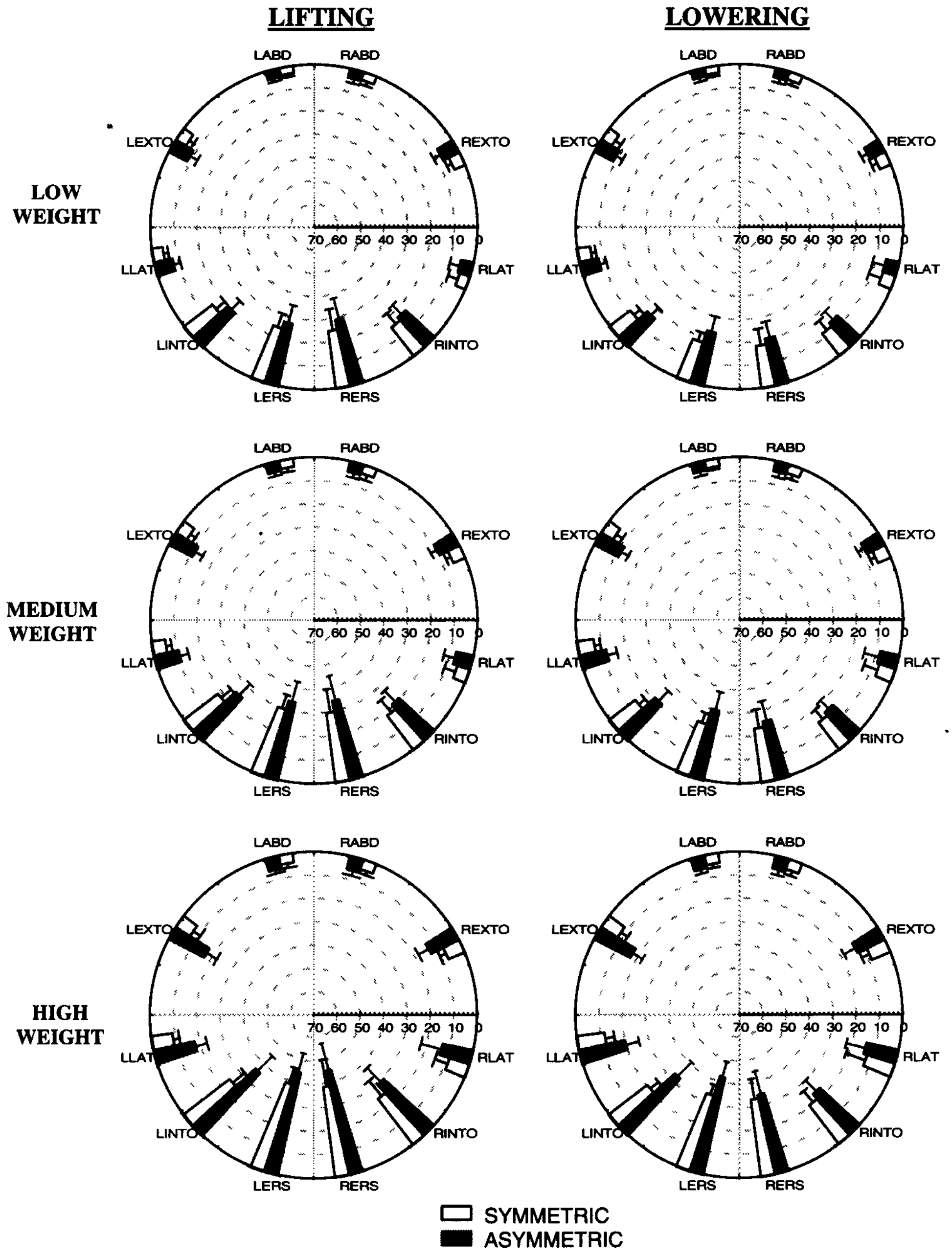


Fig. 3. Average NEMG (% of maximum) for the ten trunk muscles under all task by weight by symmetry combinations.

The increase in speed of lifting/lowering resulted in slight increase in NEMG of most of the ten muscles, especially under lowering tasks, and when comparing low speed to high speed conditions (Fig. 4).

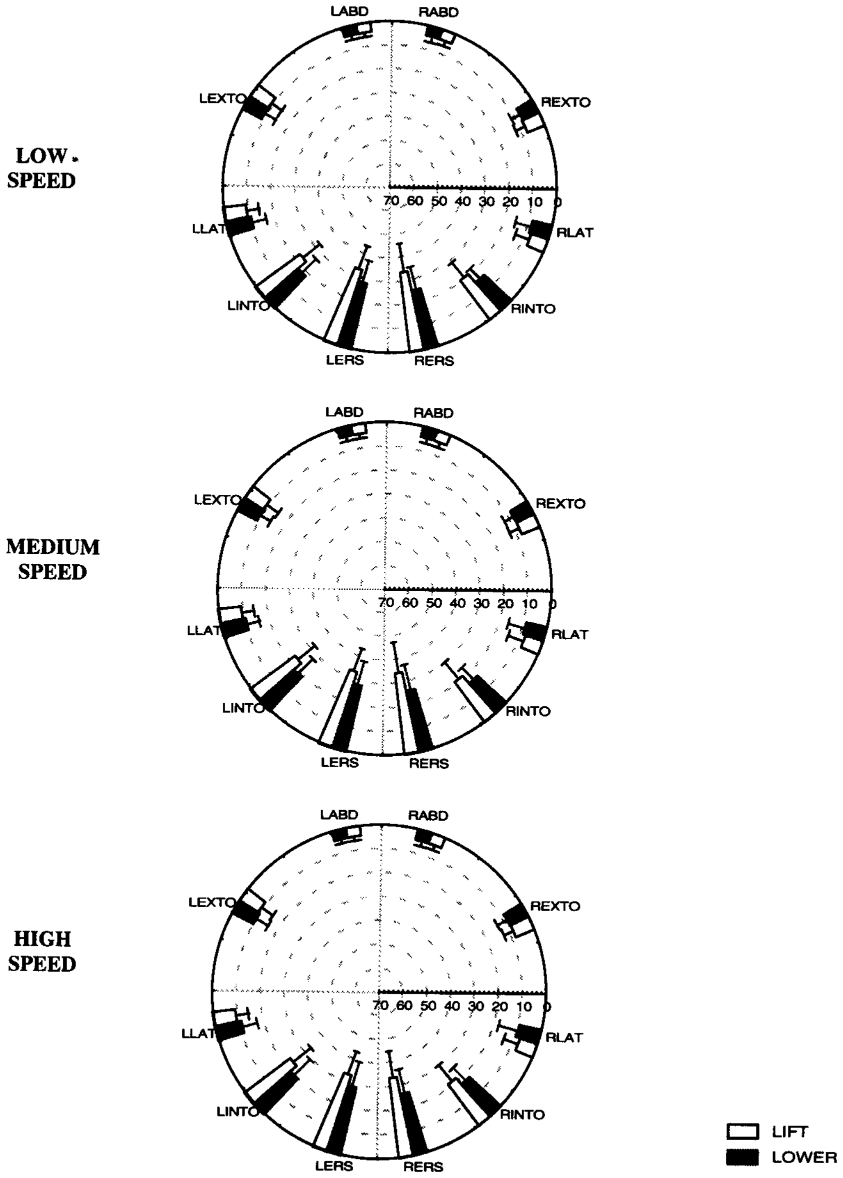


Fig. 4. Average NEMG (% of maximum) for the ten trunk muscles under the speed by task conditions.

The significant effects of various conditions on average coactivity ratio are shown in Table II. There was significant interaction between task and weight ($p < 0.01$), and between weight and symmetry ($p < 0.05$). Figure 5 depicts the average coactivity ratio under all the task (lifting/lowering) by weight by symmetry conditions. Important *post hoc* results (Newman-Keuls) are also shown. Almost all the asymmetric conditions showed consistently higher coactivity ratios than their sym-

Table II. Analysis of Variance (ANOVA) Results (*F* Ratios) for *Average* Coactivity Ratio

Condition	*df*[a]	Coactivity ratio (*F*)
TASK (T)	1,10	77.5**
WEIGHT (W)	2,20	3.0
SPEED (S)	2,20	3.9*
SYMMETRY (SM)	1,10	46.8**
T×W	2,20	7.8**
T×S	2,20	0.9
T×SM	1,10	3.8
W×S	4,40	1.6
W×SM	2,20	6.0**
S×SM	2,20	2.6
T×W×S	4,40	0.8
T×W×SM	2,20	0.1
T×S×SM	2,20	0.5
W×S×SM	4,40	0.5
T×W×S×SM	4,40	0.9

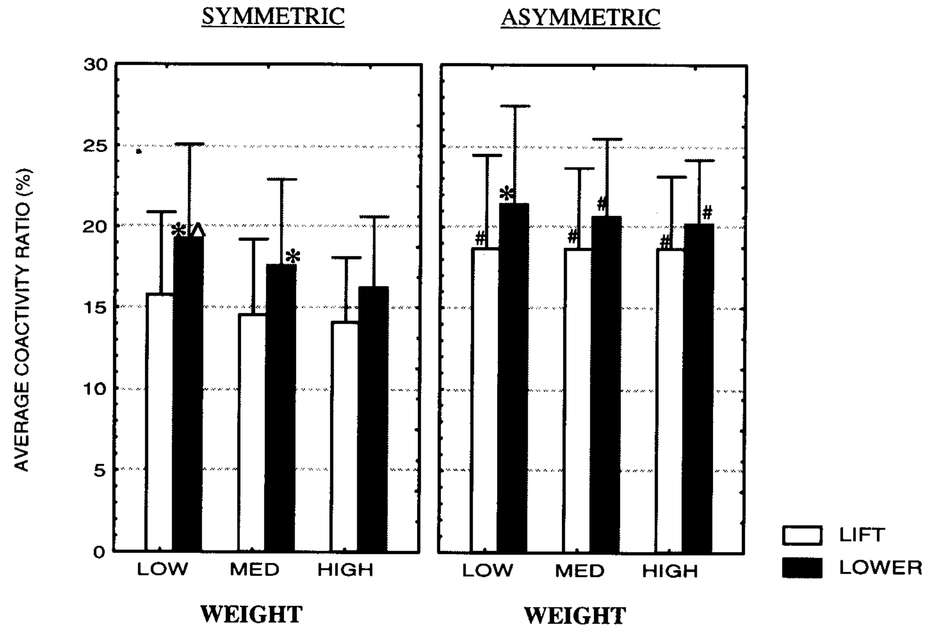
[a] *df* = Degrees of freedom: Effect, Error.
*Significant at $\alpha < 0.05$.
**Significant at $\alpha < 0.01$.

metric counterparts ($p < 0.05$). Lowering was shown to have higher coactivity ratios than lifting under conditions involving low and medium weight symmetric tasks, as well as low weight asymmetric tasks. The weight effect was shown to be significant only when comparing low and high weight levels under the symmetric lowering tasks (low weight showed higher coactivity ratio than the high weight, $p < 0.05$). The only significant "main effect" (without higher interaction levels) was observed for the "speed" factor. *Post hoc* analysis showed that the high speed level was significantly higher than the low speed level (Fig. 6, $p < 0.05$).

DISCUSSION

This study emphasizes the importance of viewing the trunk as a "system." The study shows that under more typical industrial tasks, earlier studies may have oversimplified the system response. This study illustrates how complex muscle coactivity could be in response to task parameters such as origin-destination, position, speed, and weight.

The results provided us with several insights about the role of various muscles in executing different whole-body free-dynamic lifting and lowering conditions. All the muscles monitored in the experiment have responded, with varying degree, to the different experimental conditions. In general, the erector spinae muscles and the internal obliques were the most active muscles, followed by the latissimus dorsi muscles. Marras and Mirka (17) have shown that under isokinetic controlled exertions the erector spinae and latissimus dorsi muscles were the most active muscles



Asymmetric > Symmetric at $\alpha < 0.05$

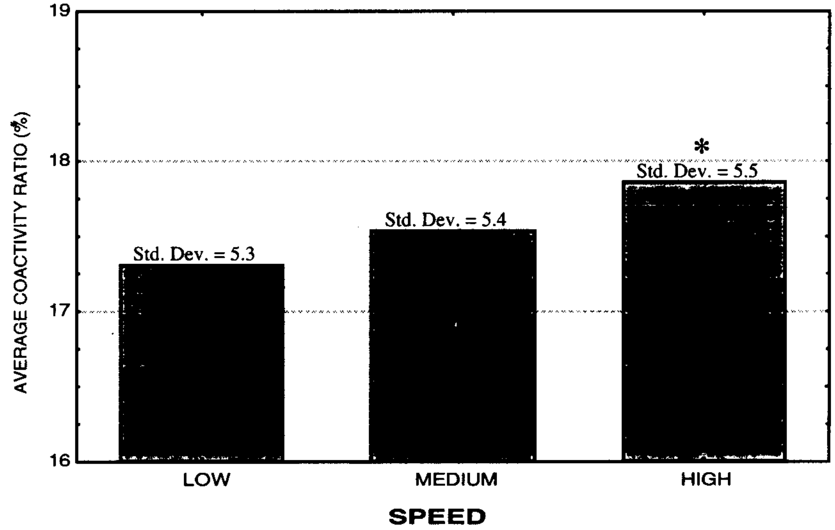
* Lower > Lift at $\alpha < 0.05$

^ Low weight symmetric > high weight symmetric at $\alpha < 0.05$

Fig. 5. Average coactivity ratio for task by symmetry by weight conditions. Statistical *post hoc* comparisons (Neuman-Keuls) were made *only* for the following matching conditions: (1) symmetry levels within each of the matching weight and task combinations (e.g., asymmetric low weight lower vs. symmetric low weight lower), (2) task levels within each matching symmetry and weight levels (e.g., lift symmetric medium weight versus lower symmetric medium weight), and (3) weight levels within each matching symmetry and task combinations (e.g., high weight symmetric lift vs. low weight symmetric lift).

of the trunk. It is possible that under free-dynamic conditions, the internal oblique muscles play a more important role in task execution than during controlled exertions, and act as synergists to the erector spinae more than the latissimus dorsi. One reason for such discrepancy could be that under controlled exertions, the subject is usually secured at the pelvis region which is very close to the sites of the origin of the lateral fibers of the internal oblique muscles (lumbar triangle), hence, possibly hindering their full activation potential. The internal obliques have also been shown to have increased activation at higher speeds which stems from their important role in maintaining the stability of the back (33).

The flexor muscles also played an important role in task execution, especially under asymmetric conditions. During asymmetric conditions, all muscles had substantial elevation in their activities, especially the left side muscles, when compared to symmetric conditions. This finding agrees with other studies that showed a similar increase in EMG for muscles that are on the contralateral side of the load (23,34, 35).



* High speed > low speed at $\alpha < 0.05$

Fig. 6. Average coactivity ratio under each of the three speed levels. Only the high speed level was found significantly different than the low speed level.

In general, the magnitudes of muscle activities under lowering conditions were lower than those observed during "matched" lifting conditions. This finding is consistent with that reported by Marras and Mirka (17), where concentric isokinetic exertion EMGs were consistently higher than those observed under "matched" eccentric conditions with the same speed levels (opposite direction). These differences in trends were anticipated since several researchers have shown the EMG/force and force/velocity relationships under eccentric conditions to be markedly different than those observed under concentric conditions (36–38). The exact cause of this difference in EMG magnitudes between eccentric and concentric conditions is still unclear; however, researchers have suggested that this phenomenon may be due to the efficient utilization of the elastic energy (passive components) inherent in the motor unit cross-bridges (38), which could lead to higher tension production during eccentric conditions. Passive tissues (e.g., ligaments) could also have played a role in the observed difference(s) between lifting and lowering conditions. Under lowering tasks, the ligaments may have shared the loads with the muscular system more than under lifting tasks.

Speed seemed to slightly increase the NEMG of most trunk muscles, particularly under lowering tasks, as well as the coactivity ratio. The magnitude of these effects was not as pronounced as had been shown by earlier studies (16,17,26). However, these studies were mostly performed under controlled conditions and with constrained hip/legs and shoulders, which could explain the observed discrepancy. It could be that under unconstrained conditions other joints of the body, besides the lower back, such as the hips and shoulders may compensate for the role of speed during lifting.

During the asymmetric lifts/lowers, the coactivity ratio was, in general, considerably higher when compared to symmetric conditions. This finding emphasizes the importance of including all the relevant muscles in exploring internal response under lifting tasks. Under these conditions, reducing the muscular response to a single equivalent muscle (12) would have resulted in obscuring a great portion of the "complete" muscular response, and would result in severe underestimation of the corresponding internal loading. This may also have an implication to rehabilitation research that assesses low back patients using EMG activities. Ignoring the role of some trunk muscles could possibly lead to erroneous judgment about the rehabilitative status of the patient, since various muscles may respond differently depending on the required task. This study indicated that more complex tasks (i.e., asymmetric tasks) elicited more complex muscular responses. Therefore, it is suggested that muscular performance assessment of low back pain patients should not only be comprehensive in muscular representation, but also should include tasks that reflect the complex responses and synergies of the muscular system. Future research should consider the relative effectiveness of work hardening/exercise studies that may include symmetric and/or asymmetric lifting/lowering components. In addition, there is a further need for studies similar to the one presented here to fully understand what really "drives" the system and loads the spine.

Study Limitations

The main limitation of this study was the fact that the continuous EMG profile of each muscle during the dynamic tasks was normalized with respect the maximum activation level of that muscle (maximum EMG) obtained during MVC exertion at *one* static posture (22 degree flexion angle). This normalization scheme may be less than optimal under dynamic conditions and could introduce an error into the continuous dynamic EMG signal (39). This is mainly due to the relationship of the EMG signal to the length of the muscle and its velocity of contraction. However, since the main purpose of the study is to show the *relative* difference among various conditions (e.g., symmetric vs. asymmetric), it is expected that the potential bias introduced due to the choice of the normalization approach would be systematic across these conditions and would have minimal effect on the comparative nature of the study. It should be noted that the muscle activation patterns presented in this study do not represent muscle forces (6,7). Further processing is required to obtain muscle force estimation.

The manner in which the coactivity ratio was defined may not represent an optimal way of describing muscle coactivity, especially under complex (asymmetric) conditions. Under these conditions, it is difficult to discern which muscles are considered the primary movers and which are considered coactive.

The study did not consider the potential gender effect and was only limited in scope to the described conditions. Further research is warranted to expand the levels of weights, speeds, and tasks as well as to consider neuromuscular response of female volunteers under these conditions.

CONCLUSIONS

This study investigated trunk muscular response under free-dynamic symmetric and complex asymmetric lifting and lowering tasks. The main findings were:

- Overall, the erector spinae and internal oblique muscles were the most responsive (had highest magnitudes) of all ten muscles. However, other muscles were also reactive, especially under asymmetric conditions
- Substantial muscular activities were observed in muscles that were on the contralateral side of the load.
- EMG magnitudes under lowering conditions were consistently lower than their corresponding (matched) lifting conditions. This may be due to the role of the inherent muscle passive components in producing tension during eccentric exertions, and/or may be due to the increased role of passive tissues under lowering conditions.
- In general, all the muscles monitored in the experiment responded, with varying degree, to the different experimental conditions. This was shown by the substantial coactive patterns observed under many conditions. Therefore, it is essential, to include multiple trunk muscles in modeling efforts of quantifying internal (and external) spinal loading, as well as in back rehabilitation research that has a focus on assessment of muscular performance.

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