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An electromyographic analysis of seated and standing lifting tasks

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The objective of this project was to compare the muscular effort exerted during manual lifting tasks performed in standing versus seated posture. Six male undergraduate and graduate students performed 12 different static and dynamic lifts in both sitting and standing positions. During each effort electromyographic (EMG) data were collected on four muscles groups (low back, upper back, shoulder, and abdominals). Four contractions were designed to elicit maximum muscular effort in the four groups being monitored. The remaining data were then expressed as a percentage of maximum EMG. Each subject performed the following: maximum static lift when sitting; maximum static lift when standing; sitting, static lift with 15·9 kg; standing, static lift with 15·9 kg; dynamic sit–forward lift with 15·9 kg, dynamic stand–forward lift with 15·9 kg, dynamic sit–twist with 15·9 kg, dynamic stand–vertical lift with 15·9 kg. Each of the lifts was performed with a wooden tray with slotted handles. Root mean square (RMS) values of the EMG data were calculated for three second periods. EMG activity in the low back, upper back, and shoulder was greater during sitting lifting than during standing lifting. The sit–twist lift resulted in the highest EMG in the abdominal muscles. Dynamic lifts resulted in more muscle activity than did static lifts. From these data it was concluded that sitting–lifting results in greater stress in the low back, upper back, and shoulders than does lifting while standing.

1. Introduction

Many of today's industrial jobs involve inspection of product and assembly of parts while in a sitting position (Eklund *et al.* 1983). While the purpose of sitting is to relieve stress imposed by the job, people who sit for prolonged periods experience more back pain than those not confined to their seats (Magora 1972). Indeed, it is known that unsupported sitting results in disk pressures 40% greater than during standing work (Nachemson 1981). The additional demands of lifting, results in even greater disc pressures (Andersson *et al.* 1975, Nachemson 1981).

Back pain is not the only problem that results from repetitive work in a sitting position. Granstrom and colleagues (1985) reported that nearly one-half long-term sick leave was due to musculoskeletal problems. Almost as many neck and shoulder problems were found as back complaints. Symptoms of the neck and shoulder region are common in both the general population and the industrial population (Allander 1974, Kvarnstrom 1983). A number of investigators have suggested a link between local muscular strain during work and these occupational disorders (Bjelle *et al.* 1979, Hagberg 1982, Maeda 1977, Westgaard and Aaras 1984). The postural demands of the job may place these regions in an unfavourable position, and therefore become an important factor in the development of shoulder and neck problems (Kuorinka and Viikari-Juntura 1982). Inspection and assembly jobs performed while sitting result in low metabolic demands, yet due to their repetitive nature result in frequent complaints of shoulder and neck pain (Laville 1985).

The relationship between sitting and standing lifting was previously investigated using the psychophysical method by Yates and Karwowski (1987). When sitting, subjects lifted 8–25% less than when in standing positions (average difference of 16%). While these data suggest that subjects prefer to handle less weight during sitting lifting, they do not offer any reasons for those limits.

The electromyogram (EMG) has been used for many years to determine the muscle activity during numerous standing and sitting postures and tasks (Andersson and Ortengren 1984, Floyd and Silver 1955, Granstrom *et al.* 1985, Kumar and Davis 1983). However, very little EMG data during seated lifting tasks are available. The data that have been published involve one-handed lifts during sitting with no corresponding lifts during the standing position (Schultz *et al.* 1982, Andersson *et al.* 1975). This project was designed to make direct comparisons between sitting and standing lifts by having subjects perform the same lifts in both positions.

2. Methods and procedures

2.1. *Subjects*

Six physically active, male undergraduate and graduate students participated as subjects in this project. Each subject was cleared by a physician prior to participation and signed a Informed Consent Form approved by the University of Louisville Human Studies Committee. No history of low back pain or other musculoskeletal problems existed in any subject. Age, anthropometry, and strength characteristics of the subjects are shown in table 1.

Table 1. Age, anthropometry, and strength characteristics of the subjects ($n=6$).

Variable	Mean	SD	Range
Age (years)	26·8	5·0	22–32
Body weight (kg)	69·5	8·3	56–79
Height (cm)	175·1	8·9	162–190
Shoulder height (cm)	143·6	7·7	134–156
Hip height (cm)	93·5	6·2	85–105
Arm span (cm)	178·4	9·5	165–192
Arm length (cm)	77·4	4·9	70–86
Forearm length (cm)	47·6	3·1	43–53
Shoulder breadth (cm)	43·7	1·6	41–46
Knee height (cm)	51·9	4·5	45–59
Isometric arm strength (N)	422·9	88·0	289–567
Isometric leg strength (N)	1734·8	335·1	1250–2238
Isometric back strength (N)	1023·4	393·8	538–1905
Isometric composite strength (N)	1513·2	323·3	1110–2149
Grip strength (N)	221·0	34·7	187–289

The individuals used in this study had been subjects in a prior study using the psychophysical method in both sitting and standing lifts. Each subject had completed six training sessions using the psychophysical method of lifting. In addition, each subject had participated in eight experimental sessions using the psychophysical method. The training sessions and experimental sessions used lifting positions identical to the ones described here. Therefore, each subject was well versed in the lifting technique.

Table 2. Abbreviations and descriptions of static and dynamic tasks performed by subjects.

TE Max:	maximum static trunk extension (trunk angle=45°)
HA Max:	maximum static horizontal abduction of the shoulder
SA Max:	maximum static abduction of the shoulder (in frontal plane)
Twt Max:	maximum static twist of the trunk from 45°
Sit Max:	maximum static lift while sitting
Sta Max:	maximum static lift while standing
Sit S15:	static sitting lift with 15·9 kg
Sta S15:	static standing lift with 15·9 kg
Sit F15:	dynamic sit-forward lift with 15·9 kg
Sta F15:	dynamic stand-forward lift with 15·9 kg
Sit Twt:	dynamic sit-twist lift with 15·9 kg
Sta V15:	dynamic stand-vertical lift with 15·9 kg

2.2. *EMG testing positions*

Each subject performed 12 tasks, four maximum static contractions, four static lifts (two submaximal and two maximal), and four dynamic lifts (table 2). The four maximum static contractions were designed to elicit maximum muscular activity in each of the four muscle groups being recorded by the EMG. For example, maximum static trunk extension (TE Max) resulted in maximum activity of the erector spinae muscles, while maximum static horizontal abduction of the shoulder resulted in maximum EMG activity in the trapezius and the rhombus (abductors of the scapula). Maximum static abduction of the shoulder (in the frontal plane) involved the deltoid, while the static twist lift required the use of the internal and external oblique muscles. The EMG recorded during the maximum static contractions were used to normalize (i.e., express as a percentage of the maximum) the EMG activity produced during the four submaximum dynamic lifts. This provided a method for making comparisons between lifting tasks. The root mean square (RMS) was the EMG parameter used to quantify muscle activity.

The EMG was also recorded during a maximum static lift in the vertical plane while sitting and standing in order to understand the relationship between these two positions. During the maximum lift, the subject held the tray approximately 10 cm in front of his body with his elbows flexed 90°. The investigator then resisted any upward tray movement while the subject attempted to lift the tray vertically.

EMG data were also collected while each subject held 15·9 kg in the sitting and standing positions. For these two tasks, the tray was held approximately 10 cm in front of the body with the elbows flexed 90°. Comparison of these EMG values with the dynamic lifts helped discern the impact that movement has on the EMG signal and the stress of the lift.

The four dynamic lifting positions used are illustrated in figure 1 and were identical to those reported previously (Yates and Karwowski 1987). The table used during seated lifting was 85 cm high, with a barrier 2·5 cm in height located 38 cm in front of the table edge. This barrier required the subject to lift the tray when moving it to the forward position (sit–forward, 1 (A)). The subject was seated on an adjustable, rotating stool with a back rest and no arm rests. Each subject was allowed to choose their own seat height just as would occur in industry with adjustable stools. In addition, a height-adjustable foot rest was provided so that individual adjustments could be made by each subject. Subjects were allowed to position the stool as near the table as they desired. The velocities of the lifts were not controlled experimentally but were left to the subjects.

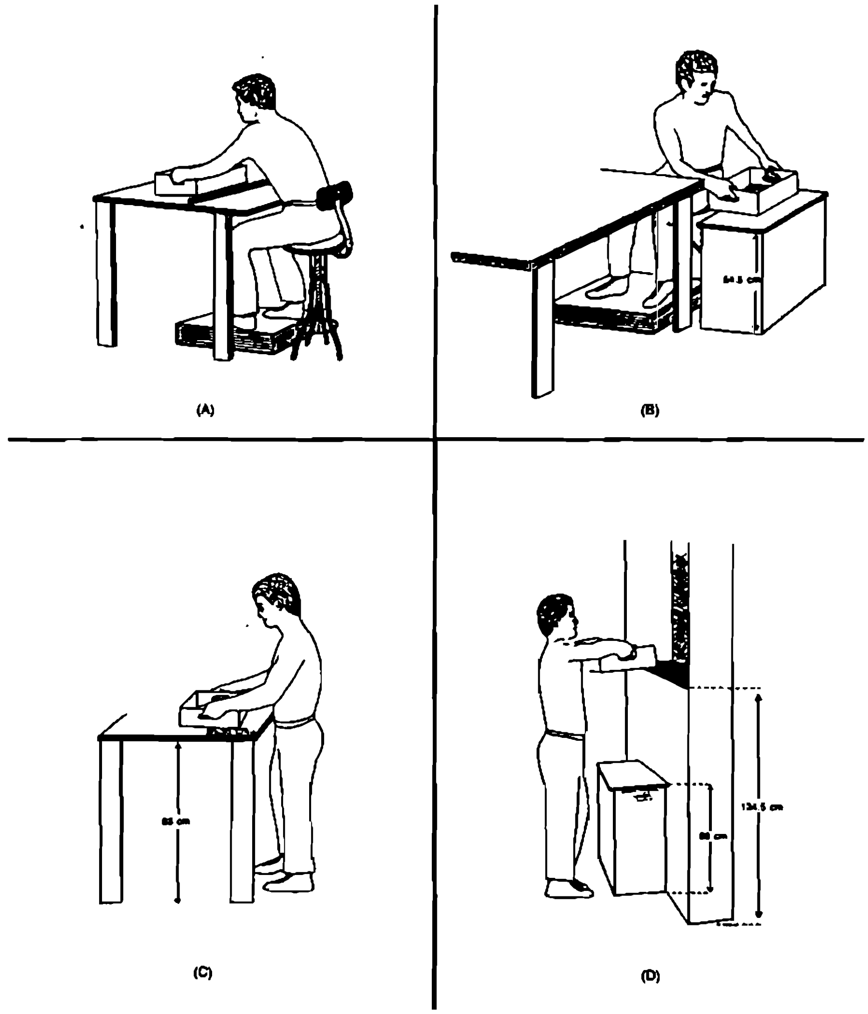

Figure 1. (A) Experimental set-up during sit-forward lift.
(B) Experimental set-up during sit-twist lift.
(C) Experimental set-up during stand-forward lift.
(D) Experimental set-up during stand-vertical lift.

To perform the stand–forward lift (1(C)), the subject stood at the same table and lifted the tray from the near position over the barrier to the far position. The stand–vertical lift required the subject to lift the tray from a height of 86 cm to a shelf 134·5 cm high (1(D)). During the standing lifts the subjects were allowed to choose how far or near they stood to the table and the tray just as they did during the sitting lifts.

When performing the sit–twist lift (1(B)), subjects lifted from a shelf located 30·5 cm below table height. In order to perform the lift, subjects were required to twist their upper body while keeping their feet in a forward position. The subject placed the tray on the table near the front edge.

During the experiment, subjects lifted a tray (45·7 × 30·5 × 12 cm) with slotted handles which contained 15·9 kg of flat lead pieces. Due to the complexities associated with recording EMG during dynamic lifts, we attempted to sample the EMG signal at the same point during each of the six lifts. A microswitch was embedded in the handle of the tray lifted by the subjects. As the subjects lifted the tray, he pressed the button of the microswitch. This resulted in a voltage spike being recorded on the FM recorder along with the EMG. This voltage spike was then used to trigger the collection of the data during the digitization process. This procedure ensured that the subject was in the same position when the EMG data were measured, thus increasing reliability of the EMG data.

Each subject completed six repetitions of the dynamic lift. In the case of the sit-forward and stand-forward lifts, three repetitions were forward lifts, and three repetitions were backward lifts. During the sit-twist and stand-vertical lifts, only the concentric lifts were performed by the subjects. A helper lowered the tray for the next lift. The RMS for the dynamic lifts represented the average RMS calculated for each individual lift.

Even though the number of lifts seems high, this procedure was not difficult for the subject to complete. Each static contraction lasted approximately 5 s and the number of dynamic lifts was small; 1–2 min was allowed between tasks so that the subject experienced little, if any, fatigue.

2.3. *Electromyogram data recording and analysis*

A Transkinetics telemetry system was used to collect EMG data. Small transmitters were attached to four muscle groups: erector spinae of the low back (L4–L5 region), over the trapezius and rhomboids of the upper back (T4–T5 region), deltoids of the shoulder (half-way between acromion process and insertion of deltoid), and the external and internal oblique muscles of the abdominal region (3 cm above and anterior to iliac spine). Prior to attaching the electrodes, the skin was cleansed with alcohol and skin resistance was reduced by abrasion. A volt-ohm meter was used to determine the resistance between electrodes. Site-preparation was deemed acceptable if the resistance was below 15 000 ohms. Pregelled, disposable, silver-silver chloride electrodes with a 1 mm diameter surface area were attached to each site. Signal quality was checked visually on an oscilloscope.

EMG data were recorded on a FM recorder (Teac R-71), bandpass filtered from 9 to 480 Hz (−3db points), and then digitized at the rate of 500 samples/second on a Apple-Issac data acquisition system. The root mean square (RMS) was calculated on a three second EMG sample. RMS was calculated on all lifting activities and then normalized to maximum activity for each specific muscle group. In other words, the EMG value produced by the low back muscles during the Sit F15 dynamic lift was divided by the EMG value produced in the low back during the maximum static trunk extension effort.

All EMG data were collected during a single day. This design eliminated the problems that occur when analyzing the EMG with multiple electrode applications. Static tasks were used to compare the changes in the EMG that occurred during movement. Movement during EMG recording can cause a variety of problems since the electrodes slide over the surface of the muscle and thus change their relative position to specific muscle fibers. During static tasks each subject held the weight steady while a three second EMG sample was collected.

2.4 *Data analysis*

EMG data were normalized by dividing the absolute EMG by the maximum EMG value generated during maximum static tasks. These data were then analysed using a repeated measures analysis of variance. *Post hoc* comparisons were performed using the least significant difference method (LSD). Results were considered significant when $p<0{\cdot}05$.

3. Results

Analysis of the normalized data revealed a significant muscle by position interaction. Therefore, an ANOVA was performed on individual muscle groups: low back, upper back, arms, and abdomen. In each case, a significant position effect was found. *Post hoc* comparisons revealed a number of significant differences which will be discussed below. Table 2 contains the list of abbreviations used in the tables and figures.

Table 3. Low back EMG values expressed as a percentage of maximum activity for various lifting tasks.*

Sit Max	Sta Max	Sit Twt	Sit F15	Sta V15	Sit S15	Sta F15	Sta S15
74·3	63·5	41·4	40·5	33·8	30·7	30·3	25·3
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			- - - -	- - - -			
				- - - -	- - - -	- - - -	

*Numbers connected by broken rules are not significantly different from each other; see table 1 for list of abbreviations.

3.1. *Effect of lifting position on low back*

Table 3 shows the results of the *post hoc* comparison for the EMG data collected on the low back muscles. The EMG activity generated during the maximum static sitting task was significantly greater than that generated during the maximum static standing contraction. Both maximum static tasks elicited significantly more EMG activity than any other task as would be expected. The sit–twist 15 task differed significantly from all other tasks except the sit–forward 15. The sit–forward 15 task resulted in more EMG activity than any standing task. The sit–forward 15 dynamic was also greater than the sit–static task, and the standing dynamic tasks were greater than the standing static task. Figure 2 gives a graphical picture of the EMG data.

3.2. *Effect of lifting position on upper back*

Table 4 shows the results of the *post hoc* comparisons for the EMG data collected on the upper back muscles. As was true for the low back, the maximum static sitting task and maximum static standing task generated the largest EMG activity, however, in contrast to the low back these two tasks did not differ significantly from each other. Overall, there were not as many differences between tasks in the upper back as in the low back region. Even so, the sit–forward 15 task elicited significantly more EMG signal than the stand–forward 15 lift. For this muscle group there was no significant difference between the dynamic and static tasks for either sitting or standing tasks. The sit–twist 15 resulted in the least EMG activity.

3.3. *Effect of lifting position on shoulder muscles*

Table 5 contains the statistical analysis for the shoulder (deltoid) muscles. A

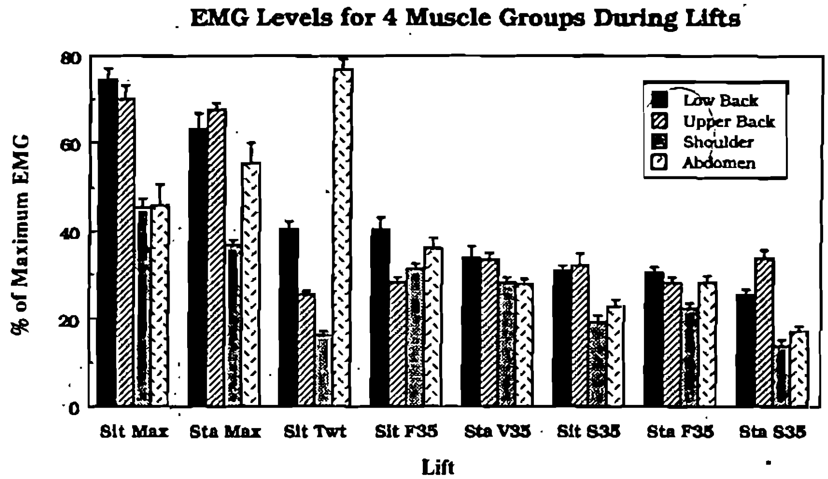

Figure 2. EMG activity during different lifts for four muscle groups expressed as a percentage of maximum EMG activity. Abbreviations for lifts can bee seen in Table 1.

Table 4. Upper back EMG values expressed as a percentage of maximum activity for various lifting tasks.*

Sit Max	Sta Max	Sit F15	Sta S15	Sta V15	Sit S15	Sta F15	Sit Twt
70·0	67·7	36·7	33·5	33·3	32·0	28·0	25·2
- - - - -	- - - - -						
		- - - - -	- - - - -	- - - - -	- - - - -		
			- - - - -	- - - - -	- - - - -	- - - - -	

*Numbers connected by lines are not significantly different from each other; see table 1 for list of abbreviations.

statistically significant difference was found between EMG activity for maximum static sitting (Sit Max) and maximum static standing (Sta Max) tasks. Once again, the sitting tasks required more muscle activity than did the standing tasks for the 15·9 kg tray lift. The muscle activity during dynamic work exceeded the activity during static work for both sitting and standing lifts.

3.4. *Effect of lifting position on abdominal muscles*

The abdominal muscles actually consisted of the external and internal oblique muscles. These muscles are involved with trunk rotation as well as trunk flexion. As one can see in table 6, the sit–twist 15 elicited the greatest activity for this muscle group ($p<0{\cdot}05$). The dynamic sit–forward 15 (Sit F15) task was significantly greater than the static–sit 15 (Sit S15) task however, few other differences were noted for the abdominal group.

4. Discussion

The data presented here suggest that lifting tasks performed in a sitting position result in more muscle activity, hence more stress, then those performed in a standing position. This was true for three of the four muscle groups studied (low back, upper back, and shoulders). In general, this relationship was true for both submaximal and

Table 5. Shoulder EMG values expressed as a percentage of maximum activity for various lifting tasks.*

Sit Max	Sta Max	Sit F15	Sta V15	Sta F15	Sit S15	Sit Twt	Sta S15
45·7	36·8	31·3	28·0	22·3	19·0	16·3	14·0
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*Numbers connected by lines are not significantly different from each other; see table 1 for list of abbreviations.

Table 6. Abdominal ENG values expressed as a percentage of maximum activity for various lifting tasks.*

Sit Twt	Sta Max	Sit Max	Sit F15	Sta F15	Sta V15	Sit S15	Sta S15
76·8	55·5	46·0	36·2	28·2	27·7	17·2	17·0
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		---	---				
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				---	---	---	---

*Numbers connected by lines are not significantly different from each other; see table 1 for list of abbreviations.

maximum activities. Therefore, changing from a standing position to a sitting position requires the involved muscles to increase their energy output to perform the same level of work. These findings are in agreement with other published reports which show that intervertebral disc pressure is greater when sitting than when standing (Schultz *et al.* 1982, Andersson *et al.* 1975).

The findings presented here are also supported by previously published work from our laboratory (Yates and Karwowski 1987). Using the psychophysical method of determining the maximum acceptable weight of lift, subjects selected 1·4 kg less weight during sitting lifting when compared to the standing lifting at a frequency of one lift per min. This self-selected value indicates that subject perceives more stress in the sitting position, therefore, he is willing to handle less weight. These data support the concept that muscle tension in the low back, upper back and shoulders play a role in determining the psychophysical lifting limits.

When an individual moves from a standing posture to a sitting posture, the pelvis rotates so that the lumbar curve flattens (Mandal 1981). This change in the pelvis and lumbar curve probably accounts for the increase in muscle activity seen in the low back when moving from a standing to a sitting position. It has been previously documented that altering the shape of the lumbar curve will affect the EMG levels of the erector spinae (Occhipinti *et al.* 1985). It is also important to note that even though the stool was equipped with a back rest, it was not used. The demands of the task were such that it was not possible for the subject to use the back rest for every lift, therefore, it was not used at all. Sitting without a backrest results in more EMG activity than when a backrest is used (Andersson *et al.* 1975).

The increased EMG activity in the upper back and arm region may be due to the increased distance of the lift imposed upon the subject while sitting. When the subject performed the stand–forward lift, he was able to move forward to brace himself against the edge of the table, thus keeping the horizontal distance of the lift to a minimum. However, when the subject performed the sit–forward lift, he was unable to move forward against the table, thus increasing the distance of the lift (i.e., the distance between the hands and the torque producing muscles in the low back). The force generated by the back muscles increases with the forward distance of the lift (Andersson *et al.* 1976, Schultz *et al.* 1982). Thus even though the requirements of the lift were the same, the biomechanical position of the subject changed from the standing to the sitting position. This is one of the problems encountered during sitting lifting. It is important to note that the work station was fitted to each individual subject. That is each subject adjusted the height of the stool and foot rest before lifting. Thus while the sitting and standing lift positions were not identical, they were similar to what would occur in an industrial situation.

The finding that dynamic lifts generated more EMG activity than did static lifts should be viewed with caution. Myoelectric recordings during dynamic activity is complicated because of changes in the length of the muscle. In addition, during dynamic activity the EMG electrodes slide over the surface of the muscle and thus change their position relative to the muscle in question. This change in position can have a great deal of effect on the results (Basmajian and DeLuca 1988). This is of more concern when EMG data is collected over several days requiring multiple electrode applications. When multiple electrode applications are made, the exact site of the electrode cannot be duplicated, therefore variability is introduced into the data. This problem was avoided in the present project by collecting all data during a single session. The increased EMG activity during the dynamic lift in this project is probably due to the forward movement of the weight that occurred during the lift, thus increasing the length of the lever arm in the back (Andersson *et al.* 1976). It is also important to understand that during dynamic lifts the biomechanical position changes, thus comparisons to static lifts must also be made with caution.

4. Conclusions

The results of this study suggest that when static or dynamic lifts are performed in a sitting position, more muscle activity occurs in the back (upper and lower) and shoulder muscles than when similar lifts are performed in a standing position. EMG levels are not different in the abdominal muscles. From this information it is concluded that lifting in a sitting position is more stressful than lifting when standing.

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