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Trunk muscle activities during asymmetric twisting motions

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Abstract

Axial twisting of the torso has been identified via epidemiologic studies as a significant risk factor for occupationally-related low back disorders. However, only recently have biomechanical studies been able to describe how twisting is accomplished through the use of the trunk musculature. These studies have been performed on subjects whose torso twists were performed in an upright posture. In this study, the electromyographic activity of ten trunk muscles was observed while 12 subjects performed twisting exertions in three different trunk postures. These postures included upright twisting, twisting while the trunk was flexed in the sagittal plane, and twisting while the trunk was flexed and rotated asymmetrically. In addition, twisting velocity and direction of motion were changed under the experimental conditions. Under upright twisting conditions, the twisting torque was generated easily and relatively efficiently through the employment of the oblique (internal and external) and latissimus dorsi muscles. When the trunk was flexed the activity of erector spinae muscles increased (about 10–15%) while the external oblique activity decreased (about 3–5%). Twisting while in asymmetric bent postures was accomplished with a reduction in oblique and latissimus dorsi muscle activities (approximately 5%) while the erector spinae muscle activity remained elevated. The change in muscle activity needed to balance the torso during twisting while bending also increased the amount of lateral torque that was produced by the trunk. These findings suggest that studies observing trunk muscle activities and trunk loading while subjects were in upright postures should be interpreted with caution when evaluating the activity of the trunk during occupational activities. Since many occupational twisting tasks are performed in awkward, asymmetric postures, application of results from upright twisting studies might underestimate the risk of these activities. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: Twisting motions; Compled trunk motions; Muscle activity; Electromyography

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1. Introduction

Axial twisting of the torso has been identified in numerous epidemiologic studies as a significant risk factor for occupationally-related low back disorders (LBDs) [1,6,8,14]. The U.S. Department of Labor [17] reported that twisting and turning was associated with a LBD event by 33% of workers. Snook [16] reported that 18% of workers' compensation costs were associated with twisting activities. Marras and associates [8] found that risk of low back disorder increased when twisting velocities of even very low magnitude were present in a job.

Even with this level of recognition about the risk associated with twisting, the biomechanical mechanisms by which the trunk musculature generate a twisting motion are poorly understood. Studies of the electromyographic (EMG) activity of the trunk muscles have described significant muscle coactivation [2,3,10,18] during twisting while standing. Carlsoo [3] noted that many of the coactivating muscles were not oriented in such a way that they should contribute to twisting torque. Pope et al. [12] reported the large amounts of EMG activity occurred in the agonist internal and external oblique muscles during twisting. They also noted a high degree of coactivation of the antagonist muscles as well as the erector spinae and rectus abdominus muscles. In a separate publication Pope et al. [13] found the bilateral symmetry of the internal oblique and rectus abdominus muscles changed significantly when the trunk was pre-rotated to either side. Furthermore, the maximum torque increased when the trunk was pre-rotated away from the direction of the twisting effort. McGill [10] observed the EMG activity in six trunk muscles while subjects performed isometric and isokinetic (30 and 60°/s) torsional exertions. Sig-

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nificant latissimus dorsi activities were noted in the study, and myoelectric activity was lower in the isokinetic trials than isometric exertions. Marras and Granata [9] observed the activity of 10 trunk muscles and modeled the loading imposed on the spine during twisting. They found that even though subjects were asked to perform pure twisting motions, significant moments were generated in the lateral and sagittal planes of the body. They also observed 62% greater levels of coactivation of the trunk muscles relative to a comparable lifting task. This coactivity resulted in significant increases in compression and lateral shear forces imposed on the spine once any degree of motion was employed during the exertion.

Studies of EMG activity while twisting in an upright seated position have also been performed. Van Dieen [18] explored muscle activation patterns during seated twisting and have found that fatigue caused a shift in activity to the more laterally situated muscles. Kumar et al. [7] reported that the agonist muscles contributed to 65% of the total electromyographic output during seated twisting, whereas the antagonists stabilizers contributed 35%.

In all of the previously mentioned studies that observed the muscle activity associated with twisting, the subject has been positioned in an upright standing or seated posture and asked to twist. However, under work-related conditions it is most common to observe workers producing a twisting motion while their trunk is flexed forward or asymmetrically [8]. Thus, a void exists in the knowledge base in that we do not know how the trunk muscles behave during realistic twisting postures.

The objective of this study was to document myoelectric activity associated with the trunk musculature when torsional exertions were performed with the trunk in an upright standing posture as well as in flexed and asymmetric postures. Since previous studies [8] have also documented increases in risk associated with increasing twisting velocity, the effect of changing twisting velocity was also observed in this study. The experimental trunk positions and trunk motion characteristics were derived from an industrial data base and represent trunk motion characteristics commonly seen in industry [8].

2. Methods

2.1. Subjects

Twelve male subjects, 21–31 years of age participated in the experiment. None had a history of low back disorder and each participated in a training session on a date prior to experimental testing in order to become familiar with the experimental protocol. Gross anthropometric characteristics were collected for all subjects. Mean weight (SD) of the subjects was 76.4 (8.4) kg and mean stature was 177.0 (16.4) cm.

2.2. Apparatus

The experimental apparatus used to test the subjects and control the experimental conditions is shown in Fig. 1. Subjects were placed within a twisting reference frame (TRF) and were asked to apply axial torque to a yoke that was placed around their back, shoulders, and chest. The position of the torso could be adjusted independently of the pelvis using the TRF. The yoke was connected to a Kin/Com isokinetic dynamometer whose motion axis was aligned vertically with the spine. The dynamometer provided an estimate of axial torque and also controlled the position and velocity of the twisting motion. Precise measurements of three-dimensional, trunk, reaction forces and moments were recorded from a force plate (Bertec™ 4060A, Worthington, USA) upon which the subject stood. A pelvic support structure limited twisting motion to the trunk while transferring three-dimensional trunk kinetics directly to the force plate [5]. A computer was employed that graphically displayed the measured force plate torque in real-time so the subject could monitor the amount of torsional moment they were exerting. In addition to the subject's twisting torque, the monitor also displayed a target level and two tolerance

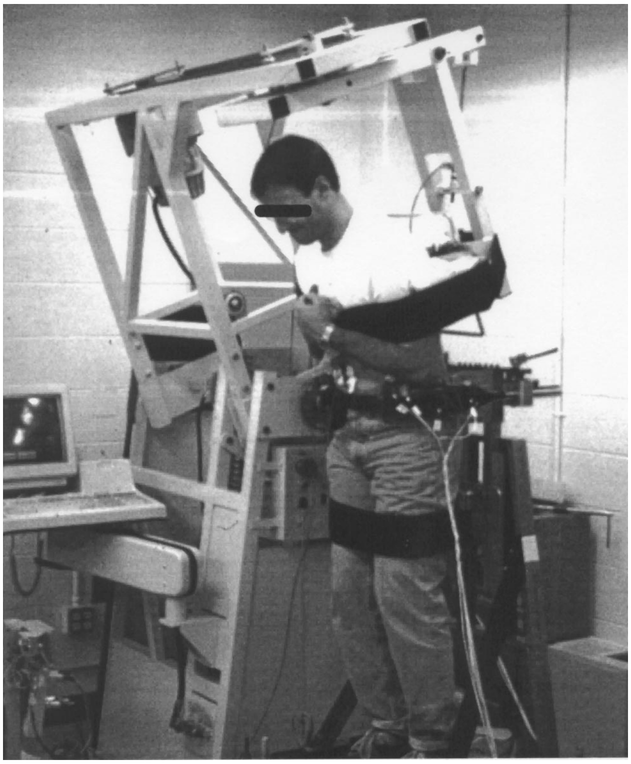

Fig. 1. Subject in the twisting reference frame.

lines indicating the envelope of acceptable variation (± 5%) from the designed level.

Electrical activity of the trunk muscles was collected using surface electromyography (EMG) during each exertion. Bipolar Ag-Cl surface electrodes were affixed to the skin over the muscles and connected to lightweight preamplifiers (amplified the signal 1000 ×) located near the electrodes. The following is the description of the electrode position: right and left erector spinae: located directly over the largest muscle mass found by palpation, approximately 4 cm from midline of the spine; right and left latissimus dorsi: most lateral portion of the muscle at the level of T9; right and left rectus abdominus: 3 cm from the midline of the abdomen and 2 cm above the umbilicus; right and left external oblique: 10 cm from the midline of the abdomen and 4 cm above the ilium at an angle of 45°; and right and left internal obliques: 4 cm above the ilium in the lumbar triangle (dorsal side of trunk) at an angle of 45° to the midline of the spine. The electrode pairs had an inter-electrode distance of 3 cm. The signal passed through shielded cables to a hardware rack where they were further amplified (52,000 ×), high pass filtered at 30 Hz and a low pass filter at 1000 Hz. The signals were then rectified and integrated via a 20 ms sliding window.

All LMM, force plate, and electromyographic signals were digitized at 100 Hz using an analog-to-digital (A/D) converter and recorded on a micro-computer. A separate microcomputer was used to control the dynamometer in the twisting reference frame.

2.3. Experimental design

2.3.1. Independent variables

The experimental task consisted of two independent variables including twisting posture and twisting velocity. Twisting was performed in three postures. These postures consisted of: (1) an upright posture; (2) a 35° flexion in the sagittal plane (flexed posture); and (3) a combined 35° flexion in conjunction with a 15° clockwise axial rotation (asymmetric posture). The subjects attempted to maintain all twisting exertions at a 40 Nm level. Trunk twisting velocity was controlled isokinetically and isometrically (0°/s). Isometric exertions were performed at three twisting angles [20° clockwise (axial rotated to the right), 0° (neutral or not-twisted), and 20° counter-clockwise (axial rotated to the left)]. The isokinetic velocities were performed at 10 and 20°/s over the range of 20° clockwise to 20° counter-clockwise. All twisting conditions were also observed in each posture. All exertions were performed in both clockwise and counter clockwise directions.

2.3.2. Dependent variables

Normalized EMG of ten trunk muscles served as dependent measures. The muscles sampled were the right and left pairs of the latissimus dorsi (LATR, LATL), erector spinae (ERSR, ERSL), rectus abdominus (RCAR, RCAL), external oblique (EXOR, EXOL) and the internal oblique (INOR, INOL). The EMG signals were processed and normalized using activity levels collected during MVC exertions for the given postures. In other words, the EMG signals were normalized relative to the maximum EMG signal observed for each muscle in each of the three torso postures (upright, flexed, or asymmetric flexion).

2.4. Procedure

Surface electrodes were placed over the muscles of interest using standard application procedures and the quality of the signals were verified. Maximum integrated EMG values for the muscles of the trunk were established via MVC exertions. In order to obtain the maximum EMG levels for those muscles which run primarily in the vertical direction (erector spinae and rectus abdominus), the maximal flexion and extension exertions were performed by the subject while in the twisting reference frame. Similar exertions were performed in the clockwise and counter-clockwise twisting directions as well as right and left lateral directions to achieve maximum EMG levels from the oblique musculature (latissimus dorsi and internal and external obliques).

There was a rest period of 2 min between each trial to minimize the effects of fatigue. Maximum and submaximum, isometric, torsional exertions were performed at each twisting position. Isokinetic exertions were performed from a pre-rotated position of 24° through a symmetric posture to a final position of 24° on the opposite side. Clockwise and counter-clockwise isokinetic exertions were collected at maximum and submaximum torsional levels. During submaximal exertions, if the subject failed to maintain the applied torque between the tolerance limits, the trial was repeated. All exertions were performed in random order while positioned in each of the three torso postures. In addition, the order of the trunk posture conditions was counter balanced across all subjects.

2.5. Analyses

The normalized EMG activities from the ten trunk muscles were statistically analyzed to determine: (1) the level of activity of the muscles, (2) which muscles were responsible for changes in the experimental variables (i.e. posture, velocity, position), (3) the onset time of the muscle activity normalized relative to the exertion duration, and (4) onset time of the maximum muscle activity normalized relative to the exertion duration. Maximal trunk torque was also described and statistically analyzed to develop an appreciation for the magnitude of torques that could be exerted by the trunk. Formal statistical analyses consisted of univariate analysis of variance (ANOVA) that evaluated statistical significance associated with the individual activities of each muscle. The specific differences associated with the statistically significant results were determined via Tukey post-hoc analyses.

3. Results

Table 1 summarizes the statistically significant kinetic and muscle activities trends observed in this study. Statistically significant differences in the magnitude of the twisting and lateral moment were observed as a function of the three postures. Even though the average moment generated over each entire exertion was controlled through feedback, the upright position resulted in the greatest peak twisting moment as shown in Fig. 2. Fig. 2 also shows that peak lateral moment was greater for the flexed and asymmetric postures as compared to the upright posture. The twisting moment was greater in the upright posture, whereas lateral moment generation was less in this posture. Thus, there appears to be a tradeoff between peak twisting moment magnitude and peak lateral moment magnitude among the three postures. The time at which the peak moment occurred also varied as function of posture. The peak twisting moment occurred approximately 10% later into the exertion under the upright posture condition compared to the other two postures.

Fig. 3 indicates that there was a statistically significant difference in the magnitude of the twisting moment generated as a function of the interaction between trunk velocity and posture. This figure indicates that, in general, upright twisting conditions produced greater peak moment under dynamic conditions as compared to static conditions. In addition, the condition that produced the lowest peak twisting moment under dynamic conditions was the asymmetric posture, whereas the lowest peak twisting moment was produced generally under the flexed static posture.

Table 1 also indicates the statistically significant differences in muscle activities that occurred as a function of the experimental conditions. The muscle activities were evaluated as a function of maximum and average activity level as well as the onset time of the activity and onset time of the maximum activity (relative to the length of the exertion). This table indicates that several significant differences in activity occurred as a function of the posture assumed during the twisting exertion. The muscles most affected by the changes in posture were the erector spinae and abdominal muscles. When the interaction of posture and velocity was considered, the right latissimus dorsi, both erector spinae, both internal oblique, left external oblique, and the right abdominal muscles exhibited statistically significant responses.

The erector spinae muscles were the most responsive to changes in posture and the posture–velocity interaction. The maximum and average activities responded in a significantly different manner to both of these changes,

Table 1
Summary of statistical significance for the kinetic variables and muscle activities as a function of the various experimental conditions

Effect	Kinetic variables		
	Maximum sagittal trunk moment	Maximum lateral trunk moment	Maximum twisting trunk moment
Velocity (Vel)	0.01	0.79	0.0001
Posture (Pos)	0.09	0.002	0.0001
Vel*Pos	0.77	0.12	0.0001

Effect	LATR	LATL	ERSR	ERSL	RCAR	RCAL	EXOR	EXOL	INOR	INOL
Maximum muscle activity										
Velocity (Vel)	0.59	0.04	0.002	0.001	0.0001	0.001	0.0001	0.0001	0.01	0.07
Posture (Pos)	0.67	0.41	0.005	0.005	0.90	0.28	0.57	0.64	0.63	0.39
Vel*Pos	0.001	0.76	0.01	0.01	0.76	0.69	0.94	0.10	0.003	0.02
Timing of maximum muscle activity										
Velocity (Vel)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Posture (Pos)	0.89	0.41	0.15	0.01	0.38	0.81	0.14	0.74	0.28	0.39
Vel*Pos	0.38	0.32	0.17	0.02	0.01	0.62	0.12	0.56	0.60	0.11
Average muscle activity										
Velocity (Vel)	0.18	0.14	0.03	0.37	0.04	0.19	0.0001	0.0004	0.02	0.54
Posture (Pos)	0.55	0.46	0.001	0.001	0.91	0.40	0.17	0.42	0.35	0.31
Vel*Pos	0.0002	0.66	0.04	0.02	0.45	0.66	0.24	0.05	0.001	0.11
Timing of onset of muscle activity										
Velocity (Vel)	0.49	0.12	0.001	0.36	0.002	0.01	0.10	0.04	0.27	0.08
Posture (Pos)	0.19	0.82	0.80	0.61	0.02	0.04	0.49	0.91	0.78	0.29
Vel*Pos	0.79	0.88	0.79	0.21	0.12	0.54	0.10	0.16	0.63	0.95

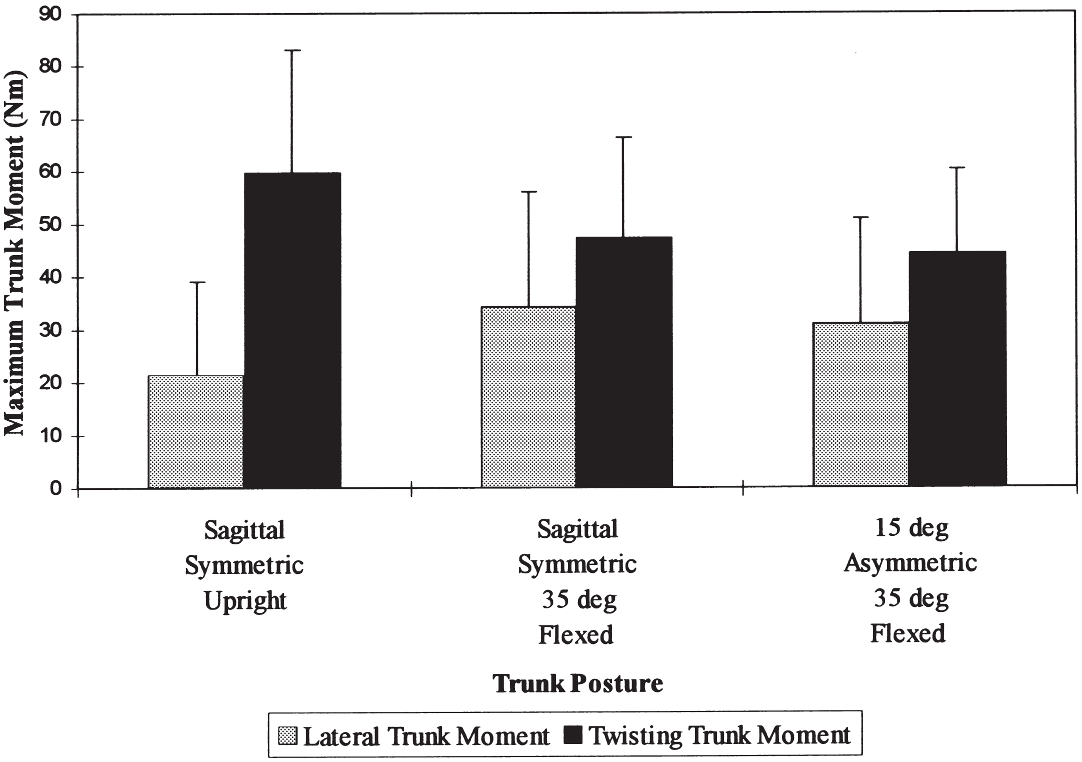

Fig. 2. The maximum lateral and twisting trunk moments as a function of trunk posture.

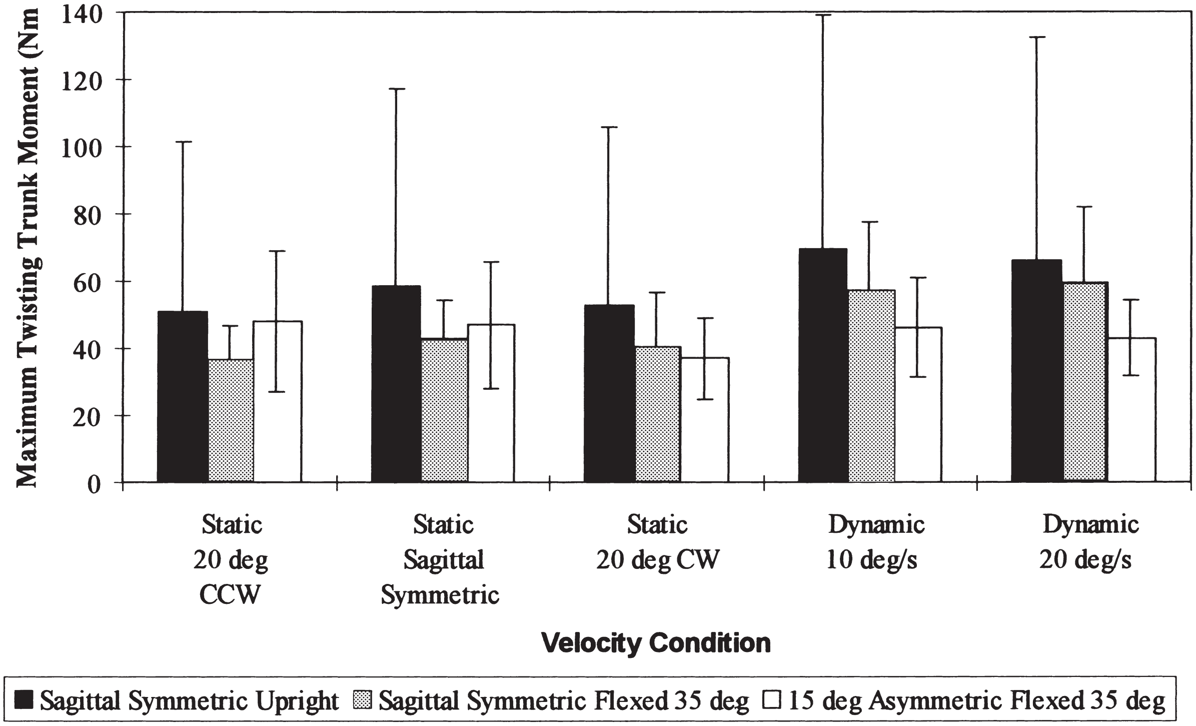

Fig. 3. Maximum twisting trunk moment as a function of velocity condition and trunk posture. (CCW: counter-clockwise; CW: clockwise).

whereas only the left erector spinae muscle exhibited differences in the point in time through the exertion at which the maximum activity occurred. Fig. 4 indicates the maximum activity pattern of the left erector spine muscle. This figure indicates that the activity level was lower for the upright posture compared to the flexed and asymmetric posture. The figure also indicates that when velocity was introduced into the exertion, the difference between the magnitude of the muscle activity in the upright and flexed postures becomes less dramatic. Similar responses were observed for the average activity of this muscle and for the right erector spinae muscle. When the time at which of the maximum activity occurred was considered, the left erector spinae muscle maximum was observed to occur later in the exertion under the upright condition compared to the other posture conditions.

The average right latissimus dorsi activity is shown in Fig. 5. The activity of this muscle was fairly similar when exertions were performed in the upright and flexed postures under both dynamic conditions and in static postures when the torso was rotated 20° counter-clockwise. These activities were greater than when twisting in the asymmetric posture. However, when twisting occurred under the other two static conditions the activity of this muscle increased as the trunk was flexed and further increased when the trunk became asymmetric. Similar trends were observed for the maximum right latissimus dorsi activity.

The maximum activity of the right internal oblique muscle in response to posture and velocity changes during twisting is shown in Fig. 6. A similar pattern was observed for the average activity of this muscle as well as the maximum activity of the left internal oblique muscle. Under dynamic conditions, the internal oblique behaves in a manner similar to the latissimus dorsi muscle and opposite that of the erector spinae muscle. Activity decreased under the asymmetric condition compared to the other two postures. Under the static conditions, muscle activity increased as the posture changed from upright to flexed to asymmetric.

The average activity of the left external oblique muscle is shown in Fig. 7. Here the activity of this muscle under the dynamic conditions was significantly greater under the upright posture twisting conditions compared to the other two conditions. However, under the static exertions the flexed posture produced activity magnitudes that were significantly less than those in the upright or asymmetric postures.

The differences in the abdominal musculature all related to changes in the timing of the onset of the activity and timing of the maximum activity. Both of the abdominal muscles were recruited later into the exertion in order to generate twisting under the flexed and asymmetric twisting exertion compared to the upright twisting exertion.

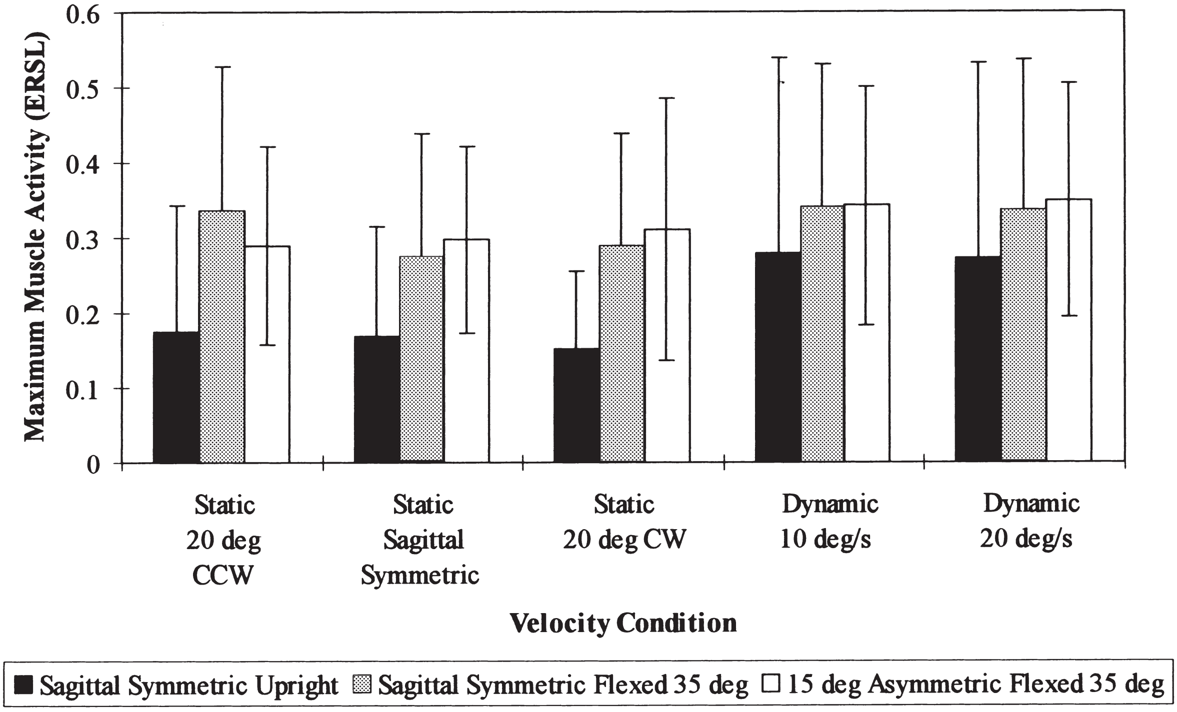

Fig. 4. Maximum muscle activity for the left erector spinae muscle as a function of velocity condition and trunk posture. (CCW: counter-clockwise; CW: clockwise).

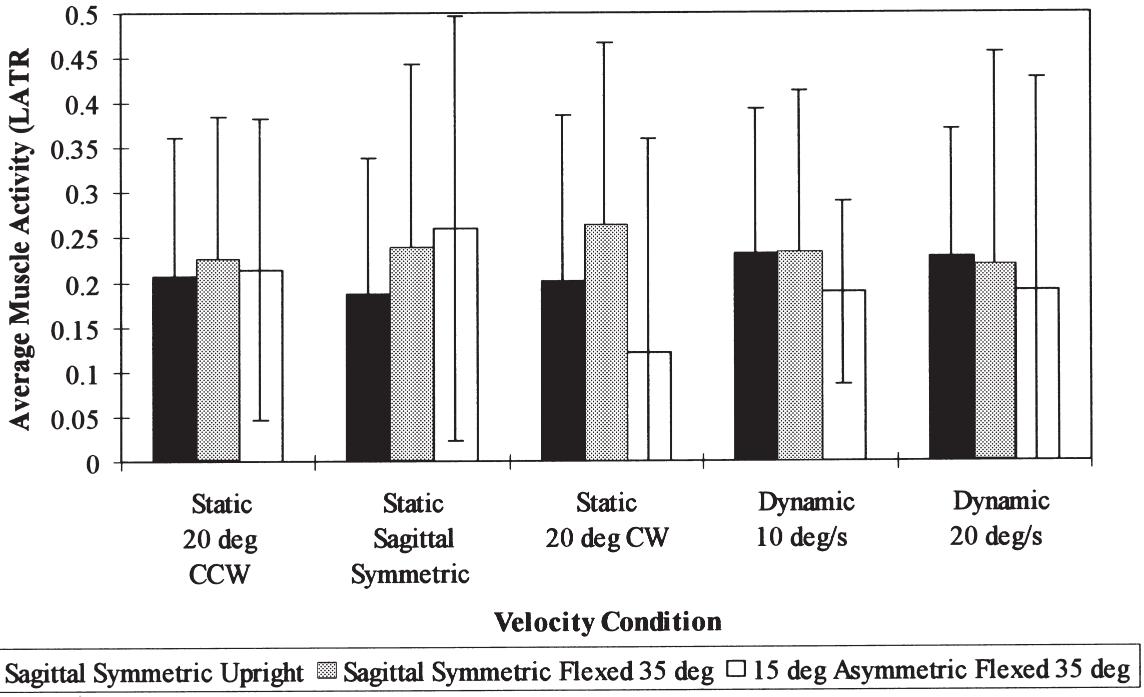

Fig. 5. Average muscle activity for the right latissimus dorsi muscle as a function of velocity condition and trunk posture. (CCW: counterclockwise; CW: clockwise).

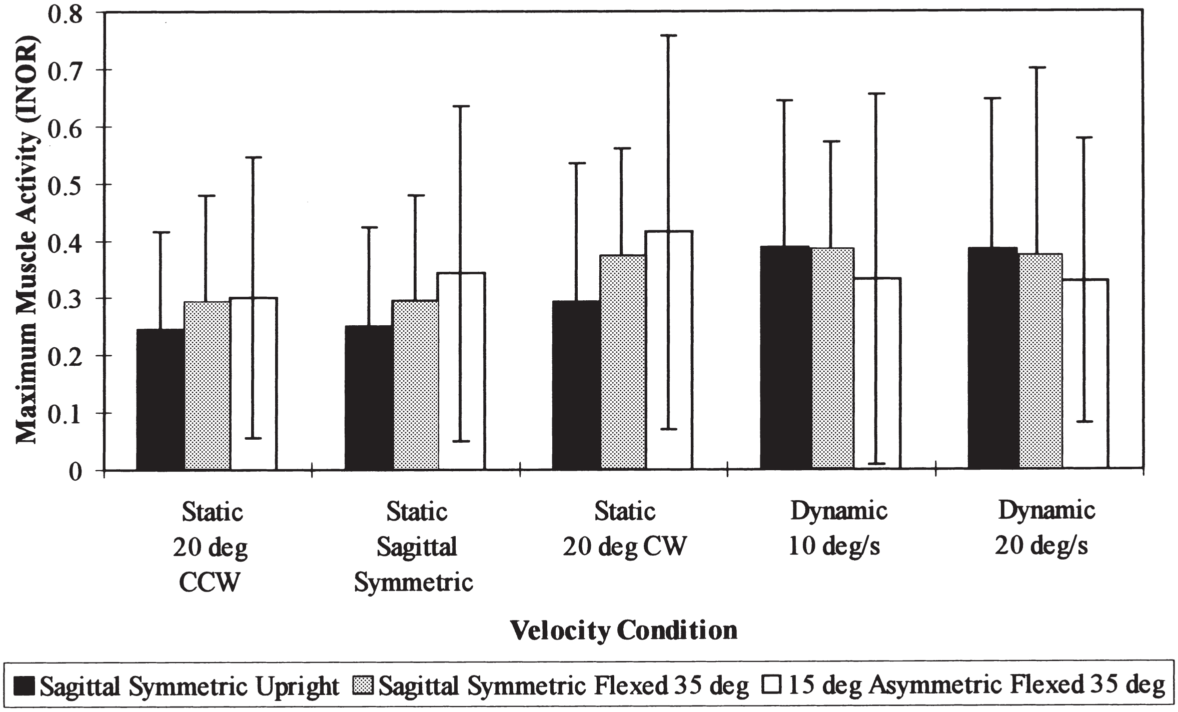

Fig. 6. Maximum muscle activity for the right internal oblique muscle as a function of velocity condition and trunk posture. (CCW: counterclockwise; CW: clockwise).

4. Discussion

These results have indicated that significant differences occur in the development and generation of twisting and lateral torque when the trunk twists in flexed and asymmetric postures compared to upright postures. Even though the experimental conditions required the subjects to generate twisting torque within a given toler-

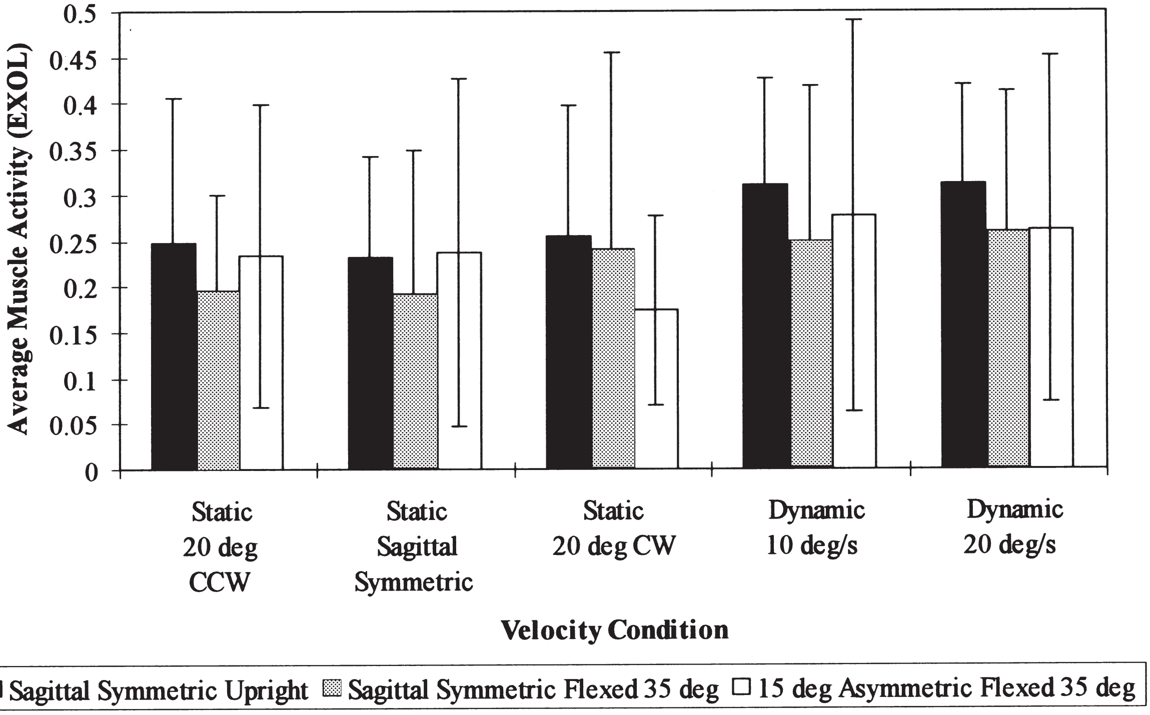

Fig. 7. Average muscle activity for the left external oblique muscle as a function of velocity condition and trunk posture. (CCW: counter-clockwise; CW: clockwise).

ance limit, the subjects consistently generated more twisting torque in the upright posture compared to the other twisting postures. In addition, the peak generation of torque occurred later in the range of motion in the upright posture. A trade-off was also observed between twisting and lateral torque generation. Subjects were asked to generate pure twisting torque, however, in the flexed and asymmetric postures lateral torque generation increased. Hence, once one assumes a non-neutral posture, it becomes more difficult to generate pure twisting motion and the muscles are recruited in such a way that more torque is generated in the accessory planes than intended. This is particularly notable since previous works [9,11] have observed far more accessory plane torque generation and more trunk muscle coactivation in upright twisting exertions compared to bending exertions. Thus, this study indicates that even greater accessory motions and trunk muscle coactivation occurs when the trunk twists while in bent postures.

The differences in torque generation were related to the muscle activities observed during these conditions. This study indicated that there was significant muscle substitution occurring in order to generate torque during twisting in different postures. The erector spinae muscles are one of the strongest and most often recruited muscles in bending exertions. However, in upright twisting they would not expect to be recruited to the extent of the oblique and latissimus dorsi muscles since they have a very small horizontal component in their vector line of action and thus less of a mechanical advantage. It has been hypothesized that during twisting while in the upright posture, the erector spinae's role is primarily related to trunk stability and only when the trunk twists to extreme rotational positions should these muscles be able to generate much mechanical advantage on the torso. However, when the trunk is flexed forward or asymmetrically, they must activate in order to support the mass of the torso. In addition, assuming a flexed or asymmetric posture changes the relative line of action of these muscles relative to the spine, thereby allowing the muscle to generate a twisting moment about the spine. Once these muscles increase their activity in these positions, the activity of the muscles with the greater horizontal vector components decreases. Under dynamic twisting conditions, the latissimus dorsi and internal oblique muscles activate at a magnitude similar to that observed during an upright twisting posture. However, these muscles reduce their activities once the twisting motion is performed in an asymmetric posture. The external oblique activities act to compliment the erector spinae muscles in that as the erector spinae muscles increase their activities the external oblique muscles decrease their activities.

This indicates that the musculature system changes the manner in which it generates torque given the posture. In upright postures, the muscles with the most horizontal vector components (internal and external obliques) are relied upon to generate twisting torque. As the torso posture changes from upright to a flexed posture, the larger stronger erector spinae muscles are used more in twisting moment generation since they must be recruited anyway to support the increased bending trunk moment. We can speculate that it would be more difficult to support the bending moment of the trunk with the oblique muscles and generate twisting moment. Since the erector spinae muscles are capable of producing more of a twisting moment when the torso is flexed, and their line of action changes relative to the spine, they are used to generate the twisting moment in place of the oblique muscles. Hence, when the torso is flexed the erector spinae, latissimus dorsi, and internal oblique muscles collectively play a role in order to generate torque. However, in asymmetric postures, the mechanical advantage of the erector spinae changes again since they have even more of a mechanical advantage for twist generation. Thus, the erector spinae play the largest role in twisting torque generation. The musculoskeletal system appears to recognize the postures in which the muscle lines of action are best suited to produce torque and changes its recruitment strategy accordingly.

The efficiency of the muscular system is also affected in its ability to generate twisting torque. As the muscles that are best suited to generate twisting torque (because of their orientation) become less active, the balance of force generation between these muscles and the erector spinae muscles changes so that the trunk generates more lateral moment and less twisting moment. Thus, this reinforces that notion that the trunk must be viewed as a system if we are to understand how force is generated and the spine loaded during work.

This study also indicated that the trunk torque occurred later in time when the trunk was upright compared to the other postures. The right erector spinae muscle's time of maximum activity appeared to be best associated with this trend. Since this muscle has the largest cross-sectional area compared to the other muscles, it is reasonable to assume this contributes the most to twisting torque generation. This muscle's activity peaked at a point in time significantly later during the upright posture compared to the other postures.

When interpreting these results one should also recognize that once the torso is flexed one would expect that a different tolerance level would be expected in the spine. In an upright posture, the facet joints would be expected to help limit the degree of trunk twisting and help support the twisting moment. However, once the trunk is flexed, one would expect that the facet joints would disengage and much of the twisting torque would be resisted by the annulus fibrosis. This would be expected to increase the risk of injury since the annulus fibrosis is not well suited to resist large twisting moments [4,15]. This expected change in tolerance might partially explain why the trunk musculature recruitment strategy changes as the trunk twists in different postures. Part of this change in strategy is obviously related to the need to support the bending moment generated by the trunk's mass. However, the decrease in oblique muscle activity might be related to the trunk's need to increase stability in order to protect the annulus fibrosis.

The differences between torque generation when in an upright standing posture compared to a flexed or asymmetric posture indicate that one must take care when assessing the risk associated with twisting motions in the workplace. All previous studies that have attempted to evaluate the activities of the trunk musculature during twisting have done so by evaluating subject's performing twists while assuming an upright posture. However, studies of trunk motions in the workplace indicate that upright twisting was fairly rare [8]. Most occupationally-related twisting is performed with the trunk in a non-upright posture. Thus, this study suggests that it might be inappropriate to try and generalize the results of studies assessing trunk muscle activities while subjects were in an upright posture to occupational twisting situations.

Two limitations should also be noted in this study. First, the twisting motions evaluated in this study were isokinetic in nature. Under occupational twisting conditions, workers may use acceleration and trunk momentum to assist in trunk motion. This would certainly alter the muscle recruitment and activity pattern of the trunk musculature. The results of this study would relate best to smooth non-accelerating and static twisting torque generation. Second, this study isolated the motions to twisting motions about the pelvis. Under realistic conditions, twisting would be accomplished through a combination of trunk rotation as well as rotation of the hips. Thus, one should note that these results would represent the 'worst case' for a twisting moment imposed about the spine.

5. Conclusions

This study has shown that the force generation and muscle recruitment activities associated with twisting change significantly as a function of the torso posture. Under upright trunk twisting conditions, twisting torque is generated easily and more efficiently with assistance from the oblique and latissimus dorsi muscles. However, when the trunk is flexed the activity of erector spinae muscles increases while the external oblique activity decreases. Finally, when twisting occurs while in an asymmetric bent posture, the oblique and latissimus dorsi muscles decrease their activities while the erector spinae muscle activity remains elevated. These findings suggest that studies observing trunk muscle activities and trunk loading while subjects are in upright postures should be interpreted with caution when evaluating the activity of the trunk during occupational activities.

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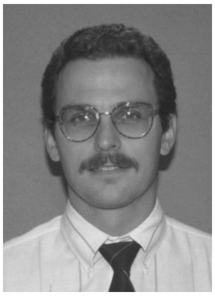

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