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Biomechanical assessment of lifting dynamics, muscle activity and spinal loads while using three different styles of lifting belt

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Abstract

Objective. To demonstrate the influence of different types of lifting belts on trunk motion, muscle activity and spine loading during symmetric and asymmetric lifting exertions.
Design. In vivo measurements were achieved representing lifting dynamics, applied trunk moments and myoelectric activity. Dynamic spinal loads were determined from a validated biomechanical model of lifting.
Background. There is a great deal of controversy as to whether lifting belts are a benefit or a liability to manual materials-handling activities. A review of the literature demonstrates that there is a large amount of conflicting evidence and few definitive, well-executed studies upon which to base an opinion regarding these devices.
Methods. Fifteen subjects lifted boxes of 14 kg and 23 kg from sagittally symmetric and asymmetric origins to an upright posture. Dynamic trunk motions, lifting moments, myoelectric activity and modelled spinal loads were examined as a function of three belt styles (elastic, leather, and orthotic) and compared with results from a no-belt condition.
Results. Lifting belts reduced peak trunk angles, velocities and accelerations in the sagittal, lateral and transverse planes. However, only the elastic belt successfully reduced trunk motions in all three dimensions. The orthotic belt significantly increased the lifting moment associated with a given weight. A minor redistribution in muscle activity was observed when wearing an elastic belt. A statistically significant reduction in spinal load was associated with the elastic belt. However, a great deal of variability between subjects was noted. Some subjects experienced increased spinal load while wearing the elastic lifting belt.
Conclusions. These results demonstrate that the biomechanical operation of lifting can be influenced by the type of lifting belts used.

Relevance

Results demonstrate that lifting belt style is a significant factor in the biomechanical response to belt usage. Although some belts influence trunk motion and statistically reduce spinal load, they should not be universally prescribed for a population. It is clear that some individuals suffer increased spinal load while wearing lifting belts.

Key words: Lifting belts, spinal load, low back pain

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Introduction

Lifting belts have been used with increasing frequency over the past decade in an effort to reduce back injury. However, there is a great deal of controversy as to whether lifting belts are a benefit or a liability to manual materials handling activities. Reviews by both McGill[1] and NIOSH[2] have concluded that there are few definitive, well-executed studies upon which to base an opinion regarding these devices.

Epidemiological studies have been limited in their scope, often generating results that were confounded

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with other factors such as training, the type of belt, or the 'Hawthorne effect'. Walsh and Schwartz[3] found back supports (hard shell corsets) reduced low back disorder (LBD) injury rates and recommended that they would be effective at controlling the risk of LBD. However, the data reported in this paper do not support the conclusion. The data suggest that back supports were only effective for those workers who had previously suffered a low back disorder. Mitchell et al.[4] evaluated injury data retrospectively over a 6-year period. Leather belts were used in the first 2 years of the study, and Velcro belts were used thereafter. They found no relationship between belt usage and injury but did find that those who wore belts suffered more costly injuries once they did occur. Reddell and associates[5] observed that when one stops wearing (fabric) lifting belts the risk of LBD increases, although this was not the intent of the study, and it suffered from small sample size. Unfortunately, none of the epidemiological studies could be considered conclusive since many of the studies suffer from low participation rates, inadequate observation periods, confounding with training, small sample size, low back-injury rates, reporting bias and/or previous back injury history[2].

Psychophysical studies have also endeavoured to assess the acceptable weight a person was willing to lift as a function of lifting belts. McCoy et al.[6] observed maximum acceptable lift weight of 12 college students as they lifting using elastic and inflatable back belts. Subjects were willing to lift 19% more weight with the belts. No difference was noted between belt types. When asked for the preferred condition most subjects reported a preference for the elastic belt condition. However, it is unclear whether any differences might be a result of a 'Hawthorne effect'. These results do not suggest that workers would be less at risk for a LBD since we do not know how spine tolerance is affected by the use of lifting belts.

Biomechanical studies have examined the influences of lifting belts upon range of motion, trunk muscle activity and indirect indicators or predictions of trunk loading. Nachemson and associates[8] evaluated the influence of three types of therapeutic lumbar orthoses on the intradiscal pressure, intra-abdominal pressure (IAP), electromyographic activity of three trunk muscles and predicted spine loading of four subjects. They demonstrated that belts increased IAP, but that IAP was unrelated to spine load. Although the authors concluded that the orthoses reduced spinal compression, as indicated by intradiscal pressure, the results suffer from an extremely small sample size, incomplete testing conditions and an invalidated model. McGill et al.[9] found increased IAP when subjects wore (leather) lifting belts; however, breath holding had a much greater effect on IAP than did belt usage. In addition they were unable to identify any significant reduction in erector spinae muscle activity when using the belt. A more recent study by McGill and associates[10] attempted to describe the effects of torso movement about the three principal axes while 22 subjects wore abdominal belts and held their breath. They concluded that both belt usage and breath holding stiffen the torso about the lateral and twisting axes but not about the flexion/extension axis. Lavender et al.[11] found similar restrictions in trunk motions within these planes when nursing personnel performing lifting tasks wore elastic lift belts. Lantz and Schultz[12] also investigated trunk movements as a function of three types of lumbar braces and found reduced trunk motion. Unfortunately the influence of external restrictions upon trunk motion via lifting belts has not been biomechanically associated with the spinal load and risk of injury.

Research results indicating the response of myoelectric trunk activity (EMG) as a function of wearing lifting belts are inconclusive. A study by Lantz and Schultz[13] noted significant variability in the EMG response between subjects but concluded EMG activity of the erector spinae and external oblique muscles was reduced when subjects wore lumbar braces. Lander and associates[14] revealed no difference in erector spinae and external oblique EMG activity when subjects lifted large amounts of weight while wearing leather belts compared to wearing no belt. In an earlier study employing EMG, IAP, and a biomechanical model, Lander et al.[15] found that conclusions about spine loading depended upon whether the differences in lifting moments were considered between belt (leather) and no belt conditions. These reports indicate variable findings regarding EMG and belt usage, possibly because none of the reports addressed the issue of electrode contact pressure interference due to belt usage *versus* the no-belt conditions. Such a factor might certainly affect EMG readings, especially when subtle differences are expected.

These studies have shown that there is a large amount of conflicting evidence as to the benefits and liabilities associated with the use of back belts. Most epidemiological and psychophysical studies have not been able to control work situations such that biomechanical insight can be gained. Biomechanical studies that have been performed have not been consistent in their lifting conditions, have used a variety of lifting belts without assessing risk as a function of belt properties and few have employed models capable of accurately and validly estimating spine loading. The most consistent finding of these previous studies is that lateral and twisting trunk motions are significantly restricted by belts, although the effects upon spine loading is unknown. Thus there is a void in the literature in that accurate, quantitative estimates of spinal load resulting from back belt usage during manual materials handling are lacking. We have developed an EMG-assisted low back model that is capable of assessing spine loading during belt usage and manual materials handling. Therefore, the objective of

Table 1. Anthropometric means (standard deviations) of the participants in the experiment

	Mean (SD)	*Range*
Age	28.3 (3.5)	23–36
Height	178.9 (7.4)	164.0–197.0
Weight	77.8 (9.1)	61.4–97.3
Knee height	65.7 (5.3)	55.9–73.7

the current study is to delineate the effects of different types of belt usage on trunk motion, muscle activity and spine loading under both symmetric and asymmetric trunk loading conditions.

Methods

Fifteen healthy males with no previous history of low back injuries volunteered to participate in this study. Subjects' anthropometrics were recorded for experimental and analytical purposes and are summarized in Table 1.

Independent variables included belt type, lift origin and box weight. Weighted boxes of 14 and 23 kg were lifted from a platform to an upright posture. The platform elevation was adjusted to place the box handles at a lift origin of knee height and 10 cm above knee height, 40 cm directly in front of the subject. Asymmetric lifts were also performed wherein the box was placed at an elevation of 70 cm and located 60° clockwise from the sagittally symmetric plane. Exertions were performed without a belt (no-belt) and while wearing a nylon elastic belt with suspenders (elastic belt), a leather weightlifting style belt (leather belt) and a fabric belt with a rigid posterior support (orthotic belt). All belts were commercially available, were applied in accordance with the manufacturers' specifications and tensioned to 4.5 kg.

Dependent variables included dynamic measures of trunk and pelvic motion, applied trunk moments, electromyographic activity and spinal loading. Three-dimensional trunk angles, velocities and accelerations were recorded from a Lumbar Motion Monitor (LMM)[16] (Biodynamics Laboratory, The Ohio State University, USA). Pelvis motions in the sagittal and transverse planes were recorded via an electrogoniometer, designed and created in our laboratory to measure the dynamic motion and orientation of the pelvis relative to the force plate[17]. Applied trunk moments were determined from the ground reaction forces and moments recorded by a force plate (Bertec 4060A, Columbus, OH, USA) using a variation of the method developed by Granata et al.[18]. Electromyographic activity was measured from bipolar surface electrodes over the right/left pairs of the latissimus dorsi, erector spinae, rectus abdomini, external abdominal obliques and posterior aspect of the internal obliques. EMG data were collected and processed as per Mirka[19]. Myoelectric data were normalized from maximum isometric flexion, extension, right and left twisting and right and left lateral bending exertions performed against a rigid reference frame[24]. The electrodes were protected against contact distortions from the belts by thin styrofoam spacers. Biomechanical loads on the spine were determined from a validated, EMG-assisted model[20].

Measured values of peak trunk and pelvic angles, velocities and accelerations, as well as trunk moments, three-dimensional spinal loads and normalized trunk muscle activity, were analysed for statistical significance. Multivariate (MANOVA) and univariate analysis of variance (ANOVA) was performed to identify factors influencing biomechanical parameters. Intersubject variability was controlled by including subjects as a covariate factor in the ANOVA tests. *Post hoc* analyses (Tukey test) were performed to describe the trends associated with significant effects.

Results

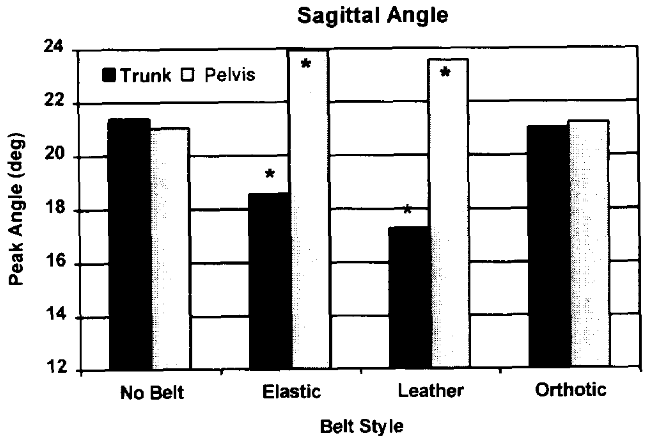
Trunk and pelvis motions

Analyses of kinematic parameters demonstrated that most measured trunk and pelvis angles were significantly influenced by task asymmetry, belt usage and their interactions. A significance summary of these effects is shown in Table 2. As shown in Figure 1, *post hoc* analyses indicated the elastic belt and leather belt reduced the peak trunk sagittal angles and increased the peak pelvis flexion angles. The peak trunk flexion angles during sagittally symmetric lifts without a back belt and using an orthotic belt averaged 21°, whereas the elastic and leather belts were associated with angles of 18 and 17° respectively. During asymmetric lifting

Table 2. Statistical analyses indicate belt style (Belt) significantly influenced peak trunk and pelvic angles during the lifting exertions. Belt style also affected the manner in peak lateral and twisting angles are achieved during asymmetrical tasks

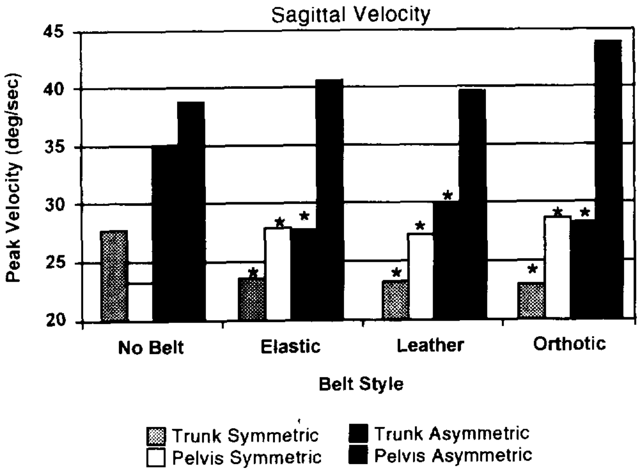
		Asymmetry	*Weight*	*Belt*	*Asymmetry weight*	*Asymmetry belt*	*Weight belt*
	MANOVA	**$P<0.001$**	$P<0.322$	**$P<0.000$**	$P<0.938$	**$P<0.000$**	$P<0.999$
A	Trunk sagittal	**$P<0.001$**	$P<0.472$	**$P<0.001$**	$P<0.728$	$P<0.879$	$P<0.995$
N	Pelvic sagittal	**$P<0.001$**	$P<0.187$	*$P<0.012$*	$P<0.973$	$P<0.793$	$P<0.948$
O	Trunk lateral	**$P<0.001$**	*$P<0.056$*	**$P<0.001$**	$P<0.283$	**$P<0.001$**	$P<0.935$
V	Trunk twist	**$P<0.001$**	$P<0.907$	**$P<0.001$**	$P<0.820$	**$P<0.001$**	$P<0.971$
A	Pelvic twist	**$P<0.001$**	$P<0.432$	**$P<0.001$**	$P<0.955$	**$P<0.001$**	$P<0.672$

Bold type indicates statistical significance at $P<0.01$.
Italic type indicates statistical significance at $P<0.1$.



* Indicates level is significantly ($P < .01$) different than no-belt condition

Figure 1. *Post-hoc* analyses (Tukey) demonstrated that the elastic and leather belts significantly ($P < 0.01$) reduced peak trunk flexion angles while increasing peak pelvic angles. Note the sum of trunk and pelvic angle was invariant, allowing the subject to bend far enough to reach the origin height.



* Indicates level is significantly ($P < .01$) different than no-belt condition

Figure 2. All the belt styles significantly reduced trunk extension velocities relative to the no-belt condition during both sagittally symmetric and asymmetric lifting tasks. Pelvic extension velocities were reduced by belt usage only during the sagittally symmetric exertions.

exertions trunk sagittal angles were reduced from 31.7 to 27.3° for both the elastic and leather belts. Belts also resulted in the reduction of peak lateral flexion during asymmetric tasks from 7.4° in the unbelted conditions to 5.0° with the leather and orthotic belts, and 3.2° with the elastic belt. Peak trunk twisting angles were similarly reduced from 6.9° (unbelted) to 4.2° (elastic belt). Examination of Figure 1 demonstrates that the reduction in trunk sagittal angle was offset by significant increases in pelvic flexion. Conversely, increased pelvic twisting associated with back belts was statistically significant in both the sagittally symmetric and asymmetric exertions. Although each belt style reduced the average range of motion in at least one dimension, only the elastic belt was associated with significant reduction in peak trunk angles in all three planes.

Trunk and pelvis velocity were significantly influenced by the use of back belts during both sagittally symmetric and asymmetric exertions as shown in Table 3. Maximum sagittal trunk velocity was significantly reduced and pelvis extension velocity increased when tasks were performed with any of the back belts as shown in Figure 2. During sagittally symmetric lifts, the belted exertions were associated with maximum extension velocities (23.0°/s) which were 16% less than the unbelted lifts (27.5°/s). Pelvic extension velocities of the unbelted conditions were lower than the belted exertions. There were no significant differences in extension velocities between the belts. Asymmetric lifting exertions were also associated with statistically significant reductions in trunk extension velocity during belted conditions. Pelvic extension velocities were not significantly influenced by belt usage during asymmetric lifts. The elastic belt reduced peak trunk lateral velocities to 3.6°/s from no-belt, a value of 7.5°/s. Twisting velocities of the trunk significantly increased with the use of the orthotic belt compared to the unbelted conditions. No other differences in trunk or pelvis twisting velocities were significant.

All of the belts significantly reduced the sagittal and twisting trunk accelerations (Table 4) compared to the unbelted conditions, as shown in Figure 3. The difference in sagittal acceleration between belts was statistically insignificant. Belts did not influence lateral trunk acceleration or any of the measured pelvic accelerations relative to the unbelted values.

Moments imposed on L_5/S_1

The evaluation of trunk and pelvic kinematics indicates that significant trade-offs in motion occur within the body when belts are used compared to no-belt lifting conditions. Such differences beg the question as to

Table 3. Belt style (Belt) significantly influenced the peak lifting velocities of the trunk and pelvis. Belt style also reduced the trunk lateral and twisting velocities generated during asymmetrical tasks

		Asymmetry	*Weight*	*Belt*	*Asymmetry weight*	*Asymmetry belt*	*Weight belt*
	MANOVA	**$P<0.001$**	**$P<0.004$**	**$P<0.000$**	$P<0.143$	**$P<0.001$**	$P<0.609$
A	Trunk sagittal	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	$P<0.681$	$P<0.476$	$P<0.725$
N	Pelvic sagittal	**$P<0.001$**	$P<0.527$	**$P<0.002$**	$P<0.282$	$P<0.588$	$P<0.177$
O	Trunk lateral	**$P<0.001$**	*$P<0.058$*	**$P<0.003$**	*$P<0.044$*	**$P<0.001$**	$P<0.242$
V	Trunk twist	**$P<0.001$**	$P<0.341$	**$P<0.001$**	$P<0.401$	**$P<0.001$**	$P<0.784$
A	Pelvic twist	**$P<0.001$**	$P<0.295$	$P<0.115$	$P<0.273$	$P<0.945$	$P<0.804$

Bold type indicates statistical significance at $P<0.01$.
Italic type indicates statistical significance at $P<0.1$.

Table 4. Statistical analyses indicate belt style (Belt) significantly influenced peak trunk acceleration in the sagittal and transverse planes only

		Asymmetry	*Weight*	*Belt*	*Asymmetry weight*	*Asymmetry belt*	*Weight belt*
	MANOVA	**$P<0.001$**	**$P<0.009$**	**$P<0.001$**	$P<0.332$	$P<0.194$	$P<0.246$
ANOVA	Trunk sagittal	*$P<0.014$*	**$P<0.002$**	**$P<0.001$**	$P<0.439$	$P<0.515$	$P<0.608$
	Pelvic sagittal	**$P<0.001$**	$P<0.649$	$P<0.135$	$P<0.438$	$P<0.745$	$P<0.370$
	Trunk lateral	$P<0.126$	$P<0.201$	$P<0.356$	$P<0.306$	$P<0.283$	$P<0.086$
	Trunk twist	**$P<0.001$**	$P<0.160$	**$P<0.001$**	$P<0.671$	*$P<0.011$*	$P<0.367$
	Pelvic twist	**$P<0.001$**	$P<0.778$	$P<0.558$	*$P<0.079$*	$P<0.662$	$P<0.463$

Bold type indicates statistical significance at $P<0.01$.
Italic type indicates statistical significance at $P<0.1$.

whether these trade-offs result in a change in the external moment imposed about L_5/S_1 during lifting. A summary of lifting moments (Figure 4) indicates that the kinematic joint changes resulted in increased applied moment about L_5/S_1. The elastic and leather belts were associated with a statistically insignificant moment increase of 3.7%, whereas the orthotic belt increased the lifting moment by 10%, which was found to be significant ($P<0.01$) during sagittally symmetric exertions. Considering that the lifted weights were identical in the belted and unbelted conditions, the increased applied moments associated with the orthotic lifting belt must be related to the lifting motions.

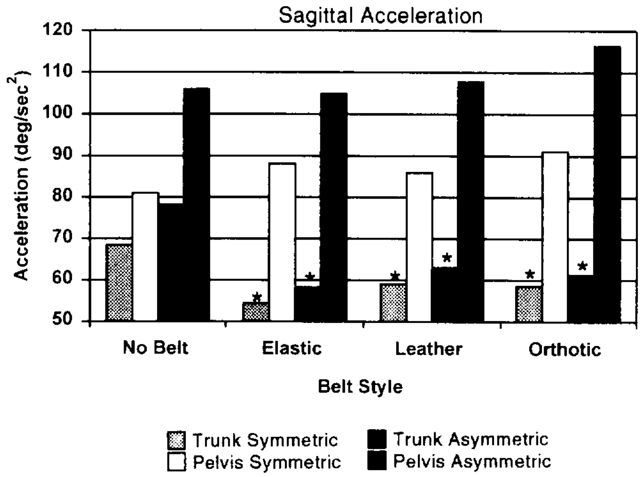
EMG

Analysis of myoelectric activity demonstrated a limited influence of lifting belts upon muscle activity (Table 5). During sagittally symmetric exertions, wearing the elastic belt significantly reduced the normalized activities in the erector spinae by 4% of the MVC value compared to the unbelted exertions. Antagonistic activity in the rectus abdomini muscles was similarly reduced when wearing the elastic belt; however, this difference was not statistically significant. Activity in the left internal oblique significantly increased with the elastic belt by 3.5% of MVC from a value of 24% during unbelted, sagittally symmetric exertions. Activity in the other obliques and the latissimus dorsi also increased during belted exertions, but these differences were not statistically significant. Only the elastic belt compared to the no-belt conditions showed any significant differences. The leather belt and orthotic belt did not influence EMG activity.

During asymmetric exertions, only the left erector spinae demonstrated a reduction in activity associated with belts. The myoeletric activity in the measured muscles followed similar trends as in the symmetric exertion, but most were not statistically significant.

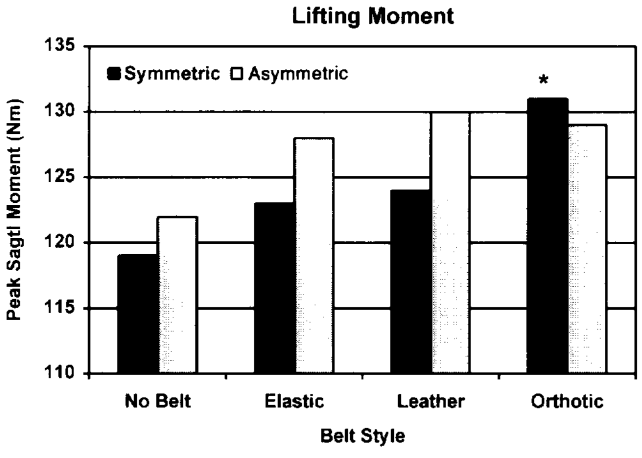
Model performance

The biomechanical model accurately predicted the trunk moments measured during the experiment. The modelled trunk moments correlated with the measured dynamic data with an average R^2 of 0.80. This value reflects the dynamic variability associated with all of the lifting tasks, including the four belt conditions, lift origin heights and asymmetries. The average magnitude of the error between predicted and measured trunk moments was approximately 17% of the average peak lifting moment. Thus the simulation agreed with the dynamic trends and magnitudes of the measured data. There were no significant ($P<0.01$)



* Indicates level is significantly ($P<01$) different than no-belt condition

Figure 3. Belt usage significantly reduced peak trunk accelerations during both sagittally symmetric and asymmetric lifting tasks. Belts did not significantly influence pelvic accelerations.



* Indicates level is significantly ($P<01$) different than no-belt condition

Figure 4. Changes in motion parameters associated with belt usage resulted in increased lifting moments despite the fact that the weight of the lifted loads were identical between belt conditions. Increases in the applied moment were not statistically significant, except for sagittally symmetric exertions while wearing the orthotic belt.

Table 5. Belt style (Belt) was associated with a significant reduction in erector spinae activity as well as a significant increase in the myoelectrical activity of the internal oblique muscles

		Asymmetry	*Weight*	*Belt*	*Asymmetry weight*	*Asymmetry belt*	*Weight belt*
	MANOVA	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	$P<0.964$
	Rt Lat	**$P<0.001$**	**$P<0.001$**	$P<0.948$	$P<0.820$	$P<0.989$	$P<0.997$
	Lt Lat	*$P<0.058$*	**$P<0.001$**	$P<0.758$	$P<0.296$	$P<0.956$	$P<0.999$
A	Rt Er Sp	**$P<0.001$**	**$P<0.001$**	*$P<0.029$*	$P<0.777$	$P<0.943$	$P<0.994$
N	Lt Er Sp	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	$P<0.900$	*$P<0.880$*	$P<0.939$
O	Rt Rect Abd	$P<0.984$	*$P<0.014$*	$P<0.717$	$P<0.997$	$P<0.932$	$P<0.974$
V	Lt Rect Abd	$P<0.990$	**$P<0.008$**	$P<0.141$	$P<0.920$	$P<0.890$	$P<0.998$
A	Rt Ext Obl	**$P<0.001$**	**$P<0.001$**	*$P<0.083$*	$P<0.198$	$P<0.808$	$P<0.929$
	Lt Ext Obl	**$P<0.001$**	**$P<0.001$**	$P<0.504$	$P<0.371$	$P<0.665$	$P<0.982$
	Rt Int Obl	**$P<0.001$**	**$P<0.001$**	$P<0.147$	$P<0.638$	$P<0.919$	$P<0.999$
	Lt Int Obl	**$P<0.001$**	**$P<0.001$**	*$P<0.039$*	$P<0.993$	$P<0.864$	$P<0.991$

Bold type indicates statistical significance at $P<0.01$.
Italic type indicates statistical significance at $P<0.1$.

differences in model performance between the experimental conditions.

Spinal load

Predicted spinal compression and anterior–posterior (A–P) shear forces were significantly influenced by the use of the elastic belt (Table 6, Figure 5). Pairwise comparisons indicated that the elastic belt reduced peak compressive loads during both sagittally symmetric and asymmetric tasks. Compressive forces were reduced by 315 N during asymmetric elastic belt conditions relative to the no-belt load of 2659 N, and by 170 N relative to the unbelted compressive loads of 2575 N during sagittally symmetric exertions from the low lifting height condition. The elastic belt also significantly reduced maximum A–P shear force by 300 N relative to the no-belt value of 1600 N during asymmetric exertions and by 150 N relative to the no-belt value of 1150 N during sagittally symmetric exertions. Comparisons between the no-belt condition and the exertions involving the leather belt and orthotic belt demonstrated no reduction in modeled spinal loads.

Although the statistical results indicated most subjects experienced reduced spinal loads while wearing the elastic belts, a great deal of variability between loadings was also observed among subjects. Compressive loads of some subjects increased as much as 400 N while wearing the elastic belts compared to the no-belt condition.

Discussion

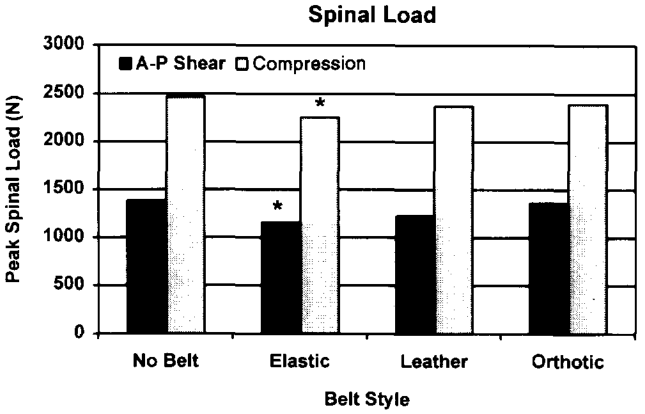
These results have shown that a major effect of back belts was to significantly reduce the range of motion, extension velocities and accelerations associated with the trunk during lifting exertions. Results demonstrate that, without a back belt, subjects typically flexed their trunks and pelvis equally in order to generate the total body angle necessary to accommodate the origin of the lift. Such effects were reported previously by Lavender et al.[11] as well as Lantz and Schultz[15]. However, the current study has shown that, while wearing an elastic belt or leather belt, the subjects accomplished the same task by recruiting greater pelvic angles, thereby allowing reduced maximum trunk flexion. This resulted in significant reductions in trunk velocity and acceleration. However, increases in sagittal plane velocities and accelerations were observed in the pelvis in order to accomplish the lifting task.

Research has demonstrated that spinal loads and the risk of low-back pain are associated with trunk motions and postures[20,21–24]. Therefore, one might be tempted to infer that, by reducing trunk flexion angles, back belts may possibly reduce the risk of low back pain. Conversely, it is possible that the reduction in the trunk motion parameters associated with back belts may be of insufficient magnitude to influence the risk of low back pain. A kinematic model of low back pain risk was developed from a large scale industrial surveillance study by Marras et al.[21]. The kinematic model permits the evaluation of trunk motion parameters associated with a task in order to determine the probability of

Table 6. Belt style (Belt) significantly influenced the compressive and anterior–posterior shear (A–P) on the spine as predicted by the EMG-assisted biomechanical model

	Asymmetry	*Weight*	*Belt*	*Asymmetry weight*	*Asymmetry belt*	*Weight belt*
MANOVA	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	$P<0.387$	$P<0.901$	$P<0.999$
Sagittal moment	$P<0.326$	**$P<0.001$**	$P<0.221$	$P<0.557$	$P<0.831$	$P<0.950$
Lateral shear	**$P<0.001$**	**$P<0.019$**	$P<0.394$	$P<0.058$	$P<0.941$	$P<0.923$
A–P shear	**$P<0.001$**	**$P<0.001$**	**$P<0.001$**	$P<0.073$	$P<0.364$	$P<0.835$
Compression	**$P<0.001$**	**$P<0.001$**	**$P<0.010$**	$P<0.423$	$P<0.415$	$P<0.909$

Bold type indicates statistical significance at $P<0.01$.
Italic type indicates statistical significance at $P<0.1$.



* Indicates level is significantly ($P<01$) different than no-belt condition

Figure 5. Pairwise comparisons demonstrate usage of the elastic lifting belt significantly reduced spinal compression and anterior–posterior shear (A–P shear) during sagittally symmetric and asymmetric lifting tasks.

belonging to a group at high risk of suffering low back pain. Analysis of the belt data demonstrated that an individual whose occupation was to perform a manual materials handling task similar to our asymmetric task condition, without a lifting belt, would have a 69.1% probability of membership in the high-risk group. The same task performed with the elastic belt reduces the risk to 67.1%, whereas the orthotic belt increases the value to 76.1 %. Although the back belts reduced trunk motions, the static and dynamic differences were not enough to significantly lower the probability of low back pain according to the industrial kinematic model. Furthermore, it should be emphasized that we do not know what effect transferring the motion and loading from the trunk to the pelvis would have upon the risk of developing pelvis problems. It may be that belts might simply trade off a back problem for a pelvic problem.

Spinal load has been associated with static trunk posture and the risk of low-back pain[25]. This association is often related to increased load and moment arm about the lumbosacral junction of the spine. Analyses demonstrated that, although back belts reduced the maximum trunk angles, there was no significant reduction in the applied moment about L_5/S_1, with or without lifting belts. In fact the orthotic belt significantly increased the lifting moment. Considering that the weight of the box was independent of belt style, the changes in applied moment must be attributed to the load path and trunk motion profiles associated with the belt styles. Thus, lifting belts may adversely influence the risk of LBD by modifying trunk motions which in turn increase the L_5/S_1 trunk moment and subsequent spinal loads. Combining this with a willingness to lift greater loads while wearing a lifting belt[10], in some situations lifting belts may compound the potential risk of overexertion, exceeding spinal loads tolerance limits and low back pain.

Trunk acceleration increases the inertial load on the spine. Studies have demonstrated that spinal compression under dynamic conditions exceeds an equivalent static load by as much as 45%[26,27]. Although back belts reduced the sagittal plane accelerations of the trunk, the magnitude of the acceleration changes were not significant enough to introduce statistically significant reduction of inertial moments about the lumbosacral junction. However, it must be noted that the accelerations observed in our study were nearly an order of magnitude smaller than those reported by Marras et al.[21] in their industrial surveillance. The controlled nature of the experimental conditions reduced the peak accelerations generated by the subjects as compared to typical manual materials handling tasks.

Three-dimensional trunk velocity has been shown to be associated with low back pain in industry[21,22]. Research indicates that this may be related to increased muscle coactivity and spinal load with lifting and twisting velocities[20,24,28]. Since lifting belts reduced trunk velocities, one might expect that muscle coactivity may be reduced with belts. In fact, there was no significant reduction in muscle coactivity with back belts. While wearing the elastic belt, subjects demonstrated reduced activities in the erector spinae muscles, but increased activities in the internal and external obliques. Thus, there appeared to be a minor redistribution of muscle forces associated with a lifting exertion when subjects were wearing back belts as compared to unbelted exertions. These findings are consistent with previous studies[9,13–15]. Lifting velocity has been shown[20] to specifically influence the antagonistic activity of the rectus abdomini. Reduced trunk velocities associated with back belts demonstrated no significant reduction in the myoelectric activity in the rectus abdomini. However, the redistribution of trunk muscle activity associated with the elastic belt may influence the spinal load during a lifting exertion.

Modelled spinal compression associated with the elastic belt exertions were significantly lower than the same exertions performed without a lifting belt. The influence was evident in both sagittally symmetric and asymmetric lifting exertions. Although all three of the belts, i.e. the elastic belt, the leather belt, and the orthotic belt, were associated with reduced loads on the spine, only the elastic belt demonstrated statistically significant reductions in spinal load. The applied lifting moment tended to increase with belts, but the spinal loads tended to decrease. Consequently, the change in biomechanical load must be attributed to the internal forces generated by the trunk musculature, albeit a minor redistribution of muscle forces.

The magnitude of spinal loads can be greatly influenced by the pattern of muscle coactivity. Previous research[29] has demonstrated that the low-level antagonistic activity associated with lifting exertions can increase dynamic spinal compression by 45% or more. Clearly, reduced rectus abdomini activity associated with the elastic belt, although it was not statistically significant by itself, may serve to influence the system and reduce the required extensor moment from the erector spinae muscles and associated spinal loads attributed to muscle contractile forces. Increased extensor moments generated by the internal obliques may reduce the necessary erector spinae activity. However, analyses of muscle coactivity[29] indicated load sharing between the erector spinae and internal oblique muscles did not influence spinal compression.

One might speculate at this point why the elastic belt affected trunk motion and spine load to a much greater degree than did the other belts. The elastic belt was unique in that it was much taller than the other belts used. It has the effect of connecting the pelvis and the thoracic region of the spine, whereas, the other belts simply resided between the thorax and the iliac crest. It was interesting to note that the only other belt that demonstrated any significance at all was the orthotic belt, which partially connected these parts of the trunk. Thus, we speculate that the reason the taller belt might be effective is because it forces the trunk to act as a unit, thereby reducing the required coactivity and the subsequent trunk loading. Even though this study showed that the trunk muscle activity was minimally affected by belts, the slight change in the muscle system behaviour may have been enough to affect trunk loading. However, it should also be emphasized that this was not true for all subjects. Some subjects responded with increased spinal load. This demonstrates the importance of considering individual differences between subjects.

Sensitivity analyses were performed to assure that the model performance did not influence the relation between lifting belts and spinal load. A key component of the biomechanical model is the muscle stress capacity, i.e. gain. The model computes an appropriate muscle force per unit area, i.e. gain, value so as to scale the trunk muscle forces to the correct magnitude, thereby solving the equations of dynamic equilibrium[20,23,24]. Therefore, spinal load, computed from the vector sum of the muscle forces, was also directly related to the gain value determined by the model. These analyses demonstrated that the gain variability may have contributed as much as 1.4% reduction in spinal load during sagittally symmetric exertions, and a maximum of 1.7% during asymmetric exertions. Biomechanical results indicated the elastic belt reduced the peak compression by nearly 7% during sagittal lifting exertions and 12% during asymmetric exertions. Clearly the influence of modelled gain upon the association between spinal load and lifting belts was inconsequential. However, the magnitude error between the measured and predicted trunk moments was on the order of 17% of the average measured values. Regression of spinal load and modelled error magnitude demonstrated a correlation of 0.01. This indicates that the modelled error did not contribute to the spinal load trends, but may have reduced the statistical significance of the results. Consequently, we believe the model performance did not influence the significant results associating spinal load and lifting belts.

Potential limitations of this study should also be acknowledged. One must be cautioned against indiscriminately applying the results of this study to industrial situations. First the influence of belts was significant but minor, resulting in about a 10% decrease in spine loading for the elastic belt only. Second, this study was a laboratory study that required subjects to stand on a force plate and not move the feet during the lifting task. This foot positioning requirement alone may have influenced the belt usage significance. Since subjects were not allowed to adjust their feet, they were forced to use the trunk musculature and pelvis to reach the origin and destination points of the load. Under realistic industrial conditions the feet are permitted to move, and therefore perhaps no belt effect would be evident under foot movement conditions. Third, some subjects increased spine loading with the use of belts. Thus, one must appreciate that all subjects do not respond in a similar fashion to belts. Finally, as mentioned earlier, the effect of the belt is to transfer motion and loading to the pelvis and we do not know the cumulative tolerance of the pelvis to these types of loading. Thus, these results must be interpreted with caution.

Conclusions

We have been able to objectively assess the influence of belt usage on trunk kinematics, trunk muscle activity and spine loading. Within the constraints of the experimental conditions tested in this study, it was found that the use of lifting belts transfers motion from the back to the pelvis, minimally effects muscle activity and significantly reduces trunk loading when elastic belts are used. It is clear from this study that the belts influence the body as a complex system. All belts influence trunk and pelvis motion, but we do not currently know the trade-offs in tolerances between trunk motion and pelvis motion. In addition it appears that only belts tall enough to cover the span from the thorax to the pelvis would be effective at reducing trunk loading.

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