Industrial Health 1999, **37**, 390–397 **Original Article**

Lumbar Vertebral Angles and Back Muscle Loading with Belts

Yung-Hui LEE* and Chih-Yong CHEN

Department of Industrial Management, National Taiwan University of Science and Technology, No. 43, Kee-Lung Rd., Sec IV, Taipei, Taiwan ROC

Received May 13, 1999 and accepted August 17, 1999

Abstract: The study examined belt effects on the change of lumbosacral angle (LSA) and back muscle activity in postures of standing, erect sitting, and slump sitting. We thought that the resulting changes of LSA and back muscle activity when wearing belts with different mechanical characteristics should be different. Eighteen healthy male subjects participated in this study. Though we failed to identify a significant belt effect on the back muscle EMG, the radiographic data revealed an interactive effect of postures and belts on the change of LSA. In standing, the belts increased LSA by increasing almost every lumbar vertebral angle. In erect sitting, the lumbar belt had no effect but the pelvic belt decreased LSA through a decrease in the L1/L3. While sitting slump with a trunk flexion of 15 degrees, both belts increased LSA by restricting the movement of the pelvis. Belt effect on LSA was accompanied with a change of pelvic angle. Significant correlation was found between the backward rotation angles of the pelvis and the angles of LSA ($r=0.692$, $p<0.0001$), also between the decrease of pelvic angles and the increase of back muscle EMG ($r=-0.4$, $p=0.017$). A change in LSA and pelvic angle after wearing a belt along with posture change seems lead to an increase of the myoelectric activities on the back.

Key words: Back belt, Pelvic belt, Lumbar vertebral angle, Electromyograph

Introduction

Back belts are used to prevent lower back pain[1–3]. Related studies have provided conflicting evidence as to the merits and the disadvantages associated with the use of back belts[1, 4–7]. In their review of the pertinent literature, the NIOSH Back Belt Working Group concluded that the effectiveness of using back belts to lessen the risk of back injuries to previously uninjured workers remains unknown[8]. Further and in-depth elucidation of the mechanism by which back belts modulate the lumbosacral angles (LSA) may provide clues to the proper design and possible effectiveness of these devices.

Biomechanical studies have shown that some back belts restrict trunk motion, especially in twisting and bending[9–11]. Granata *et al.* found lifting belt reduced peak trunk angles, velocities and accelerations in the sagittal, lateral and transverse planes[3]. However, the applied moments about L5/S1 were the same with or without the belt. This indicates that a reduction of trunk angle dose not necessarily reduce the loads on the spine. In fact, Granata, *et al.* found that subjects accomplished the same lifting task by recruiting greater pelvic angles, thereby allowing for a reduction in the maximum trunk motion. Since spinal loading and LSA are closely related to the position of trunk and pelvis[12], belt restriction on pelvis in addition to lumbar spine is worthy to explore.

Any decrease in the loads on the lumbar trunk structures brought about by the wearing of a belt would decrease the muscle contraction forces need to perform a task and/or to maintain a posture; this result should be evidenced by decreases in measured myoelectric activities. However, the literature on the back muscle loading with back support is equivocal[13]. For example, McGill *et al.* found EMG to be

*To whom correspondence should be addressed.

less during a valsalva, but a use of lifting belt did not decrease the EMG further[6]. It will be interesting to know that would the transferring motion and loading from the trunk to the pelvis after wearing a belt increase the myoelectric activities on the back.

Many types of belt are used in the workplace. Since different belts are designed based on different mechanical principles, their effects on the mobility of lumbar spine and pelvis are likely to be different. We thought that if the belts appreciably affected the magnitude of spinal loading by changing the LSA and pelvis, then the resulting changes of these angles when wearing belts with different mechanical characteristics (e.g. lumbar belt and pelvic belt) should be different. Based on the fact that when wearing a belt in the workplace, alternative working postures of standing, sitting, knee bending, and lifting are used, examination of the belt effect on LSA due to variations in static postures seemed a relevant task. Therefore, we formulate this study and tests the following two hypothesis: (1) whether LSA, pelvic angle, and back muscle loading changed when wearing a belt; and (2) whether LSA, pelvic angle, and back muscle loading changed more when wearing a lumbar belt than that of a pelvic belt.

Methods and Materials

Subjects

Eighteen healthy male subjects participated in the study. Their ages ranged from 19 to 24 (average 21.8 years). Subjects were informed of the risks of radiation and gave their consent to participate. The subjects were selected from the members of the university swimming team. They were selected on a voluntary basis, had no medical record of back pain, and were free from scolisosis and other problems of the axial skeleton. Table 1 lists their anthropometric characteristics. The Ethics Committee of Chang Gung Memorial Hospital in Taiwan approved the study.

Belts

LSA was examined when subject was not wearing a belt, wearing a lumbar belt, and wearing a pelvic belt only. The lumbar belt (Scott Specialties Inc., USA) was an unpadded, stretchable belt, which is worn around the waist. It has a posterior width of 22 cm and an anterior width of 12 cm. A BackMagic belt (Posture Research Institute, Canada) was used to test the effect of pelvic support. This pelvic belt is worn around the sacro-iliac joint, 2–3 inches below the iliac crest. It is not stretchable and has no lumbar or abdominal pad. The belt has a width of 7 cm. The pressure between the belt and the abdomen was set at 10 mmHg in all test conditions. This was achieved by inserting a volume-adjustable blood pressure meter (cuff-type, mercury barometer, and with digital read out) between the belt and the abdomen of the subject. Figure 1 illustrates the belts.

Table 1. Summary of subjects' physical data (n=18)

	Mean (SD)	Range
Age (yr)	22.4 (1.4)	19–25
Weight (kg)	66.0 (5.3)	56–75
Height (cm)	168.9 (3.3)	163.6–177.0
Abdominal depth (cm)	17.5 (3.0)	13.0–24.0
Waist circumference (cm)	73.1 (5.8)	65.0–86.0
Body Mass Index (Kg/m^2)	23.1 (1.8)	19.3–25.9
L4 skin-fold (cm)	1.0 (0.5)	0.4–2.1

Posture

The effects of the belt on LSA were examined in the static postures of standing, erect sitting, and slump sitting. These postures were selected because they were considered to be the most frequently observed working postures in a workplace. A stool with a horizontal seat surface was provided for the sitting task. The height of the stool was adjusted about 5 cm below the popliteal height for each subject. While sitting erect, the subject was requested to sit with his hip flexed and back straight. This posture allowed us to examine the effect of the belt in relation to lumbar lordosis along with hip flexion[14]. While sitting in a slumped position, the subject was requested to flex his trunk 15 degrees (It will be difficult for subjects to flex beyond 15 degrees when wearing a belt). This provided an opportunity to examine the effect of the belt in relation to lumbar kyphosis along with hip flexion. To ensure that the subject was positioned at the desired flexion angle, the subject was asked to make adjustments until his torso line (link between markers at acromion and the greater trochanter), as determined by the experimenter, matched with a preset line in the feedback monitor of the video system. While maintaining this static posture for ten seconds, X-ray and video recordings were taken in sequence.

Radiographic measurements

When a radiographic measurement was taken, the subject was asked to position the right side of his body so that it faced the film, with arms folded across his chest, and hands on opposite shoulders. The film was set 100 cm away from the radiographic tube. The radiation dose was 150 ms and

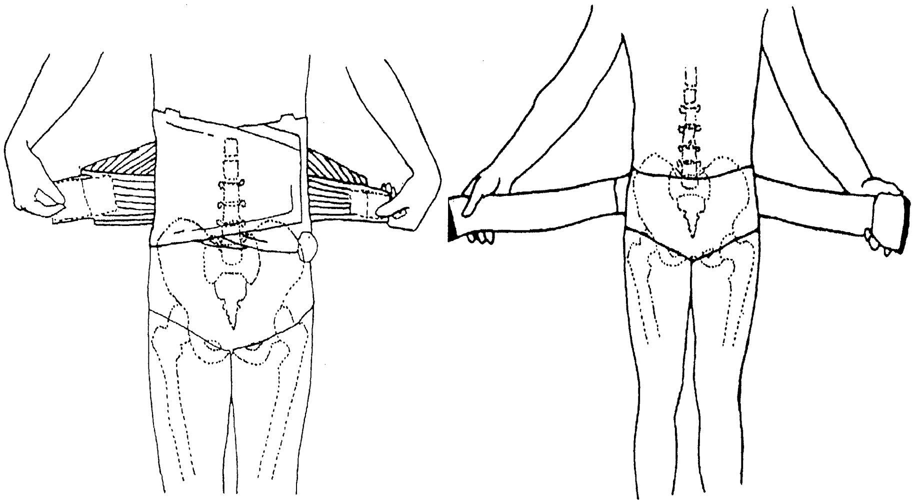

Fig. 1. Lumbar belt and pelvic belt used in the study.

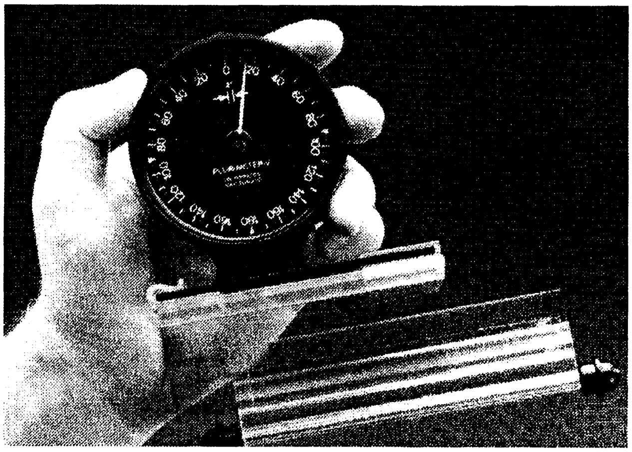

Fig. 2. The gravity inclinometer for measuring lumbar vertebral angles.

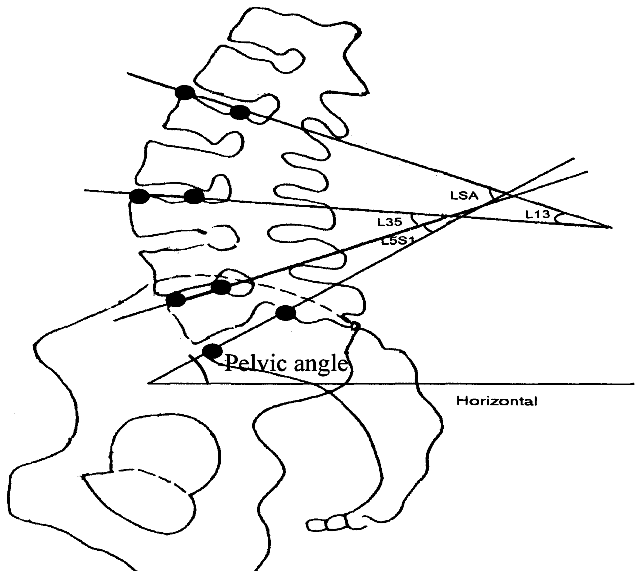

Fig. 3. The measured vertebral angles and their geometric relationships.

80 KVP. To minimize radiation risk, the experiment was conducted following a 3^{2-1} fractional factorial design[15]. Thus three tests out of the nine test-combinations (three belts and three postures) were measured for each subject. For example, one subject might be measured in standing with no belt, in erect sitting with a lumbar belt, and in slump sitting with a pelvic belt. As a result, a total of fifty four radiographic pictures were taken (three pictures for each of the eighteen subjects).

LSA was measured using a gravity inclinometer (BASELINE, Fabrication Enterprises Inc., New York, USA). See Fig. 2 for illustration. The instrument was chosen over others because of its ease of use in obtaining measurements. Two superior anatomic landmarks were identified on each of the L1, L3, L5, and S1 vertebra of each radiogram. The base of the radiogram was used as a horizontal reference. LSA was defined as the angle between the superior endplate of the first lumbar vertebra and the superior endplate of the sacrum (L1/S1). The angle of pelvis was defined as the angle between the horizontal line and the line along the superior surface of S1[16]. Figure 3 illustrates the geometric relationships of all the measured angles (L1/L3, L3/L5, L5/

S1, LSA, and pelvic angle). Their geometric relationships were used to verify the measurement accuracy[17].

Electromyograph

Muscle activities of the left and right erector spinae were collected simultaneously along with video recording for three seconds. The muscles were chosen with regard to their expected roles of prime actor in a lifting motion. The EMG data were collected with surface electrodes using BTS TELEMG (Milan, Italy). For each subject, the electrodes were placed on the L3/L4 level, 3 cm lateral to the midline. Pairs of Ag/AgCl surface electrodes (lead-off area 10 mm × 10 mm, center-to center electrode distance 45 mm) were applied to the muscles after standard skin preparation. The electrical signal was filtered (bandpass 20–600 HZ), sampled (1000 HZ), and full wave rectified. The rectified signal was processed to provide an integrated EMG (IEMG). In order to compare EMG data between the experimental trials for a given subject, a normalization procedure was performed[18, 19]. For each subject the IEMG values were rearranged as an APDF (amplitude probability distribution function). And the value of 95%ile amplitude was chosen as the reference value. Then the IEMG values were normalized (in % RV). The mean of the left and the right EMG was used for analysis.

The means and the standard deviations of all angular measurements were calculated by standard methods. Analysis of Variance (ANOVA) was used to study the effect of inter-subject variability, posture and belt effects on lumbosacral orientation, and possible interaction of these parameters. Duncan's multiple range test was used for post hoc comparisons. An alpha level of 0.05 was selected as the minimum level of significance.

Results

Table 2 presents the mean and standard deviation (SD) of lumbar vertebral angles, pelvic angles, and back muscle EMG in each posture with and without the belts. ANOVA results showed a statistically significant individual ($p<0.009$) and postures ($p<.0001$) effects on LSA. Duncan's multiple range test showed that, when no belt was worn, the LSA slightly reduced from 50.0° (6.8) in standing to 46.0° (7.6) in erect sitting. The angle decreased to 22.8° (15.4) in the slumped sitting posture. This change was accomplished mainly through decreasing the inter-segmental angle of the upper-lumbar spine (L1/L3). There was only slight L5/S1 movement when the subject changed postures from erect sitting (16.0° (7.6)) to slump sitting (14.8° (5.6)) when no belt was worn.

Table 2. Vertebral angles of subjects in different postures with lumbar belt, pelvic belt, and no belt

		No belt	Lumbar belt	Pelvic belt
Standing	L1/L3	8.5 (4.7)	9.8 (4.5)	10.2 (3.3)
	L3/L5	23.7 (4.2)	28.3 (6.1)	28.5 (4.6)
	L5/S1	17.8 (4.6)	19.5 (5.2)	22.3 (2.6)
	LSA	50.0 (6.8)	57.6 (4.2)	61.0 (5.7)
	Pelvic angle	36.7 (2.0)	43.3 (4.6)	43.0 (5.2)
	EMG	55.9 (16.0)	49.4 (20.3)	55.5 (4.2)
Erect Sitting	L1/L3	9.3 (1.8)	12.0 (6.2)	3.8 (5.4)
	L3/L5	20.7 (6.7)	19.3 (3.2)	18.3 (8.6)
	L5/S1	16.0 (2.8)	14.8 (1.6)	16.0 (6.7)
	LSA	46.0 (7.6)	46.1 (9.5)	38.1 (9.4)
	Pelvic angle	32.5 (3.7)	29.3 (3.0)	25.5 (4.9)
	EMG	51.2 (7.0)	62.2 (15.9)	67 (13.7)
Slump sitting	L1/L3	-2.5 (7.2)	1.0 (8.8)	-1.5 (6.3)
	L3/L5	10.5 (11.5)	15.0 (10.1)	15.2 (8.8)
	L5/S1	14.8 (5.6)	13.2 (3.1)	18.0 (4.2)
	LSA	22.8 (15.4)	29.2 (14.5)	31.7 (12.5)
	Pelvic angle	21.7 (10.0)	27.5 (12.0)	31.3 (10.5)
	EMG	70.2 (7.1)	67.5 (12.5)	69.4 (3.0)

*All angles are given in degrees, mean (SD). *EMG are given in % of reference value.

There was also a significant interaction effect of posture and belt ($p<0.046$). Figure 4 illustrated posture and belt effects on the changes of LSA and L5/S1, respectively. In a standing posture, LSA was 8° greater with the lumbar belt and was 11° greater with the pelvic belt than when no belt was worn. In erect sitting, LSA was unaffected by the lumbar belt, but was decreased by 8° with the pelvic belt compared to no belt. When the subject sat in a slumped posture, LSA was increased by 6° and 9° with the lumbar and pelvic belt, respectively. While standing there was a 4° increase in L5/S1 with the pelvic belt and 2° increase with the lumbar belt compared to no belt. This angle was only slightly affected by the belt in the erect sitting posture. In slump sitting, the lumbar belt decreased this angle by 2° but the pelvic belt increased it by 3° compared to no belt.

Mean of the left and the right back muscle EMG was significantly affected by the posture but not affected by the use of belt. When averaged across belt usage, there was a significantly lower EMG on erector spinae (53.6% RV) in standing than that in erect sitting (60.1% RV) and slump sitting (69.0% RV).

Belt effect on LSA was accompanied with a change of pelvic angle. When no belt was worn, pelvic angle reduced from 36.7° (2.0) in standing to 32.5° (3.7) in erect sitting and to 21.7° (10.0) in slump sitting. Significant correlation was found between the backward rotation angles of the pelvis and the flatten angles of LSA ($r=0.692$, $p<0.0001$), also between the decrease of pelvic angles and the increase of back muscle EMG ($r=-0.4$, $p=0.017$). A change in LSA and pelvic angle after wearing a belt along with posture change seems lead to an increase of the myoelectric activities on the back.

Discussion

The accuracy of our measurements must be carefully examined before the discussion can be proceeded. In this study, error of perspective and error of parallax were considered important since they affect the accuracy of geometrical descriptions of the vertebrae. According to Sicard and Gagnon's report, the perspective error is smaller than 4% of the distance measured on vertebrae[20]. In this study, the parallax error was minimized by applying a frame which ensured subject performed his task without twisting the spine. To ensure the quality of angular measurement, angles on each radiogram were repeatedly measured three times, and the mean of these three measurements was used in the statistical analysis. The coefficients of variance for these three measurements were 4.3%, 3.8%, and 5.7% for L1/L3, L3/L5, and L5/S1, respectively. Mean L5/S1 in the standing posture was 17.8° (4.6°). The angle measured by radiograph was in close agreement with Chen and Lee's findings[13] in male Chinese subjects. The mean LSA in the standing was 50.0° (6.8°). This angle was slightly larger than the 46° (6°) of Chen *et al.* Study[21] and the 47.3° (9.6°) of Chen and Lee's findings[12]. Our subjects were recruited mainly from the members of the university swimming team and were considered to have a flexible posterior structure of the hamstrings, thereby, resulting in above flexibility in their lumbar movement.

In standing, LSA with lumbar belt was 8° greater and LSA with pelvic belt was 11° greater than when no belt was worn. In a study of belt effect using a stadiometer, Magnusson and Pope found that the application of support could increase the stature of the subject and a removing of the support could decrease the stature[13]. The results of this

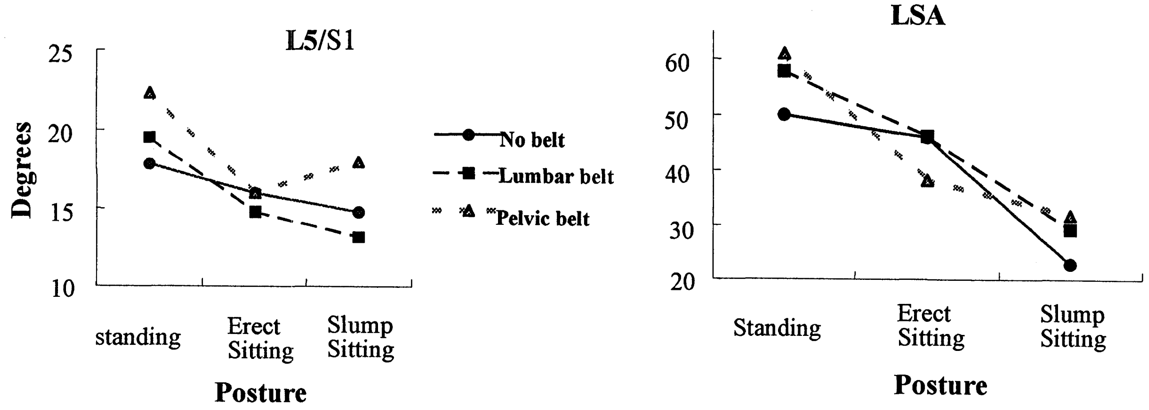

Fig. 4. Illustration of the LSA and L5-S1 changes with postures and belts.

study suggest that it is the changes of LSA that account for the height change.

LSA was less in all sitting in comparison with standing. This result is in general agreement with the findings of many previous researchers. It was known that a hip flexion causes the hip extensors (e.g. the hamstrings) to tilt the pelvis so that the upper portion moves rearward, thus flatting the L5/S1[22]. Decrease of the LSA while sitting could raise the stress on lower back. Our measurement of EMG showed a significantly lower activated level of erector spinae (53.6% RV) in standing than that in erect sitting (60.1% RV) and in slump sitting (69.0% RV). The myoelectric activity increased with trunk flexion. Andersson *et al.* reported that the LSA was inversely proportionate to the amount of intradiscal pressure[23]. In this study, LSA and angular changes in the upper lumbar vertebrae in the slumped posture were reduced to or even less than half of their values in the standing posture. These observations emphasized the importance of sitting as a cause of stress on low back.

The effects of pelvic and lumbar belts on LSA were not the same in different postures. Figure 5 shows that in standing, use of lumbar and pelvic belt increased LSA by increasing nearly all of the vertebral angles. It was calculated by taking the angle with no belt as a reference. When wearing a lumbar belt, LSA increased by 8° and L5/S1 increased by 2° compared to no belt. Wearing a pelvic belt increased LSA by 11° and L5/S1 by 4° compared to not wearing a belt.

Belt effects in erect sitting seem to relate to the particular belt design. When wearing a lumbar belt, small angular change of LSA was due mainly to the fact that the para-spinal muscles and the ligaments were so tighten as to allow very limit movements of the lumbar vertebrates. However, the pelvic belt decreased the LSA by an average of 8°. The decreased LSA can be attributed to the additive effects of backward rotation of the pelvis and the belt constraint on the pelvis[24]. It seems much more difficult to sit erectly with a pelvic belt because the front of belt limited the pelvic forward rotation. When considering the amount of time spent on sitting, it becomes clear that the pelvic belt may increase the risk of a development of back problem by increasing the already increased spinal loading in erect sitting.

In slump sitting, a flexion of the trunk is normally accomplished through a combination of lumbar flexion and pelvis backward rotation. It is interesting that LSA increased with both belts in slump sitting, however, the mechanism responsible for these increases appeared to be different. When the subject flexed the torso at a 15° angle with lumbar belt, there was an increase in L1/L3 and L3/L5 compared to the no belt along with a forward rotation of pelvis. When flexing with a pelvic belt, changes in LSA was achieved mainly by increasing the lower vertebral angles along with a forward rotation of pelvis. It is not clear whether a forward rotation on pelvis would increase the risk of developing low back pain, when the belt was used extensively in a slumped sitting posture (or in other similar working postures with hip flexed, e.g. a pre-lifting posture).

Back muscle EMG was significantly affected by a change of posture but not the belt. Muscle EMG measured at L1/L2 with pelvic belt has been found to be reduced (vs no belt)[25] while holding a weight of 10 and 20 kg and was considered as a load relief brought about by the belt, however, the measurement was not always reduced with belt[6, 9]. In

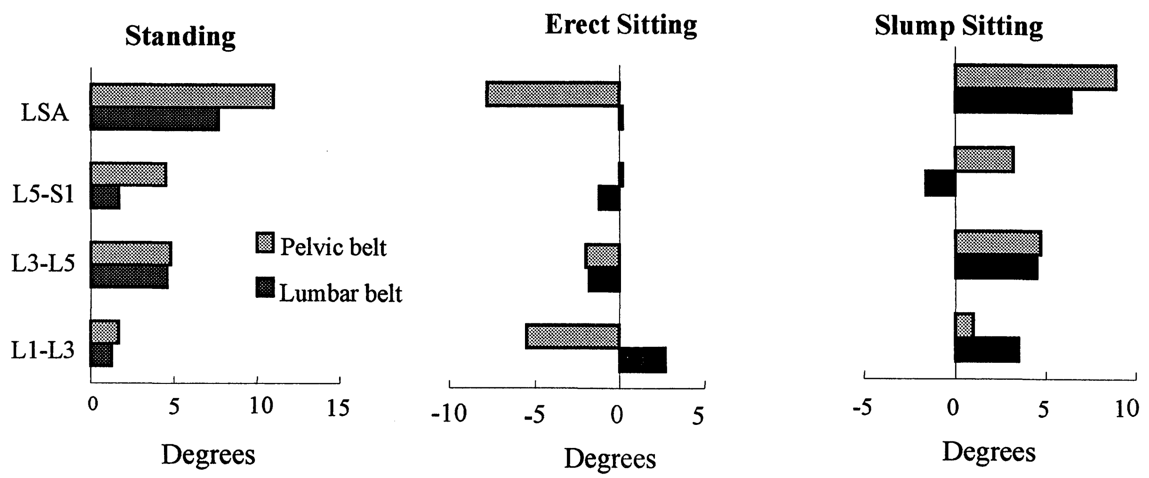

Fig. 5. Effects of the pelvic belt and lumbar belt in reference with the no belt condition.

the study, mean EMG was 58% RV in the no belt condition, 60% RV with lumbar belt, and 64% RV with pelvic belt. Small but non-significant increases in measured EMG during belt wearing may be due to increase antagonistic muscle activities[9]. The correlation between EMG and pelvic angles was statistically significant ($r=-0.4$, $p=0.017$), however, the correlation between EMG and LSA was also negative but not significant ($r=-0.18$, $p=0.36$). We suspected that a backward rotation of the pelvis, tilted by the hip extensors, flatted the L5/S1, might increase the muscle EMG. The lack of concurrence between back muscle EMG and the change of LSA indicate other active spinal load relieving mechanism, such as intra-abdominal pressure, Valsalva manoeuvre, and a concerted effort of entire trunk musculature, need to be examined systematically.

This study had several limitations and caution should be given against indiscriminately applying the results of this study to industrial situations. First, although the influence of belts on LSA and L5/S1 was identified, the amount of spinal load changes and the cumulative tolerance of the spinal structure to this change of loading were not evaluated. Second, although the subjects in this study were selected from a homogeneous population, there were significant individual differences in all responses. Thus, all subjects did not respond in a similar fashion to the same belt. Third, this study was a laboratory study that only examined the effect of different types of belt support on three static postures. Because the difference of loading between static and dynamic working postures can be varied significantly, under realistic industrial lifting conditions, the pattern of trunk extension, knee flexion, and their interactive effects might change the results. Thus, these results must be interpreted with caution.

It can be concluded from the results of this study that there is an interactive effect of working posture and the belt on the change of LSA. Belt effect to the back were not the same in standing as in other postures with knee flexion and trunk flexion. A change in LSA and pelvic angle after wearing a belt along with posture change lead to an increase of back myoelectric activities.

Acknowledgements

The authors would like to thank Dr. Wen-Jer Chen for his help on subject health review, identifying the anatomical landmarks and radiographic recordings. We would also like to thank Cheng-Kung Cheng, PhD, Wen-Ko Chiou PhD, as well as Yi-Lang Chen, PhD, for their recommendations and assistance in the equipment setup.

References

1) McGill SM (1993) Abdominal belts in industry: a position paper on their assets, liabilities and use. Am Ind Hyg Assoc J **54**, 752–4.
2) Reuna JR, Leggett SH (1995) The effect of lumbar belts on isolated lumbar muscle. Spine **20**, 68–73.
3) Granata KP, Marras WS, Davis KG (1997) Biomechanical assessment of lifting dynamics, muscle activity and spinal loads while using three different styles of lifting belt. Clin Biomech **12**, 107–11.
4) Nachemson AL, Andersson GBJ, Schultz AB (1986) Valsalva maneuver biomechanics: effects on lumbar trunk loads of elevated intra-abdominal pressure. Spine **11**, 476–9.
5) Krag MH, Byrne KB, Miller I, Haugh L, Pope MH (1987) Failure of intra-abdominal pressure to reduce spinal loads without and with lumbar orthoses. Proc Orthop Res Soc 33rd Annual Meeting, San Francisco, CA, USA.
6) McGill S, Norman R, Sharratt M (1990) The effect of an abdominal belt on trunk muscle activity and intra-abdominal pressure during squat lifts. Ergonomics **33**, 147–60.
7) CirielloVM, Snook SH (1995) The effect of back belts on lumbar muscle fatigue. Spine **20**, 1271–8.
8) National Institute for Occupational Safety and Health (1994) Workplace Use of back belts. Department of Health and Human Service, Publication No. 94–122, Cincinnati, Ohio.
9) Lantz SA, Schultz AB (1986) Lumbar spine orthosis wearing. Spine **11**, 834–7.
10) Filder MW, Plasmans CM (1983) The effect of four types of support on the segmental mobility of the lumbosacral spine. J Bone Joint Surg **65A**, 943–7.
11) McGill S, Seguin J, Bennett G (1994) Passive stiffness of the lumbar torso in flexion, extension, lateral bending, and axial rotation. Spine **19**, 696–704.
12) Chen YL, Lee YH (1997) A noninvasive protocol for the determination of lumbosacral vertebral angle. Clin Biomech **12**, 185–9.
13) Magnusson M, Pope MH (1996) Does a back support have a positive biomechanical effect? Applied Ergonomics **27**, 201–5.
14) Chaffin DB, Andersson GBJ (1991) Occupational biomechanics. 2nd ed, 335–8, John Wiley & Sons, Inc, USA.
15) Montgomery DC (1991) Design and analysis of

experiments. 3rd ed, 395–408, John Wiley & Sons, New York.

16) Burdett RG, Brown KE, Fall MP (1986) Reliability and validity of four instruments for measuring lumbar spine and pelvic positions. Physical Therapy **66**, 677–84.

17) Lee YH, Chiou WK, Chen WJ, Lee MY (1995) Prediction model of inter-segmental mobility of lumbar spine in the sagittal plane from skin makers. Clin Biomech **10**, 413–20.

18) Jonsson B, Hagberg M (1974) The effect of different working heights on the deltoid muscle. Scand J Rehabil Med [suppl] **3**, 26–32.

19) Janda DH, Geiringer SR, Hankin FM, Barry DT (1987) Objective evaluation of grip strength. J Occup Med **29**, 569–71.

20) Sicard C, Gagnon M (1993) A geometric model of the lumbar spine in the sagittal plane. Spine **18**, 646–58.

21) Chen MW, Yang SW, Lee MC (1994) Changes in lumbar disc angles of Chinese subjects from upright to flexion. Spine **19**, 1490–4.

22) Bridger RS, Wilkinson D, Houweninge TN (1989) Hip joint mobility and spinal angles in standing and in different sitting postures. Human factors **31**, 229–41.

23) Andersson GBJ, Ortengren R, Nachemson AL, Elfstrom G, Broman H (1975) The sitting posture: An electromyographic and discometric study. Orthop Clin North Am **6**, 105–20.

24) Andersson GBJ, Murphy RW, Ortengren R, Nachemson AL (1979) The influence of backrest inclination and lumbar support on lumbar lordosis. Spine **4**, 52–8.

25) Udo H, Yoshinaga F (1997) Effect of a pelvic belt on abdominal pressure by various weights and bending angles. Industrial Health **35**, 229–34.