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The Effect of Wearing a Back Belt on Spine Kinematics During Asymmetric Lifting of Large and Small Boxes

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Study Design. A crossover design was used to evaluate kinematic measurements collected with an infrared-based motion measurement system.

Objectives. To evaluate belt effects on spine kinematics during asymmetric lifting of large and small boxes and to test for carryover effects between trials from belts.

Summary of Background Data. Conflicting evidence in the literature exists regarding whether belts are beneficial or detrimental to manual material handlers. Studies have not examined belt effects when lifting different sized boxes, nor carryover effects from belts.

Methods. Twenty-eight subjects with manual-handling experience (17 male and 11 female) were randomly assigned to lift either a large or small box (weighing 9.4 kg), from a sagittally symmetric origin at pallet height to a 79 cm height, 60° to the right. Spine flexion, lateral bending and twisting, hip and knee flexion, and angular velocity measurements of the torso with respect to the pelvis were collected for each of three lifting periods, 50 lifts each at 3 lifts per minute, with 18-minute breaks between periods.

Results. Belts significantly reduced maximum spine flexion, spine flexion and extension angular velocities, and torso left lateral bending angular velocity, and increased hip and knee flexion, regardless of box size. When lifting large boxes, belts significantly reduced torso right lateral bending and torso left twisting. No significant differential carryover effects were detected from belts.

Conclusions. Subjects with belts lifted more slowly and used more of a squat-lift technique, regardless of box size. Belts reduced more torso motions while lifting large boxes. [Key words: back belts, lifting, torso, kinematics] **Spine 2001;26:1794–1798**

Several laboratory studies have investigated whether the use of back support belts affects the kinematics of the low back during manual material handling.[3,8,11,14,15] However, the kinematic effects of back belts when lifting boxes of different sizes has not been previously investigated, even though lifting with different box sizes is a practical concern in the workplace and torso kinematic parameters have been reported to be predictive of low back disorder risk.[9,10]

The primary purpose of this study was to determine if the use of an elastic lumbar back support has an effect on spine kinematics during asymmetric lifting of both small- and large-sized boxes. In general, small objects can be lifted with a stoop or squat lifting style; large objects may impose a stoop lifting style. Back supports may affect the low back differently during stoop and squat lifts.

A secondary objective was to determine whether or not this experimental design is appropriate for evaluating multiple belts by testing for a carryover effect between trials as a result of wearing back supports. It may be hypothesized that the effect of back support use on kinematics may carry over beyond the individual test trial. This learning effect could confound back belt experiments. Prior studies have neglected to consider the effects of carryover from back support use on kinematics. In this study both differential and nondifferential carryover effects were investigated. Differential carryover tests whether the effect of the belt is influenced by the order of starting with or without the belt. Nondifferential carryover tests for a residual (learning) effect from wearing the belt in the previous period.

Materials and Methods

Twenty-eight volunteers (17 male and 11 female) were used with an average age of 29.5 years (range 18–42 years; median 30 years). The average height was 172.5 cm (7.7 cm SD) and mass was 77.5 kg (16.1 kg SD). Health questionnaires verified that subjects had no history or symptoms of low back pain, were not pregnant, and had a minimum of 6 months manual materials-handling experience. A musculoskeletal physical examination and ECG check by a licensed physician were completed before participation. Compensation for time and inconvenience was given for both the physical and test sessions. The protocol was approved by the Human Subjects Review Board of the National Institute for Occupational Safety and Health (NIOSH).

Experimental Design. The experimental design was a three-period, two-treatment, crossover clinical trial design with two sequences of treatment assignment.[8] The design was selected to assess the effect of belt wearing and carryover effects between periods. This design allows treatment tests in the presence of carryover. Subjects were randomized into two groups with different belt treatment sequences: 1) BNN (*i.e.*, belt worn in the first data collection period; no belt worn in the remaining two data collection periods) and 2) NBB (*i.e.*, no belt worn in the first data collection period; belt worn in the remaining two data collection periods).

Apparatus. Subjects were randomly assigned to lift either a small box (46 cm high × 30 cm wide × 25 cm deep) or a large box (46 cm high × 50 cm wide × 25 cm deep). Both boxes weighed 9.4 kg and had no handles.

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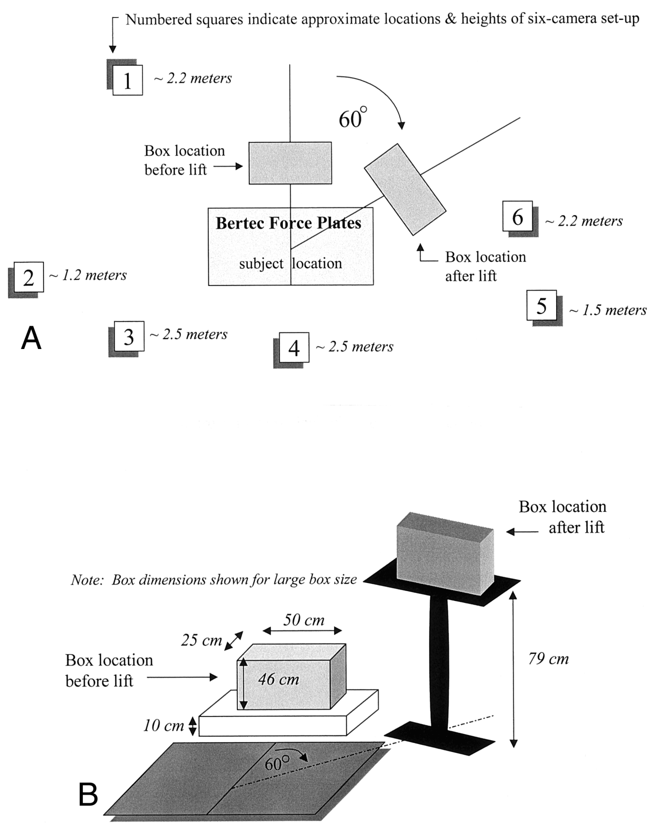

Figure 1. Experimental setup. **A,** Top view. **B,** Perspective view.

The experimental setup (Figure 1) consisted of two 4060-08 Bertec force plates (Bertec Corp., Worthington, OH) and a six-camera ProReflex Motion Capture Unit (Qualisys, Glastonbury, CT). Force plate data were captured using an AT-MIO-16E-10 National Instruments DAQ card (National Instruments, Austin, TX) and an interface developed in LabView version 3.1.1 on a microcomputer. Force plate and motion data were sampled at 120 Hz, and the two systems were synchronized using a Transistor-Transistor Logic (TTL) signal from the ProReflex system indicating the start of data collection.

The ProReflex system was calibrated using a CAB1000 calibration frame (Qualisys, Glastonbury, CT) before testing each subject. Fixed angles representative of the back belt study were examined to assess the accuracy of the motion measurement system. Results indicated no appreciable bias (<1.0°) in these angular measurements (unpublished observation).

A plate of three reflective markers was placed on the left force plate to form a global coordinate system in which +X pointed in the same direction that the subject faced, +Y pointed to the left, and +Z pointed upward. This plate was placed on each force plate at prescribed locations to also define the location of each force plate in the global system. Similarly, all position data measured with the ProReflex system were converted to the global coordinates.

The lifting setup was designed to simulate the task of stocking shelves from a pallet. The box to be lifted was located on a board 10 cm above the top surface of the force plates, 3 cm in front of the toes of the shoes. A 79-cm tall stand was placed 60° to the subject's right. The box was aligned with the midsagittal plane of the subject, and the subject lifted the box and set it down on the stand. The same elastic belt that was tested in the companion NIOSH epidemiologic study[17] was also used in this study. The belt (Figure 2) was constructed of mesh in the back that was connected to Velcro ends. The mesh was 21 cm wide at the middle, and the length ranged from 76 cm for the extra-small size belt to 129 cm for the extra-extra-extra-large size. Two 33-cm elastic bands stretched from the midline to Velcro tabs that attach to the velcro on the ends of the mesh. Seven sizes ranging from extra-small to extra-extra-extra-large belts were available for subjects to select.

Reflective markers were placed on the subject at the greater trochanter, anterior superior iliac spine, lateral femoral condyle, tibial tubercle, lateral malleolus, heel, and the fifth metatarsal. The lower extremity markers were used for computing hip and knee kinematics using the gait analysis method described by Vaughan et al.[16]

Triads were constructed with three reflective markers placed on the ends of 13-cm wooden dowels attached to a wooden base. The thoracic triad was placed on the subject at T6 and the sacral triad was placed over the sacrum (Figure 3). Spine kinematic measures were computed from triad marker positions. An orthogonal coordinate system was constructed at the pelvis: **i** pointed from the right to left anterior superior iliac spines (ASIS), **j** was the cross product of a vector pointing from the posterior superior iliac spine (estimated from the sacral triad position) to the left ASIS and **i**, and **k** was the cross product of **i** and **j**. One of the sacral triad markers was chosen to be the origin of the new coordinate system. The location of each triad marker was transformed into the new coordinate system. The rotation matrix describing the rotation of the thoracic triad relative to the sacral triad was estimated using a least squares procedure.[13] A 2–3'-1″ Euler rotation sequence was used to compute twisting, lateral bending, and flexion, respectively, from the rotation matrix.[1]

Procedures. After receiving an oral briefing of study procedures, subjects gave written consent to participate and changed into black tights. Belts were placed with the lower edge over the sacrum posteriorly. The inferior edge was generally located at the level of the ASIS anteriorly. The proper size, appropriate tightness, and instructions for wearing the belt were based on manufacturer's instructions. Subjects were instructed to tighten belts until snug but not causing discomfort. Tightness was ad-

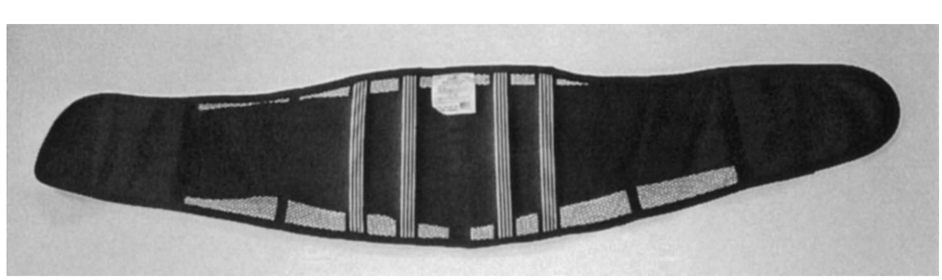

Figure 2. Elastic-type back belt.

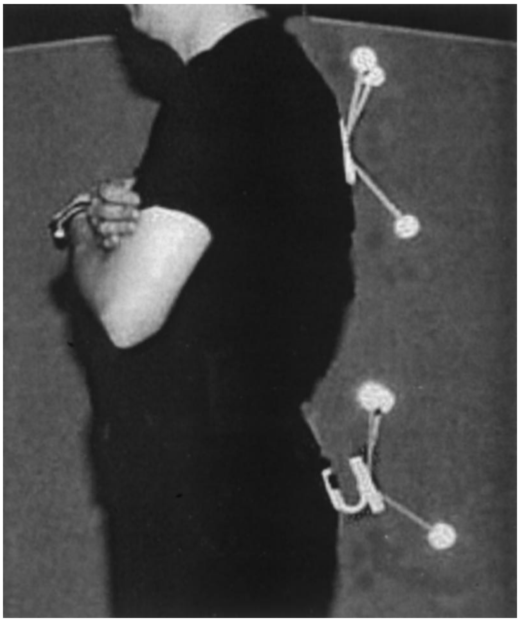

Figure 3. Locations for thoracic and sacral triads.

justed by the location of bands on each side of the belt onto the front Velcro. Reflective markers were placed on subjects using adhesive and Velcro. The pelvis triad base was placed underneath the belt, using double-sided tape and Velcro straps. The thoracic triad was placed through a hole in the shirt onto the skin using double-sided tape.

Anthropometric measurements that were taken included all measurements required by the method of Vaughan et al.[16] These include the following: body mass, ASIS breadth, thigh length, midthigh circumference, calf length, calf circumference, knee diameter, foot length, malleolus height, malleolus width, and foot breadth. The vertical distance from the top of the pelvis triad base plate and the top of the iliac crest was also measured. Subjects were asked to stand on the force plates, perform a practice lift session, and find a comfortable foot placement. This placement was marked to ensure consistency during subsequent lifting periods. Subjects were instructed not to take a step during the lifts. During this time the ProReflex system was checked to ensure that markers could be identified and tracked.

Each test period consisted of a "neutral posture" measurement (subjects stood looking forward) followed by 50 lifts at a rate of three times per minute. The pace was set by an electronic tone generator. Subjects were instructed to lift at the end of the 1-second tone. Data collection occurred on the 36th, 42nd, and 48th lift without the subject's awareness. Eighteen-minute rest periods were given between test periods so that lifting tasks would be within the recommended NIOSH lifting equation weight limit.[18] Subjects were instructed to hold the far upper left corner of the box with the left hand and the near lower right corner with the right hand. No instructions were given about how to lift (*i.e.*, stoop or squat). The belt was removed or worn according to the belt treatment sequence assigned.

Motion data were tracked using MacReflex version 3.41 PPC software (Qualisys, Glastonbury, CT). The kinematic calculations were programmed in MATLAB v.5.2 (The Mathworks, Natick, MA) on a Silicon Graphics O2 workstation. Data were digitally filtered using a fourth-order low-pass Butterworth filter having a cutoff frequency of 6 Hz. Motion data were plotted and reviewed for obvious faults. Statistical analysis was performed using S-PLUS 4 software (Mathsoft, Seattle, WA).

Data Analysis. Possible differential carryover effects were considered using data from the first two periods.[2] This test assesses the difference for the averages of the first two periods comparing the two belt treatment sequence groups, BNN and NBB, or $(B_1 + N_2)/2 - (B_2 + N_1)/2$. The results of this study were analyzed using within-subject linear function analysis.[4] Data from the second and third periods were used to perform a within-subject linear function analysis to assess the significance of nondifferential carryover effects. This test assesses the differences between periods 2 and 3 for the same belt treatment sequence, or $(N_3 - N_2) - (B_3 - B_2)$. The within-subject linear functions were also examined graphically for diagnostic purposes.[12] Because of the limited sample sizes, exact nonparametric methods based on the Wilcoxon signed rank test[5] were used to obtain estimates, approximate 95% confidence intervals, and obtain *P* values of the linear function test of belt effects. The most efficient linear function test of a belt effect compares the difference between the first period measurements and the mean of the values in the second and third periods for each test subject. This test is a valid test of the belt effect even in the presence of nondifferential carryover effects.

The within-subject linear function analysis was used to test the large- and small-box data sets separately. In contrast to other linear model data-fitting approaches, this test has fewer assumptions and only a single parameter estimate for the belt effect. The results from the two separate data sets were combined to achieve greater statistical power when all of the following three conditions were observed:

1. Both large- and small-box results are of a similar magnitude and sign.
2. Both large- and small-box results have "borderline" *P* values (>0.05 but ≤ 0.10).
3. The combined results simply gain power without much change in the estimates resulting in a $P \leq 0.05$.

Results

Maximum spine flexion, right lateral bending, and left twisting were significantly reduced while wearing a belt and lifting a large box (Table 1). Maximum flexion angular velocity and maximum extension angular velocity were also significantly reduced. Right and left hip maximum flexion and left knee maximum flexion increased significantly with belt while lifting a large box.

The belt worn while lifting the small box (Table 2) resulted in a significant reduction for maximum flexion. No significant effects were found for torso lateral bending or twisting. As in the large-box data set, both maximum flexion angular velocity and maximum extension angular velocity significantly decreased while wearing a belt and lifting a small box. Right and left hip maximum flexion and right knee maximum flexion increased significantly when wearing a belt.

The belt effect for left lateral bending maximum angular velocity while lifting small and large boxes was similar (4°/sec and 3°/sec, respectively) with *P* values of 0.10 and 0.07, respectively. The data sets were combined

Table 1. Statistical Analysis Results of Belt Effects for Large Box Data Set

Variable	Median*	95% CI	*P* Value
Spine maximal flexion	−4.9	−8.6, −2.0	<0.01†
Maximal right lateral bending	−1.7	−4.5, −0.6	<0.01†
Maximal left lateral bending	−0.1	−1.1, 0.7	0.63
Maximal right twisting	+0.7	−0.1, 1.8	0.08
Maximal left twisting	−2.8	−4.7, −1.3	<0.01†
Flexion maximal angular velocity	−18.9	−32.5, −9.5	<0.01†
Extension maximal angular velocity	+9.0	1.8, 22.2	0.02†
Right bend maximal angular velocity	−3.3	−9.4, 1.8	0.19
Left bend maximal angular velocity	+3.4	−0.3, 6.1	0.07‡
Right twist maximal angular velocity	−3.1	−9.4, 3.5	0.19
Left twist maximal angular velocity	+1.2	−4.9, 10.3	0.72
Right hip maximal flexion	+13.0	1.1, 28.9	0.03†
Right knee maximal flexion	+7.5	−1.9, 18.7	0.10
Left hip maximal flexion	+11.9	5.1, 19.6	<0.01†
Left knee maximal flexion	+8.0	0.8, 16.7	0.02†

Angular motion (degrees); angular velocity (degrees/second).
* Belted minus no belt condition.
† Significant difference.
‡ Significant when combined with small box results.

to gain power for evaluating the belt effect. The combined results indicated that the belt significantly decreased left lateral bending angular velocity by about 3°/s ($P = 0.01$), regardless of box size.

No statistically significant differential carryover effects were detected. A significant nondifferential carryover effect in the large-box data set occurred for left lateral bending angular velocity ($P = 0.03$) and left hip maximum flexion ($P = 0.04$). No nondifferential carryover effects occurred in the small-box data set.

■ Discussion

Belt use significantly affected spine kinematics by decreasing maximum spine flexion, maximum spine flexion angular velocity, maximum spine extension angular velocity, and maximum torso left lateral bending angular velocity for both box sizes, and maximum torso right lateral bending and maximum torso left twisting for lifts with the large box.

Table 2. Statistical Analysis Results of Belt Effects for Small Box Data Set

Variable	Median*	95% CI	*P* Value
Spine maximal flexion	−8.1	−11.8, −2.5	<0.01†
Maximal right lateral bending	−2.2	−4.2, 0.5	0.10
Maximal left lateral bending	+0.5	−1.5, 2.1	0.50
Maximal right twisting	−0.6	−3.5, 1.2	0.46
Maximal left twisting	−0.0	−1.4, 1.2	0.86
Flexion maximal angular velocity	−21.1	−37.3, −2.4	0.03†
Extension maximal angular velocity	19.7	14.1, 25.9	<0.01†
Right bend maximal angular velocity	−2.5	−7.2, 2.0	0.30
Left bend maximal angular velocity	+3.7	−0.9, 9.8	0.10‡
Right twist maximal angular velocity	−0.8	−9.7, 4.8	0.76
Left twist maximal angular velocity	+5.1	−2.6, 14.3	0.24
Right hip maximal flexion	+11.3	4.3, 17.5	<0.01†
Right knee maximal flexion	+9.9	1.4, 17.7	<0.01†
Left hip maximal flexion	+10.8	3.3, 17.5	<0.01†
Left knee maximal flexion	+7.9	−0.7, 21.3	0.07

Angular motion (degrees); angular velocity (degrees/second).
* Belted minus no belt condition.
† Significant difference.
‡ Significant when combined with large box results.

Although the effect of the belt reduced motions in the sagittal plane, regardless of box size, there were no significant effects on torso lateral bending and torso twisting when lifting small boxes. By placing the left hand on the upper left corner of the box and the right hand on the lower right corner of the box, the subject naturally bends laterally more to the right and twists more to the left as the box size increases. Belt use may be more restrictive as the subject's torso posture becomes more asymmetric, possibly explaining the reduction in right lateral bending and left twisting of the torso that is observed while wearing a belt during lifts with large boxes but not observed during lifts with small boxes. Torso posture would tend to be more symmetric when lifting a smaller box. Therefore, the restrictive nature of the belt may not affect the subject.

Sparto et al[14] reported reduced sagittal trunk angular motion with no significant effects in the transverse or lateral planes using a flexible-type belt during asymmetric lifting with the LIDOLift (Loredan Biomedical, Sacramento, CA). The LIDOLift box, which has holes for handles on either side to promote symmetric lifting, may be the major contributing factor for the similarity between these results and the small-box results in our study. Lavender et al[8] found that belt use during asymmetric lifting reduced lateral bending, angular velocity, and torso twisting, but no statistically significant effects were found in sagittal plane lifting. Subjects in this study wore the belt for 1 week during normal working duties before the lifting session and wore a measurement device with straps during the experiment. These factors may have contributed to the difference in torso flexion during belt use as compared with our study, which had no restriction on subjects.

The subjects lifted more slowly when wearing the belt. This finding lends support to the results regarding belt use on trunk angular velocities in the sagittal plane reported by Granata et al,[3] Jonai et al,[6] and Sparto et al.[14] Additionally, the reduction in trunk lateral bending angular velocity from belt use is similar to the results reported by Granata et al.[3] It should be noted that the results from this study are based on a controlled motion of the box throughout the lifting exertion and, therefore, may not be applicable to other types of manual material-handling jobs.

Belt use increased both right and left hip maximum flexion at about equal magnitudes regardless of box size. This was also true for right and left knee maximum flexion. Considering that belt use also decreased torso movements, it appears that using a back support belt causes the subject to use more of a squat-lift technique as opposed to a stooping technique. Similar findings were reported by Granata et al[3] and Sparto et al.[14] McGorry and Hsiang[11] reported decreases in lumbar range of motion but did not find a change in pelvis range of motion when the subjects performed symmetric lifting/lowering tasks.

The significant nondifferential carryover effects for left lateral bending and left hip maximum flexion indicated a residual or learning effect from wearing the belt while lifting large boxes in consecutive periods for these variables. Despite the limitation that the tests for nondifferential carryover are across subjects, which includes subject variability, significant carryover effects were still detected. According to Jones and Kenward,[7] some effects (of secondary importance) may be confounded in this design; however, it still provides a valid test of belt effects even in the presence of carryover. Previous studies that have not considered the effects of carryover may have had invalid results. Winer[19] recommended that repeated measures analyses are to be avoided when carryover or order effects are likely, even if the design is counterbalanced with paired treatment sequences.

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■ Key Points

- This study indicated that the effects on torso lateral bending and twisting when using a lifting belt were significantly different for different box sizes.
- A tendency to use a squat-lift technique and lift more slowly was indicated while wearing a lifting belt, regardless of box size.
- The experimental design would be appropriate for evaluating multiple belts.

References

1. Crawford NR, Yamaguchi GT, Dickman CA. Methods for determining spinal flexion/extension, lateral bending, and axial rotation from maker coordinate data: analysis and refinement. Hum Mov Sci 1996;15:55–78.
2. Fleiss JL. The Design and Analysis of Clinical Experiments. New York: John Wiley and Sons, 1986:432.
3. Granata KP, Marras WS, Davis KG. Biomechanical assessment of lifting dynamics, muscle activity and spinal loads while using three different styles of lifting belt. Clin Biomech 1997;12:107–15.
4. Hafner KB, Koch GG, Andrew TC. Some analysis strategies for three-period changeover designs with two treatments. Stat Med 1988;7:471–81.
5. Hollander M, Wolfe D. Nonparametric Statistical Methods. New York: John Wiley & Sons, 1973:26–66.
6. Jonai H, Villanueva MB, Sotoyama M, et al. The effect of a back belt on torso motion: survey in an express package delivery company. Ind Health 1997; 35:235–42.
7. Jones B, Kenward MG. Design and analysis of cross-over trials. New York: Chapman and Hall, 1989:152–63.
8. Lavender SA, Thomas JS, Chang D, et al. Effect of lifting belts, foot movement, and lift asymmetry on trunk motions. Hum Factors 1995;37:844–53.
9. Marras WS, Lavender SA, Leurgans SE, et al. Biomechanical risk factors for occupationally related low back disorders. Ergonomics 1995;38:377–410.
10. Marras WS, Lavender SA, Leurgans SE, et al. The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. Spine 1993;18:617–28.
11. McGorry RW, Hsiang SM. The effect of industrial back belts and breathing technique on trunk and pelvic coordination during a lifting task. Spine 1999; 24:1124–30.
12. Miller WE. A visualization of cross-over data using linear functions. Stat Med 1999;18:975–87.
13. Soderkvist I, Wedin P-A. Determining the movements of the skeleton using well-configured markers. J Biomech 1993;26:1473–7.
14. Sparto PJ, Parnianpour M, Reinsel TE, et al. The effect of lifting belt use on multijoint motion and load bearing during repetitive and asymmetric lifting. J Spinal Disord 1998;11:57–64.
15. Thoumie P, Drape JL, Aymard C, et al. Effects of a lumbar support on spine posture and motion assessed by electrogoniometer and continuous recording. Clin Biomech 1998;13:18–26.
16. Vaughan CL, Davis BL, O'Connor JC. Dynamic of Human Gait. Champaign, IL: Human Kinetics, 1992.
17. Wassell JT, Gardner LI, Landsittel DP, et al. A prospective study of backbelts for prevention of back pain and injury. JAMA 2000;284:2727–32.
18. Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 1993;36:749–76.
19. Winer BJ. Statistical Principles in Experimental Design. New York: McGraw-Hill, 1971:517.

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