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Effects of a New Industrial Lifting Belt on Back Muscular Activity, Hand Force, and Body Stability during Symmetric Lifting

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Abstract: This work investigated how wearing a new design of back belt affects erector spinae activity, hand force, and body stability. The belt was first tested with static holding tasks and found to significantly decrease the back muscle activity. Actual lifting tasks were further carried out to test the effect of the belt. Ten male subjects performed a symmetric lifting task of low-lying loads (11 and 16 kg) at natural toting velocity, using either a squat or stoop lifting posture, both with and without a belt. The study measured various independent variables using electromyography (EMG), load cells, and motion capture device. The results demonstrated that the belt reduced the load on the erector spinae, as well as the triceps brachii and biceps brachii. The overall mean values of the peak (hand) force did not appear significantly affected while wearing the belt, but the force peaks appeared postponed. The belt did not alter body stability while lifting. From the present findings, the belt effectively changed the force distribution during lifting, at least reducing the muscle load on the back. The belt may be a potentially useful device for symmetric industrial lifting tasks.

Keywords: Back belt, EMG, Hand force, Body stability, Lifting

Introduction

Numerous industrial jobs involving manual materials handling (MMH) require employees to lift objects with various weights and shapes from various locations. Consequently, many workers face a high risk of lifting-related injuries. Waters[1] observed that MMH is generally considered a major hazard in the workplace. Back pain is one of the injuries to result from MMH. Back pain is an extremely common complaint, and affects an estimated 60 to 80% at some time in their lives in the united states[2]. Meanwhile, low back pain is the second leading cause of absenteeism in industrial settings[3]. Approaches for reducing the incidence of MMH-related pain have involved engineering design/redesign to fit the task to worker, proper training in MMH, using personal protective equipment, and so on[4]. Among those methods, the use of back belt became a common means of preventing low-back injuries during the late 1980s and 1990s.

Common claims regarding the effect of back belts include that they are an increment of intra-abdominal pressure (IAP), reduce compressive and shear forces on the spine, restrict torso movement, stiffen the spine, provide circumferential support around the pelvic ring, and so on[5]. Although the above opinions have been used to support the use of back belts and many studies have investigated the effect and mechanisms of various abdominal belts, the literature remains equivocal. Van Poppel *et al.*[6] systematically reviewed lumbar supports. The effect on the EMG of the low back musculature was ambiguous. Some studies indicated that the belt reduces the EMG signal for dorsal muscles[7, 8]. Meanwhile, some authors reported an increase in low back activity[9, 10]. Others found no significant effects[11, 12]. Apparently, no definitive conclusions can be drawn with respect to the effects of waist

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belts on musculoskeletal load.

On the other hand, the most cited mechanism was IAP. It has long been suggested that increasing IAP can decrease spinal load. Researchers have hypothesized that decreased spinal load, for example that achieved by increased IAP, can reduce EMG activity in truck musculature5). However, the relationship between IAP and EMG activity of the erector spinae muscles is controversial, since some of the findings did not support the above hypothesis. Lander13) demonstrated a significant increase in IAP and a significant decrease in EMG activity of back extensors when wearing a belt vs. not wearing a belt. However, Krag *et al.*9) noted IAP increased with increasing dorsal muscle activity. Furthermore, McGill *et al.*14) also examined whether the theory that IAP reduced disc loading had received excessive emphasis. Obviously, those studies were inconsistent. Additionally, the relationship between IAP and prevention of back injury and reducing force on the spine is not fully understood, and evidence supporting this relationship is scant. Bauer *et al.*15) showed that recent research has questioned the validity of using these belts to reduce the stress imposed on the regional musculoskeletal system (such as lumbar and sacral spine) and the muscles acting posteriorly to these structures, mainly the erector spinae. NOISH16), had also concluded that even if a back belt increased IAP, no evidence existed to support its reducing the forces on the spine and thus helping to prevent back injury.

To summarize, considerable controversy continues to exist regarding whether the belts are helpful in MMH. In addition, an obvious and serious side effect caused by high IAP was the uncomfortable feeling by tightly wearing the waist belt. This study tries to apply a different approach to the problem. Instead of relying on the waist belt (IAP) effect, a new belt was designed with focus on the linkage of straps across the upper-body and leg (patent registered in Taiwan, No.188786). This paper describes the design and evaluation of the belt.

The belt comprised three main parts: hand-suspenders, waist belt, and thigh-straps. The waist belt follows the design of the conventional industrial lifting belt. The hand-suspenders and the thigh-straps are connected to the waist belt. The width of the waist belt was about 5 cm which was more slender than the conventional belt. Most part of the belt was made from a woven mesh material that was stretchable and equipped with Velcro closures for tightening. The belt is designed to be worn around the waist as a conventional belt except that the hand can be placed in the open glove at the end of the hand-suspender and the thigh-straps can be closed around the thigh while in use. The hand-suspender was made from flexible material and was treated as an artificial muscle spreading the arm. While lifting, the hand-suspender was extended and it may store elastic potential energy before lifting, which may then be released during lifting. Some of the force may also be passed to the thigh area. When the thigh-strap is not closed and the hand-suspender is not used, the belt is in fact identical to most conventional industrial lifting belts. It was hypothesized that the new belt primarily alters the spatial distribution of force on the body and may also alter the temporal pattern of force. The belt was tested with two experiments, one static holding task (Experiment 1) and the other a dynamic lifting task (Experiment 2). The static holding experiment first confirmed that the belt significantly reduced the muscle activity of the erector spinae under isometric contraction. The second experiment then tested the belt under a dynamic industrial lifting condition. In particular, belts used in two experiments were slightly different. The difference appeared at the hand structure. In dynamic experiment, the end of suspender of the belt was glove, while the end was hook in the static experiment. As space was limited, we just showed the outline of the gloved belt in Fig. 1. This paper reports the results of the two experiments as follows.

Materials and Methods

Experiment 1

Ten healthy male students participated in the experiment. Their mean age, height, and weight (± SD) were 23.5 ± 1.84 yr, 174.5 ± 4.19 cm, and 66.5 ± 12.24 kg. EMG electrodes were attached bilaterally to all subjects on the surface of the erector spinae at L1–L2 location after cleaning and gentle abrasion of the skin. The sampling frequency was 200 HZ and sampling duration was 5.

There were three independent variables, weight of load, height, and belt use. The weight was set at two levels: 0 kg and 10 kg. The heights included three levels: 0 cm, 22 cm, and 75 cm above the floor. Each subject was tested for three belt conditions: no belt (NB), in which the load was held with hands without wearing any belt, hand lifting with belt (HaB), in which the belt was worn but the load was held with hands, and hooks lifting with belt (HoB), in which the load was held with the hand-suspender with hooks attached to it. As a result, a total of eighteen (2 weights × 3 heights × 3 belt conditions) tasks were performed by each subject. In each task, the subject lifted the load up to the specified level of height and held the load statically and symmetrically. The EMG signal was recorded for the static

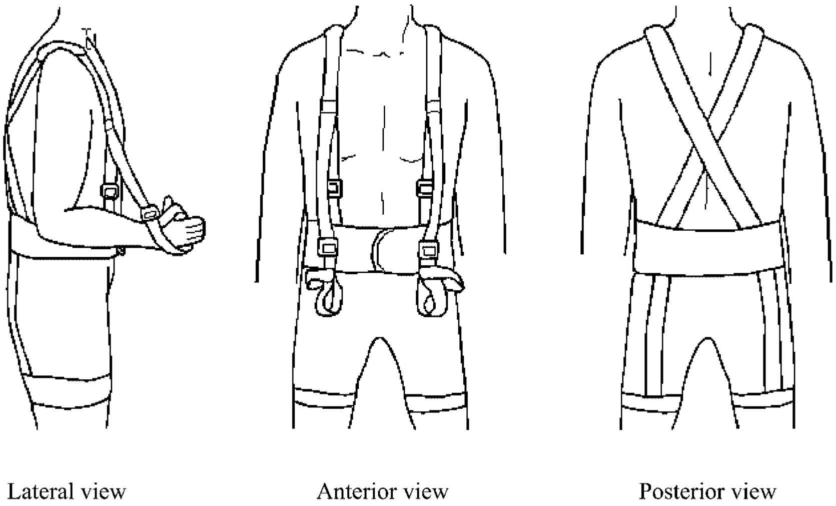

Fig. 1. The self-designed lifting belt used in the study.

holding period. At least 5 min of rest was given between two successive lifts to avoid muscle fatigue.

Experiment 2

Subjects

Eleven male students were recruited as subjects. The subjects had no history of low-back pain or other musculoskeletal complaints. The mean values for age, height, and body weight were 23.5 yr (SD=1.8), 1.74 m (SD=4.19) and 66.5 kg (SD=12.2), respectively. All subjects signed an informed consent form before the experiment and were paid for their participation.

Materials and apparatus

During the testing, body motion was measured in three-dimensions using PCReflex Motion Capture System (Qualisys Inc.). The system included two integrated LED cameras placed 5 m directly right of the subjects. The camera tracked reflective markers attached on the body at 60 Hz. The markers were pasted to six body joints, including the shoulder, elbow, wrist, hip, knee, and ankle.

A 48 × 32 × 28 cm^3 wooden box with an open handle on each side was used as the load object in this study. Load cells (max. load: 250 lbs, Nonlineraity: 0.03%) were mounted on the handles of the box. This device converts force or weight value into electrical signals. The data were amplified and recorded at a sampling rate of 60 Hz using a 16-bit A/D converter.

The EMG signals were recorded from the left and right Ag/AgCl electrodes (3 cm apart). Four pairs of electrodes were positioned longitudinally over the right and left erector spinae muscles, biceps brachii, and triceps brachii (Fig. 2), respectively. Generally speaking, the electrodes mounted at erector spinae was higher than the top edge of the waist belt. It appeared that there was not interference between the electrodes and the waist belt or straps. The EMG signals were sampled at 1,000 Hz and amplified at gain 1000, and fed to a computer via an A-to-D converter.

Since several measurements were made by different equipment, synchronization acknowledgement was required. A switch (on/off) linked to a light bulb via a wire was fitted to the bottom of the box. At each lift-off, the switch was turned on, +5 volt was accepted by A/D acquisition, and the light bulb lit up, which would be recognized by the motion capture system while digitizing. The lift-off event marked in log files was useful for later analysis. Figure 3 shows the layout of these apparatuses.

Experimental design

Because of the variation among lifting conditions in actual factories, three additional independent variables were chosen for the belt vs. no-belt evaluation, including lifting load, lifting height, and lifting posture. The lifting tasks involved lifting either 11 kg or 16 kg low-lying loads. There were two lifting heights: one lift began at 22 cm above the floor and ended at knuckle height 75 cm above the floor (H_HL), while the other was from the floor to knuckle height (H_FL). Two lifting postures were considered, namely squat and stoop. Each trial was performed with or without the use of the belt. Sixteen lifting task combinations (2 × 2 × 2 × 2) were performed according to a randomized schedule.

Several measurements were made as dependent variables.

Biceps brachii and triceps brachii

Erector spinae

Fig. 2. Four pairs of EMG electrodes layout.

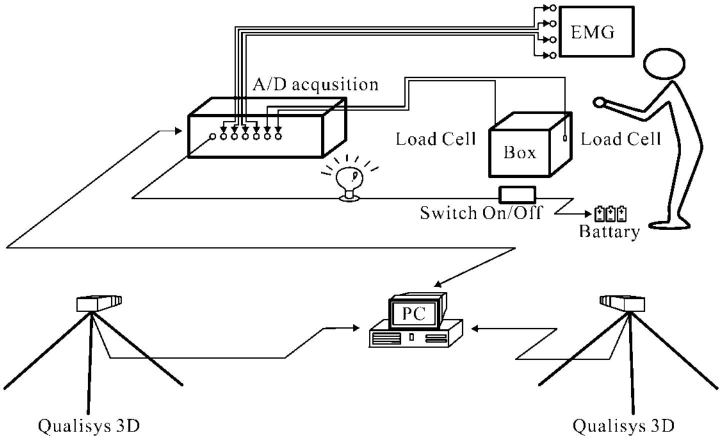

Fig. 3. The apparatus layout and synchronization acknowledgement mechanism.

The EMG signals were sampled for the biceps brachii, triceps brachii, and erector spinae muscles. Hand forces were collected at the handle with load cells. Joint motion data were obtained and center of mass was calculated.

Procedures

During the experiment, each subject was asked to position their feet comfortably. The location of the two feet was then marked and the subject was requested to stand in the same place for subsequent lifting activities. Subjects were instructed to practice symmetric lifts along the sagittal plane without holding their breath and asked to perform all lifting activities as smoothly as they could. Subjects were required to lift the box onto the knuckle-height table.

After completing some training, each subject was asked to wear short trousers and a T-shirt to minimize interference from clothes. Reflective markers were attached to the six joints, and the four pairs of electrodes were fixed to the relevant muscle groups. To ensure the effect of the belt was maximized, each subject was also instructed to wear the belt correctly by the experimenter, and the belt was adjusted to ensure it fit properly to a comfortable tightness.

The experimenter adjusted the experimental conditions according to the testing combinations. The subject was told to stand at the marked-position. During each trial, the subject first prepared the stoop or squat lifting posture as required. At this point, the subject still remained a static stance and both hands were near the handles of the box without contacting it. Then the subject was asked to start the lift, place the box on the table, and then return to an erect standing posture. After completing each trial, the box was returned to the starting position by a lab assistant.

Data Analysis

When statistically analyzing the effect of the new belt, the study used a randomized complete block design. The subject was regarded as the blocking factor. Within each block, the treatment factors were all complete and randomized. The dependent variables were analyzed with balanced ANOVA using MINITAB Release 12.1. The level of significance was $\alpha=0.05$.

Results

EMG muscle activity

In the experiment 1, the mean EMG signals at the left and right erector spinae differ significantly between the three belt conditions (F(2,18)=10.338(left), 12.875(right), P<0.001), with the largest mean EMG occurred in the no belt condition (NB), and the smallest mean EMG observed in the hook condition (HoB). From Table 1, hand lifting with belt (HaB) had lower EMG than lifting without belt (NB) but it did not reach statistical significance with the LSD test. The major significant reduction in EMG occurs between hook lifting (HoB) and no belt condition (NB). It is believed that the straps across the back linking to the thigh had caused the significant reduction.

While analyzing the EMG data in the experiment 2, signals from the right erector spinae appeared noisy in two participants. This phenomenon could have resulted from electrode slackness. Basically, the trials all involved symmetric lifts in the sagittal plane. The muscle activity would not differ much between the right and left erector spinae. It was determined to analyze only the EMG signals from the left erector spinae (ES).

The hand suspender of the new belt was designed to store potential energy while the hand reaches to the load and releases the energy at lift-off, hoping to cope with the large amount of the initial inertial load. This study hypothesized that the effect on the hand muscle would show up at both the elbow flexing and extending stages. The EMG signal was analyzed for different sections in time to investigate this effect. For triceps brachii, one second period prior to lift-off (TB_O) was compared, which would show the effect while the suspender was being extended and the elbow was extending while the hand was reaching to the load. In addition, 1 before the touchdown of the box on the table was also analyzed (TB_E), which would then show the effect of the belt at the final loading stage where the body must endure a large moment arm because the load was going away from the body. For biceps brachii (BB), signals from lift-off to after lift-off were compared, which would show the effect of the suspender at the elbow flexing period. Besides, it was worth analyzing 1 before the load was placed on the table (BB_E), which would indicate the effect of belt on biceps brachii for lowering activity. Furthermore, we could compare the difference of EMG signal between biceps brachii and triceps brachii during the lowering section. Finally, the erector spinae (ES) was analyzed for the entire lifting period from lift-off till touchdown of load. The results of EMG and hand force analyses were shown in Figs. 4, 5 and 6 which presented main effects of the four factors in each condition.

Table 1. Mean EMG (mV) for right and left erector spinae under various lifting condition in the experiment 1

	Level	Left erector spinae	Right erector spinae
Load*	0 kg	0.029	0.026
	10 kg	0.045	0.044
height*	0 cm[a]	0.026	0.025
	22 cm[b]	0.043	0.043
	75 cm[b]	0.042	0.037
belt*	NB[a]	0.043	0.044
	HaB[ab]	0.036	0.032
	HoB[b]	0.032	0.029

*: significant, p<0.05; [a, b]: grouping by LSD test.

Figures 4 and 5 shows the main effects obtained from the ANOVA analysis for the EMG signal. For biceps brachii after lifting- off (BB), the significant effects were found for weight, posture, and belt. Figure 4a indicates that belt-wearing has lower EMG than no-belt-wearing (F(1,150)=3.27, P<0.05), which would be beneficial for the biceps at the initial elbow flexing stage. Obtained from Fig. 4b, wearing the belt did not result in a significant difference in EMG signal of biceps brachii during lowering activity (BB_E). (F(1,150)=0.51, P=0.478).

Significant effects were also observed for the triceps brachii for the belt effect. (TB_O, F(1,150)= 47.08, P<0.05; TB_E, F(1,150)=15.26, P<0.05). From Fig. 4c and 4d, the triceps show some trade-off effect when comparing no-belt and belt conditions. When the belt is used, the triceps must exert more to lengthen the hand-suspender initially before load is engaged. At the later stage of the lift, the triceps will then save some exertion because of the help of the hand-suspender.

The erector spinae EMG was also significant for the belt effect (ES, F(1,150)=5.39, P<0.05). Figure 5 shows that the belt condition has lower EMG indicating that the belt decreases the back muscle activity during lifting.

Hand force

Data for the peak force immediately after lift-off (PF), time to peak force from lift-off (TPF), and root mean square

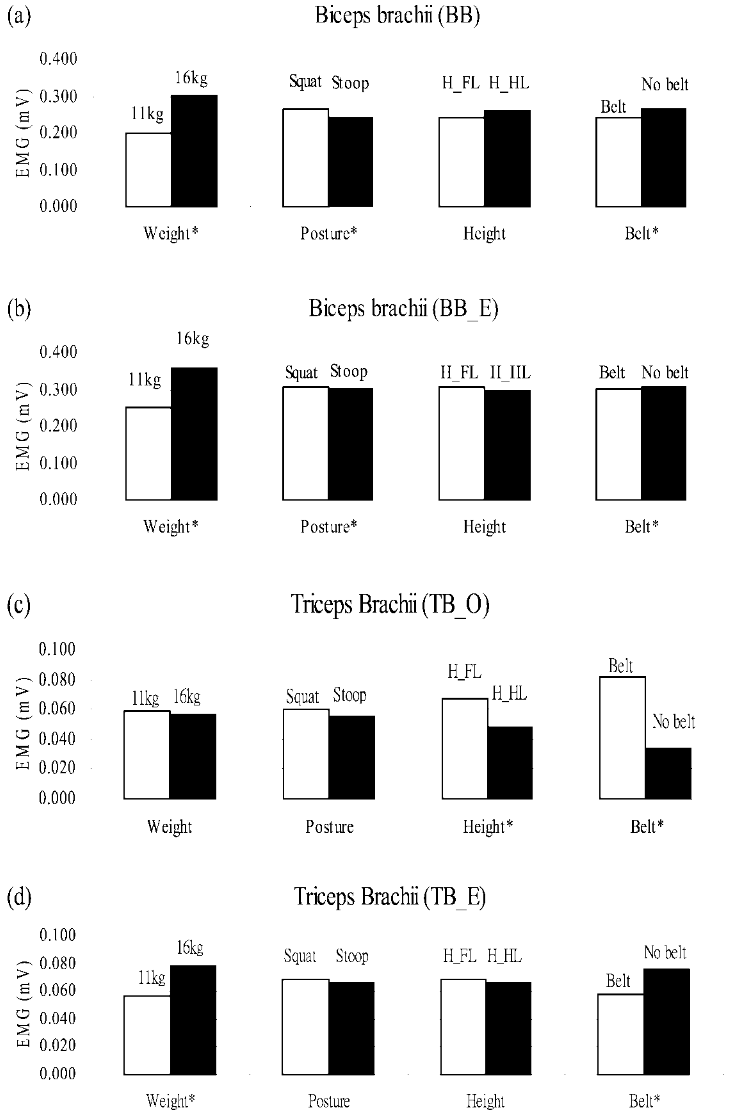

Fig. 4. **(a)–(d), Mean EMG of the four independent variables for the biceps brachii and triceps brachii (*: significant at α=0.05).**

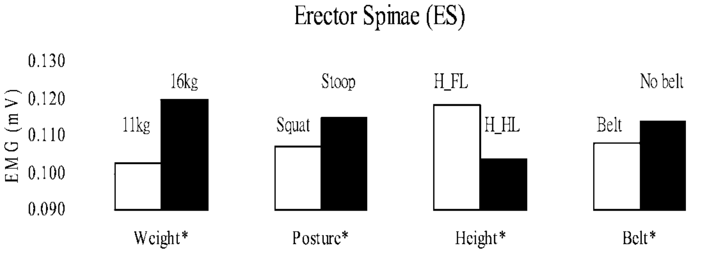

Fig. 5. **Mean EMG of the four independent variables for erector spinae during the entire lifting period (*: significant at α=0.05).**

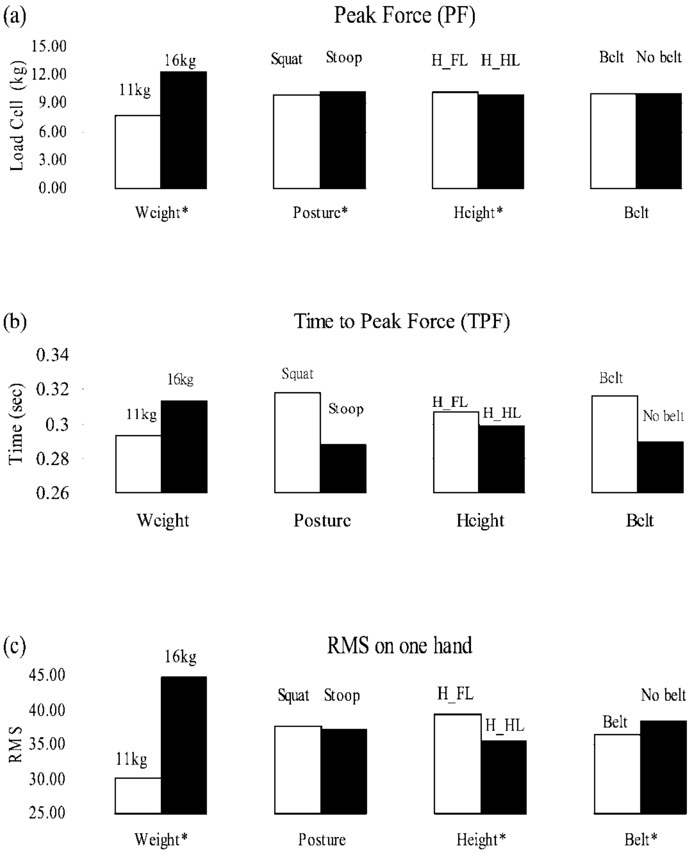

Fig. 6. (a)–(c), Means of the three dependent measures (Peak force, Time to peak force, and RMS on one hand) for the four independent variables.

of peak force for the entire lifting period (RMS) were calculated from the load cell measurements.

This study hypothesized that the hand forces at both hands were about even, and thus the four indicators were only calculated based on the data from the right hand. It was found that wearing the belt did not cause a significant difference in mean PF and TPF (Fig. 6). However, RMS was significantly lower for the belt condition ($F(1,150)=5.01$, $P<0.05$) indicating a reduction of load for the hand.

Stability

Since the belt was a first attempt of this kind, the belt may influence movement stability. The center of mass may be altered in terms of its movement range. An indicator called sum of extreme value square (SEVS) was analyzed to check whether the range of movement of the center of mass was enlarged.

$$\text{SEVS} = (\text{CMX}_{max}-\text{CMX}_{min})^2 + (\text{CMY}_{max}-\text{CMY}_{min})^2 \quad \text{(1)}$$

Where

CMX_{max} (CMX_{min}): the maximum (minimum) x-axis value of displacement of the center of mass.

CMY_{max} (CMY_{min}): the maximum (minimum) y-axis value of displacement of the center of mass.

Additionally, the starting position of the center of mass may also have been affected while wearing the belt. $\text{CMX}_{initial}$ and $\text{CMY}_{initial}$ were defined as the starting positions on the x-axis and y-axis of the center of mass, respectively. Fortunately, none of the measures examined here were altered by the use of the belt as shown in Table 2.

Discussion

Using the belt reduced the EMG signal on biceps brachii for symmetric lifts (Fig. 4a for the belt effect). This reduction was probably caused by the elasticity of the belt which counteracted a part of the body and box gravity when lifting the load upwards. The elastic hand-suspenders could restore

Table 2. Results of p-value on a variety of center of mass position

	$CMX_{initial}$	$CMY_{initial}$	SEVS
Weight	0.264	0.203	0.732
Posture	0.024*	0.000*	0.000*
Height	0.02*	0.000*	0.000*
Belt	0.95	0.554	0.409

*Value indicates significant difference (P<0.05).

the potential energy while extending the hand away from the body. At the start of the lifting movement, the biceps brachii and hand-suspenders contracted simultaneously. Consequently, the hand-suspenders acted like another biceps brachii in assisting with lifting.

As is well known, the triceps brachii and biceps brachii have complementary functions, with one contracting while the other extends. The triceps brachii contracted when the subject prepared to grasp the handles of the box. The triceps brachii displayed a vivid contrast while wearing the belt than without (Fig. 4c and 4d for the belt effect). Clearly, the triceps brachii spent the extra energy against the elasticity of the hand-suspenders. Although the additional consumption before lifting seemed to counteract the ergonomic benefit of the belt after lifting, the trade-off was worthy because the positive effects are felt immediately following lifting off, which is precisely the period where there is highest risk of arm or back injury. Simultaneously, Fig. 4d indicated another advantage of the belt. While the body gradually moved into the erect standing posture at the end of the lifting process, the subject prepared to lower the box onto the table ahead, at which point the triceps brachii would contract again. This study assumed that wearing the belt would increase the muscle activity of the triceps brachii compared to wearing no belt due to the addition of anti-elasticity force. Unexpectedly, the result from Fig. 4d showed that wearing the belt apparently reduced the EMG signal. The phenomenon can be viewed from different aspects. Originally, the triceps brachii should contract violently to retard the ballistic movement during lowering process. The belt elasticity created a cushioning effect preventing muscle strain owing to fast jerky movement. Accordingly, the belt cooperated with the triceps brachii to reduce muscle activity and facilitate soft landing of the load. Additionally, the result also revealed the EMG signal for biceps brachii with belt was similar to no belt condition while lowering the load to the table (Fig. 4b). Obviously, biceps brachii was extending at this moment such that the required force was provided by triceps brachii. Hence, the belt would directly act on triceps brachii. As mentioned above, we could make a preliminary conclusion that the belt would produce effect on contracted muscle rather than extended muscle.

Following the above discussion, the force via hand-suspenders would be conveyed to two back straps which were folded around one another. The back straps were linked to two thigh-straps via a back-shaped support such that the force was transferred to the lower body. Accordingly, it was assumed the force passing through the hand and upper-body could be reduced. Total force through the back muscles determined the degree of contraction in the erector spinae, which created resistance against the movement resulting from gravitational forces. As expected, the EMG signal in the erector spinae decreased markedly while wearing the belt (Fig. 5). It is worth noting that the purpose of the new belt is to get around the controversial IAP effect since wearing the belt too tight has other side effects. The major feature of the belt is the straps across the upper body and leg plus the suspender. The study was designed to test the effect of the straps and suspender, not the IAP. In the static experiment (experiment 1), comparison between hand lifting with belt (HaB) and no belt shows the effect of IAP by the waist belt. Unfortunately, the effect is not significant by LSD test although the EMG is lower with the belt. When the hook is not engaged, the straps across the body would not function. If there's reduction in EMG, it must have been due to the waist belt. Note that our waist belt is not as wide as the conventional one and we had not asked the subject to wear it as tight as possible. Maybe because of this, the IAP effect is not significant. However, the result of LSD test shows that hook lifting has significant reduction in EMG than no belt condition. We believe this indicates the effect the straps and the linkage design across the upper body and leg. Of course, the IAP effect may have been added within this overall effect, but it certainly was not significant by itself as the comparison between no belt and HaB has shown.

Danz and Ayoub[17)] indicated that the peak force appeared immediately after lift-off. The peak force may be the main cause of back injury so reducing the peak force is worthwhile. This research expected that the use of the belt could degrade peak force or prolong the time to peak force, that is, completely change the magnitude and temporal pattern of the peak force. Unfortunately, the results from Fig. 6a showed that wearing the belt did not significantly influence peak force. The phenomenon can be explained by the fact that the peak force always occurred within a very short timeframe and function of the belt did not performed in time. Therefore, the decrease of peak force was very limited. On the other hand, the delay of time to peak force may provide enough time for adjustment of the musculoskeletal mechanism to cope with emergent and rapid lifting, thus reducing the likelihood of injury. Consequently, it may be an important contribution to reduce the risk for injury. However, in this study the time to the peak force did not differ significantly between the belt and no belt situations. Notably, Fig. 6b indicated a tendency to prolong the time to peak force, although not statistically significant in the study. Additionally, this study demonstrated significantly reduced overall RMS when wearing a belt. The belt thus appeared to have the capability to cause the decrease in EMG signal in the erector spinae to agree with the decrease in hand force. Although the belt did not effectively reduce the peak force, it did reduce the hand load during the whole-lifting.

Finally, this study needed to investigate the expectation that the belt would negatively affect stability due to the use of additional straps crossing over the upper-body than the conventional lifting belt. Stability was divided into two parts for examination: one was the starting position of the center of mass, while the other was the change in the lifting trajectory of the center of mass. Clearly, the belt did not influence the starting position of the center of mass shown in Table 2. The belt was relatively light and thin compared to other weight-lifting belts and subjects felt that the belt was sufficiently comfortable that they had not alter their posture during lifting. Regarding the result of SEVS, the belt also did not considerably increase the displacement or trajectory of the center of mass during lifting. The large variation and movement of the center of mass may indicate an additional energy cost for the body. Wearing the belt did not influence the magnitude of energy consumption.

Conclusions

This study examined a novel design of back belt for reducing lifting stress. The findings demonstrated that wearing the belt significantly reduced muscle activity for biceps brachii, triceps brachii, and erector spinae in different lifting sessions. Apparently, the belt produced ergonomic benefits. Although the measured results for the peak force and time to peak force did not display the expected reductions when using the belt, the belt tended to prolong the time to peak force. Encouragingly, the belt did not appear to affect stability or alter lifting posture. Regarding muscle activity and body stability, the belt can be considered a useful assistive device to reduce loading in handling manual materials.

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References

1) Waters TR, Putz-Anderson V, Garg A, Fine LJ (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics **36**, 749–76.
2) Andersson GBJ (1991) The epidemiology of spinal disorders. In: the Adult Spine: Principles and Practice, Frymoyer JW (Ed.), 107–46, Lippincott-Raven Publishers, New York.
3) Deyo RA, Bass JE (1989) Lifestyle and low-back pain: the influence of smoking and obesity. Spine **14**, 501–602.
4) Marley RJ, Duggasani AR (1996) Effects of industrial back supports on physiological demand, lifting style and perceived exertion. Int J Ind Ergon **17**, 445–3.
5) Smith EB, Rasmussen AA, Lechner DE, Grossmen MR, Qunitana JB, Grubbs BL (1996) The effects of lumbosacral support belts and abdominal muscles strength on functional lifting ability in healthy women. Spine **21**, 356–66.
6) Van Poppel MNM, De Looze MP, Koes BW, Smid T, Bouter LM (2000) Mechanisms of action of lumbar supports: a systematic review. Spine **25**, 2103–13.
7) 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**, 107–15.
8) Magnusson M, Pope M, Hansson T (1996) Does a back support have a positive biomechanical effect. Appl Ergon **27**, 201–5.
9) Krag M, Gilberson L, Pope MH (1986) A rest of the hypothesis of abdominal pressure as a disc load-reducing mechanism: a study quantitative electromyography. In: Proceedings of the American Society for biomechanics, **111**, Tucson, Arizona.
10) Miyamoto K, Iinuma N, Maeda M, Wada E, Shimizu K (1999) Effects of abdominal belts on intra-abdominal pressure, intra-muscular pressure in the erector spinae muscles and myoelectrical activities of trunk muscles. Clin Biomech **14**, 79–87.
11) Ciriello VM, Snook SH (1995) The effect of back belts on lumbar muscle fatigue. Spine **20**, 1271–8.
12) Lander JE, Hundley JR, Somonton RL (1992) The effectiveness of weight-belts during multiple repetitions of the squat exercise. Med Sci Sports Exerc **24**, 603–9.
13) Lander JE, Simonton RL, Giacobbe JKF (1990) The effectiveness of weight-belts during the squat exercise. Med Sci Sports Exerc **22**, 117–26.
14) McGill SM, Norman RW, Sharratt MT (1990) The effect of an abdominal belt on trunk muscle activity and intra

abdominal pressure during squat lifts. Ergonomics **33**, 147–60.

15) Bauer JA, Fry A, Carter C (1999) The use of lumbar-supporting weight belts while performing squats: erector spinae electromyographic activity. J Strength and Conditioning Res **13**, 384–8.
16) National Institute for Occupational Safety and Health (NIOSH) (1994) Workplace use of back belts: review and recommendations. DHHS (NIOSH) No, 94–122. NIOSH, Cincinnati.
17) Danz ME, Ayoub MM (1992) The effects of speed, frequency, and load on measured hand forces for a floor to knuckle lifting task. Ergonomics **35**, 833–43.