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Physiological effects of back belt wearing during asymmetric lifting

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Abstract

This study investigated the effect of wearing a back belt on subjects' heart rate, oxygen consumption, systolic and diastolic blood pressure, and respiratory frequency during asymmetric repetitive lifting. Thirty subjects with materials-handling experience utilized three different belts (ten subjects per belt). Subjects completed six 30-min lifting sessions—three while wearing a belt and three without. Data analyses were conducted on the second, third, and fourth lifting periods. A 9.4 kg box, without handles, was lifted 3 times/min, starting at 10 cm above the floor, ending at 79 cm, with a 60° twist to the right. Data analysis indicates that belt-wearing did not have a significant effect on the overall mean values for heart rate, systolic and diastolic blood pressure, and respiratory frequency. Belt-wearing had a significant effect on the overall mean oxygen consumption of the subjects. Published by Elsevier Science Ltd.

Keywords: Manual lifting; Physiology; Back belt

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1. Introduction

During the late 1980s and early 1990s, wearing back belts became quite popular in an attempt to reduce the number of low-back injuries occurring in the workplace. In 1994, the National Institute for Occupational Safety and Health (NIOSH) released a report (DHHS, 1994), which was a review of the published scientific literature, that stated that NIOSH "does not recommend the use of back belts to prevent injuries among uninjured workers, and does not consider back belts to be personal protective equipment". In an effort to evaluate the effectiveness of back belts, NIOSH planned and conducted a field study and two laboratory studies. The field study was a prospective epidemiological investigation of back belt usage in a national chain of retail establishments (Wassell et al., 2000). One laboratory study dealt with the biomechanical effects (Giorcelli et al., 2001) and the second one (the current study) dealt with the physiological effects of repetitive lifting while wearing a back belt.

The technical literature in the last 5–10 yr related to physiological (i.e., cardiovascular and respiratory) effects of lifting while wearing a back belt is quite limited. Two studies evaluated a traditional weightlifter's belt (Hunter et al., 1989) and a medical orthosis (Duplessis et al., 1998). Industrial workers do not use these types of back supports.

Five studies (Rafacz and McGill, 1996; Marley and Duggasani, 1996; Aleksiev et al., 1996; Soh et al., 1997; Rabinowitz et al., 1998) evaluated commercially available back belts typically used in industrial workplaces. Only one of the five studies (Soh et al., 1997) evaluated more than one belt type. Three of the five studies required subjects to handle items that were of an industrial nature—a tote box (Marley and Duggasani, 1996), a bucket (Soh et al., 1997), and a beverage crate (Rabinowitz et al., 1998). The other two studies used activities that were non-industrial. However, none of the studies investigated handling typical warehouse or grocery store boxes, which are smooth cartons not equipped with handles or cut-out openings. Waters et al. (1993) indicate that the lifting capacity of workers is decreased when having to lift cartons without handles.

Basically, either a single belt was used to evaluate one or more physiological parameters (Marley and Duggasani, 1996; Rabinowitz et al., 1998) or multiple belts were used to evaluate a single physiological parameter, which was respiratory frequency (Soh et al., 1997). The primary dependent variables that were investigated

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during the five studies included heart rate (HR), respiratory frequency (RF), oxygen consumption ($\dot{V}O_2$), systolic blood pressure (SBP), and diastolic blood pressure (DBP). Only one study (Marley and Duggasani, 1996) simultaneously evaluated the effect of belt-wearing on these primary physiological parameters.

Significant differences did not occur for HR, in any of the four studies that evaluated it, or for $\dot{V}O_2$, which was investigated in a single study. A significant increase in RF occurred with only one of the three belts that were evaluated by Soh et al. (1997). Marley and Duggasani (1996) found a significant increase in both the SBP and DBP when wearing a back belt, but Rafacz and McGill (1996) found a significant increase in DBP only.

In summary, different results have been reported in the literature regarding the physiological effects of lifting when wearing a back belt. In addition, there is a void in the literature regarding the effect of wearing a back belt when lifting boxes not equipped with handles. Finally, only one previous study simultaneously evaluated all primary physiological parameters.

The objective of this research investigation was to determine whether wearing a back belt during the repetitive handling of a moderate-weight box, without handles, would have an effect on subjects' HR, RF, oxygen consumption, and blood pressure measurements.

2. Methods and materials

2.1. Subjects

A convenience sample of 30 subjects participated in this laboratory study. The test subjects were a mix of full-time employees of the Physical Plant of West Virginia University ($n = 20$) and University students ($n = 10$). All subjects had to have at least 3 months of prior materials-handling experience. The average age for the sample was 30 yr (sd = 7.7), with an average height of 175.2 cm (sd 8.1), average weight of 81.1 kg (sd 14.7), and average body mass index (BMI) of 26.4 (sd 4.9). Five of the subjects were women and 25 were men. Table 1 provides a breakdown of age, height, weight, and BMI by gender. All subjects were free of low-back pain and other musculoskeletal complaints. An informed consent form was signed by each participant. Each subject was compensated for undergoing the physical and for participating in the test sessions.

2.2. Experimental design

The original design of this experiment was a within-subjects, repeated measures design, with six repeated trials per subject, so that in three randomly selected trials the subjects lifted while wearing a back belt, and in the other three, lifted without the belt. Based on a simulation study, which used data from Rafacz and McGill (1996), a sample size of 30 subjects was found to provide at least 80% power to detect a difference of 3.75 mmHg in the SBP. The order of belt- or no-belt-wearing was randomized across all subjects. Three different belts were used, with ten subjects assigned to each belt type. Once a belt was assigned, it was used throughout the test day. Due to the uncontrolled variability with the lunch period, which is described in Section 2.7, the analysis was conducted as a three-period crossover evaluation.

2.3. Test method

After the subjects were recruited, they completed a health questionnaire that was managed by a medical doctor. If the initial health screening was acceptable, a clinical history was completed for each subject, and a physical exam, which included an EKG, was conducted by a medical doctor on staff with NIOSH. After passing the physical, each participant was scheduled for the 6-h test procedure. On the test day, the experimental protocol was thoroughly reviewed with each subject.

2.4. Test procedure

The test protocol consisted of six 30-min lifting sessions—four were completed in the morning, the remaining two after a 75-min lunch break. A 15-min rest period was scheduled between each lifting session. A wooden box, without handles, measuring 30 cm wide × 25 cm deep (front to back) × 46 cm high, was grasped at opposing corners and lifted 3 times/min.

The lifts started at 10 cm above the floor (pallet height) and ended at 79 cm (table height), with a 60° twist to the right, relative to the subject's mid-sagittal plane at the beginning of the lift. In an attempt to mimic

Table 1
Anthropometric characteristics of test subjects

Subjects	Number	Age (yr)	Height (cm)	Weight (kg)	Body mass index
		Mean (sd)			
Men	25	30.1 (8.2)	177.5 (6.6)	84.6 (12.9)	27.0 (4.9)
Women	5	29.6 (4.7)	163.6 (4.3)	63.3 (9.1)	23.5 (3.7)
Total	30	30.0 (7.7)	175.2 (8.1)	81.1 (14.7)	26.4 (4.9)

the real-world, the subjects were not told to use a specific lift type, such as a stoop lift (bent back) or a squat lift (bent knees). They used a free-style lifting technique that is typically used during normal work activities. Thus, slight variations in the subjects' lifting posture occurred from one lift to the next. Fig. 1 provides a view of the test set-up. Figs. 2 and 3 show the beginning and end of the lift, respectively.

Before lifting, the subjects could position their feet however it was comfortable for them. Their foot location was then marked (see Fig. 1) so they would start at the same location for all subsequent lifting sessions. They were instructed, however, that foot movement during lifting was not permitted. This was in accordance with the 1991 revised NIOSH lifting equation (Waters et al., 1994, p. 21).

The weight of the box, 9.4 kg, was determined with the 1991 revised NIOSH lifting equation (Waters et al., 1993), by using the physical parameters of the simulated industrial task that was just described. This equation provides guidance for weights to be lifted that will not exceed the acceptable lifting capacity of 99% of male workers and 75% of female workers (Waters et al., 1993). The researchers felt that 9.4 kg, which corresponded exactly to the recommended weight limit of the revised equation (i.e., RWL = 1.0), would be an appropriate weight to ensure that the subjects would not be at risk for an injury during the 6-h protocol.

Subjects were required only to lift the box. It was lowered to the starting location by a lab assistant, who is shown in Fig. 1.

2.5. Belt types

The three belts utilized in this study were: (a) a woven mesh material that was stretchable and equipped with Velcro® closures on both sides for proper tightening, (b) a firm-woven belt, which was bendable but not stretchable, that had a 5-cm adjustable nylon strap (Velcro® on one side only) equipped with a plastic clip-lock buckle closure, and (c) a stretchable mesh material with two side panels of flexible rubber material, equipped with two 2.5-cm straps that fold back on themselves (after passing through ovals), using Velcro® for closing. This third belt type was worn lower on the pelvis than the other two.

2.6. Instrumentation

During the testing, subjects wore a heart rate monitor (Polar Vantage, Polar USA, Inc., Stamford, CT) against their skin. The monitor consisted of an adjustable latex chest belt that contained two electrodes. This monitor automatically sampled the subject's HR for every 12 s,

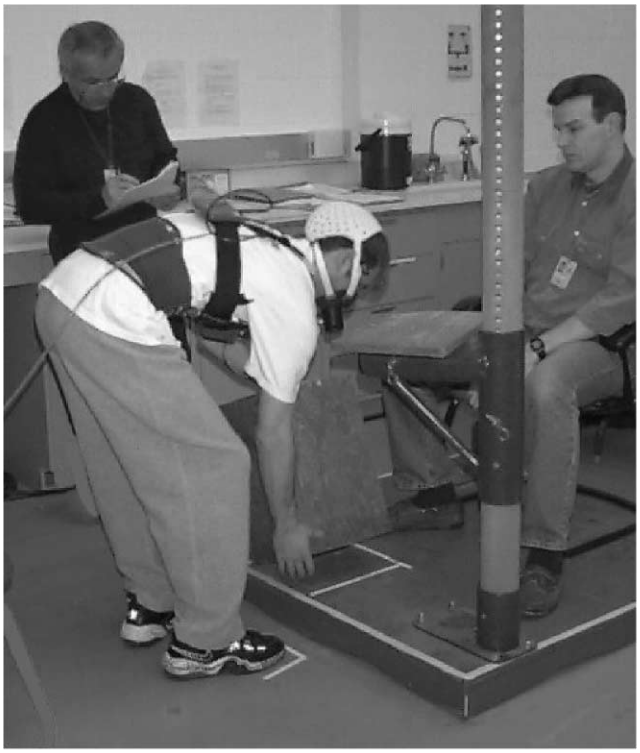

Fig. 1. Overall view of task lay-out, with lab assistant seated on right.

Fig. 2. Beginning of lift.

Fig. 3. End of lift.

and stored an average value every minute during the six 30-min lifting sessions. Subjects also wore a chest-mounted light-weight (0.8 kg) oxygen analyzer (CosMed K2, CosMed Corp., Rome, Italy) on the outside of their clothes. This portable device is an integrated telemetry system that measures RF and calculates minute ventilation and oxygen consumption. According to the documentation with the equipment, it has a reliability of ±10%. The face mask contains a mini-turbine respiratory flow meter and a capillary tube for sampling expired air, which is analyzed by a small polarographic electrode. Information is transmitted to a receiver unit that processes, archives, and displays data in real time.

Finally, blood pressure readings were collected at the beginning of each session, as well as at times 10, 20, and 30 min into the sessions. These measurements were taken manually during the 20-s pause between timed lifts by a medical doctor using a manual sphygmomanometer (Baumanometer, Baum, Inc., Copiague, NY).

2.7. Data analysis

Before leaving for lunch, subjects were requested to avoid caffeinated beverages and refrain from smoking. However, the researchers noted a variety of personal activities that may have contributed to inconsistencies in the data collected in the afternoon, including smoking cigarettes, drinking caffeine beverages, eating spicy or filling foods, and having to hurry to return on time after lunch. The research team initially attempted to document what the subjects ate or drank at lunch, or whether they had to hurry back to the facilities after lunch. We realized that we could not adequately quantify these variations.

Since a number of subjects had already completed the testing, we decided that the afternoon sessions would be completed by all, but the data would not be included in the final analysis because of the extensive discrepancies among the subjects' lunch activities.

In addition, subjects did not have an opportunity to participate in any practice sessions prior to testing to become familiar with the lifting procedure and the physiological equipment to be worn. So, unbeknownst to the subjects, the first lifting period was used as a practice/warm-up session and was not included in the data to be analyzed.

Therefore, only data from the second, third, and fourth lifting periods were included in the analyses. This resulted in a more reliable data set for determining whether the back belt truly had an effect on the measured physiological parameters.

When conducting any type of aerobic activity (exercise, or work such as repetitive lifting), a person requires an initial period of time to ramp up to a steady-state condition of energy expenditure. Thus, only the final 20 min of the second, third, and fourth lifting periods were analyzed for this experiment. Heart rate, RF, and $\dot{V}O_2$ data were collected each minute, and blood pressure readings were collected every 10 min during each of the three analysis periods.

A three-period crossover analysis was used (Jones and Kenward, 1989, Design 3.6.1, p. 175). Mean values and variances were calculated for each parameter in the three analysis periods, for each of the 30 subjects. A three-factor analysis of variance (subject, belt, and lifting period) was conducted using the mean values, as suggested by Crowder and Hand (1990), which were weighted by the inverse of the variance, from each of the three periods for all 30 subjects. All analyses included a check for a carryover effect, but none was found. The carryover parameter investigates whether a residual effect may have occurred (in a subsequent period) because the belt was worn in a prior period. The effect due to belt type was not analyzed because of insufficient statistical power.

Paired-comparison *t*-tests were conducted for HR, $\dot{V}O_2$, and RF for each subject for the belt-on versus belt-off conditions. The Fisher exact test was used for both blood pressure values. Due to the random allocation of belt-wearing, one subject wore the belt during the three analysis periods and could not be used in the paired-comparison analyses. The data from this particular subject, however, was used in the estimate of the error variance in the three-period crossover analysis.

3. Results

3.1. Overall group data

Table 2 provides a summary of the mean values, *F*-statistics, and corresponding *p*-values from the ANOVA analyses for the five physiological parameters when a back belt was worn during the repetitive lifting of a moderate weight. Table 3 provides a summary of the overall statistically significant effects, both increased and decreased, that resulted from the paired comparisons for the five physiological parameters.

3.2. Heart rate

Wearing the back belt did not result in a significant difference in the average HR of the subjects. The overall mean HR of the group for the no-belt condition and belt-wearing condition ($p = 0.462$) was 91.7 and 91.0 beats/min, respectively. Paired-comparison *t*-tests were conducted for 29 of the 30 subjects. Table 3 shows that 12 subjects had significantly ($p < 0.05$) larger mean HR values for belt-wearing (range = 2.5–7.7 beats/min, mean = 5.0 beats/min), and nine had significantly smaller mean HR values for belt-wearing (range = 3.0–15.6 beats/min, mean = 6.3 beats/min).

3.3. Respiratory frequency

Wearing the back belt did not result in a significant difference in the average RF of the subjects. The overall mean group value for RF was 19.2 breaths/min for no-belt-wearing versus 19.4 breaths/min for belt-wearing ($p = 0.398$). Paired-comparison *t*-tests for 29 subjects (Table 3) indicated that three had significantly ($p < 0.05$) larger mean RF values for belt-wearing (range = 0.8–2.5 breaths/min, mean = 1.5 breaths/min), and eight had significantly smaller mean RF values for belt-wearing (range = 1.0–3.1 breaths/min, mean = 1.7 breaths/min).

3.4. Blood pressure

Wearing the back belt did not result in a significant difference in the average values of both SBP and DBP. The overall mean group value for SBP for no-belt-wearing and belt-wearing ($p = 0.081$) was 123.5 and 124.6 mmHg, respectively. The overall mean group value for DBP for no-belt-wearing and belt-wearing ($p = 0.095$) was 74.3 and 75.1 mmHg, respectively.

The follow-up analysis used the Fisher exact test for SBP and DBP for each subject. None of the subjects had a statistically significant result for the systolic values (Table 3). Only three of the subjects had a significant difference ($p < 0.05$) for the diastolic values when the

Table 2
Summary of mean values, *F*-statistics, and corresponding *p*-values from ANOVA analyses

Variable	Mean values (Belt off)	Mean values (Belt on)	*F*-statistics (with d.f.[a] = 1,57)	*p*-values
HR (beats/min)	91.7	91.0	0.5481	0.4621
SBP (mmHg)	123.5	124.6	3.1659	0.0805
DBP (mmHg)	74.3	75.1	2.8848	0.0949
RF (breaths/min)	19.2	19.4	0.7244	0.3983
$\dot{V}O_2$ (l/min)	0.762	0.711	4.6708	0.0349

[a] d.f. = degrees of freedom.

Table 3
Summary of statistically significant effects ($p > 0.05$), based on paired comparisons of no-belt-wearing versus belt-wearing, for five physiological parameters evaluated during repetitive lifting of a moderate-weight box

Subjects	Heart rate (beats/min)	Respiratory frequency (breaths/min)	$BP_{systolic}$ (mmHg)	$BP_{diastolic}$ (mmHg)	$\dot{V}O_2$ (1/min)
$N = 29$[a]	12↑	3↑	0↑	3↑	9↑
	8 n.s.	18 n.s.	29 n.s.	26 n.s.	13 n.s.
	9↓	8↓	0↓	0↓	7↓

[a] One subject wore the belt during the three analysis periods and could not be evaluated with paired-comparison analyses. See data analysis section for more detail.

↑ = number of subjects showing a significant increase in the parameter when wearing the back belt.

↓ = number of subjects showing a significant decrease in the parameter when wearing the back belt.

n.s. = number of subjects showing no significant difference in the parameter when wearing the back belt.

belt was worn. These three had higher average DBP while wearing the belt (Table 3).

3.5. Oxygen consumption

Wearing a back belt resulted in a statistically significant decrease in the average $\dot{V}O_2$ of the subjects. The overall mean group value for $\dot{V}O_2$ during lifting with no-belt-wearing was 0.762 l/min versus 0.711 l/min for belt-wearing ($p = 0.035$). Paired-comparison *t*-tests conducted on the 29 subjects indicated that nine had significant increases ($p<0.05$) in mean $\dot{V}O_2$ values for belt-wearing (versus no-belt-wearing) (range = 0.052–0.702 l/min, mean = 0.264 l/min, median = 0.099 l/min) and seven had significant decreases ($p<0.05$) in mean $\dot{V}O_2$ values for belt-wearing (versus no-belt-wearing) (range = −0.033 to −0.370 l/min, mean = −0.125 l/min, median = −0.074 l/min).

4. Discussion

Results from the current study indicate that repetitively lifting a moderate-weight box, while wearing a back belt, did not have a significant effect on subjects' HR. This agrees with the studies conducted by Rafacz and McGill (1996); Marley and Duggasani (1996); Aleksiev et al. (1996), and Rabinowitz et al. (1998).

Similarly, the current study did not show a significant effect on subjects' RF when lifting while wearing a back belt. This agrees with the data from Marley and Duggasani (1996), but disagrees with the study by Soh et al. (1997) that found that one of the belts they evaluated had a significant increase in the RF. The researchers conjectured that the rigidity of that particular belt might have contributed to the increase in the RF. Since the belts that were evaluated in the current study did not have a rigid construction, it seems quite logical that, in fact, there would not be an increase in RF.

Results from the current study indicate that wearing a back belt did not have a significant effect on the overall values for both SBP and DBP. These results disagree with the study by Rafacz and McGill (1996) and Marley and Duggasani (1996). This difference may be the result of the different types of tasks and work loads that were used in these studies. The present study used a moderate weight and involved a completely dynamic task. Rafacz and McGill (1996) used heavier weights and had isometric components as a part of their test procedure. Aleksiev et al. (1996) indicated that DBP was significantly ($p<0.05$) increased for isometric exertions versus dynamic lifting activities. The mechanical work load is greater in static work than in dynamic work because the heart has to work against the peripheral resistance caused by isometric exertions (Armstrong et al., 1980).

Marley and Duggasani (1996) found a significant increase in both SBP and DBP when wearing a back belt. That study had subjects lifting a tote box weighing 7 and 14 kg at 3, 6, and 9 lifts/min, with and without belt-wearing. The values for their 7 kg/3 lifts/min condition can be compared to the current study (9.4 kg/3 lifts/min). The data for the 7 kg/3 lifts/min resulted in a non-significant increase in SBP and DBP. This agrees with the current study.

Finally, the current study resulted in a significant decrease in $\dot{V}O_2$ of the subjects when wearing the belt. These results disagree with the study by Marley and Duggasani (1996) which did not find a significant effect on subjects' $\dot{V}O_2$ when wearing a belt while lifting.

The difference in $\dot{V}O_2$ between belt-wearing (0.711 l/min) and no-belt-wearing (0.762 l/min) is 0.051 l/min (= 51 ml/min = 1.72 fluid oz/min). The resting metabolic rate for humans is about 3.5 ml O_2 consumption/min/kg of body weight (deVries, 1986). Using the average body weight for the subjects in this study, which is shown in Table 1 to be 81.1 kg, results in a total of 284 ml O_2 utilized/min when resting. Thus, the difference in $\dot{V}O_2$ (i.e., 51 ml/min) is less than one-fifth of the $\dot{V}O_2$ level needed by our "average" subject *when resting*.

Interestingly, the biomechanical study recently completed by NIOSH (Giorcelli et al., 2001) indicated that the subjects in that study bent their torso less and hips more, and they moved at a slower pace when wearing a back belt. Perhaps the slower lifting pace may have contributed to the slight reduction in the $\dot{V}O_2$ consumed during the lifting while wearing the belt. A possible alternate explanation might be that the breathing pattern of the subjects was slightly altered when the belt was worn, thus causing the slight decrease in the $\dot{V}O_2$ consumed during the lifting while wearing the belt. It should be mentioned that the subjects were instructed to wear the belt according to the manufacturer's instructions of "snug, but not too tight to be uncomfortable". None of the subjects complained during or after any of the six 30-min lifting sessions that the belt felt uncomfortable.

A future study is suggested which will involve lifting a heavier weight. A heavier weight will increase the metabolic load, thus raising the HR and other physiological parameters, so any changes that may be caused by belt-wearing may be more obvious during the new test conditions. A future study may also want to evaluate an increase in the lifting frequency. Since a sizable portion of warehouse work involves handling weights heavier than 9.4 kg, or involves lifting boxes faster than 3 times/min, future studies that investigate one or both of these conditions would be valuable by simulating these more demanding conditions.

Finally, a future study that uses more subjects and multiple belt types may provide more insight regarding the effect of different belt types on cardiovascular and respiratory variables. Individual belt effects from the current study were not presented since there was not enough statistical power with a sample size of only 10 subjects per belt type.

5. Summary

This limited research study did not find an effect, either positively or negatively, in four of the five variables studied—HR, SBP, DBP, and RF—when subjects wore a back belt while repetitively lifting a moderate-weight box that did not have handles. This study indicated that a significant decrease occurred in the average $\dot{V}O_2$ consumed by subjects when wearing the belt. The difference in $\dot{V}O_2$ between wearing a belt and not wearing a belt is less than one-fifth of the value required by our "average" test subject when resting.

A future study that will use a heavier weight and/or an increase in the lifting frequency, involving more subjects and multiple belt types is suggested. Such a study may yield more detailed information on the effect of belt-wearing on subjects' cardiovascular and respiratory responses.

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