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The effectiveness of weight-belts during multiple repetitions of the squat exercise

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ABSTRACT

LANDER, J. E., J. R. HUNDLEY, and R. L. SIMONTON. The effectiveness of weight-belts during multiple repetitions of the squat exercise. *Med. Sci. Sports Exerc.*, Vol. 24, No. 5, pp. 603–609, 1992. The purpose of this study was to examine the effectiveness of weight-belts during multiple repetitions of the parallel back squat exercise. Five subjects were filmed (50 fps) as they performed eight consecutive trials at each of two weight-belt conditions [with belt = WB, without belt = WOB] in random order at their eight-repetition maximum effort. Other parameters examined were ground reaction forces, intra-abdominal pressure (IAP), and mean electromyography (mEMG) for the external oblique (EO), erector spinae (ES), vastus lateralis (VL), and bicep femoris (BF) muscles. All parameters were collected and interfaced to a computer via an A/D converter. WB repetitions were generally performed faster than WOB repetitions, especially by the later repetitions (3.34 vs 3.56 s). WB IAP values were consistently greater ($P < 0.05$) than WOB values by 25–40%. IAP increased by approximately 11.5% from the first to the last repetitions. No differences were observed for ES and EO mEMG for belt usage, but values increased by up to 20% across repetitions. Several differences were observed between WB and WOB for the VL and BF mEMG, with WB values being significantly greater. These data suggest that a weight-belt aids in supporting the trunk by increasing IAP, and that any differential effect due to wearing a weight-belt did not occur over eight repetitions.

BIOMECHANICS, EMG, INTRA-ABDOMINAL PRESSURE, POWERLIFTING, SPINE

While injuries during weight lifting are not prevalent (1,3,5,11,12), the large forces involved (>10,000 N) can exceed recommended levels for safe performance (11). Many biomechanical studies have been conducted on various types of heavy weight lifting. Similarly, several studies have investigated the use of back and abdominal support devices for corrective measures and for the relief of low back pain (2,8,17,20,22,23). Unfortunately, few studies have examined the use of weight-belts during heavy weight lifting activities (9,16).

It has been shown that weight-belts can increase the intra-abdominal pressure (IAP) thereby effectively reducing the forces acting on the spine (8,9,14,16,19,21). A tightly worn weight-belt can help to pressurize the abdominal cavity enabling it to bear some of the load (up to 50%) normally placed on the spinal column and associated structures (9,15,16,20,21).

The purpose of this study was to investigate the effectiveness of weight-belts during multiple repetitions of the squat exercise. It was hypothesized that weight-belts may become more important in reducing the forces acting on the spine during later repetitions after fatigue begins to affect performance.

METHODS

Subjects and general protocol

Five skilled male adults (mean age = 23.4 yr) volunteered to serve as subjects for the study after signing consent forms in accordance with human subjects regulations. At the time of testing, all were engaged in weight training programs three times per week and had demonstrated a mean eight repetition maximum effort (8RM) of 125.5 kg or 1.6 times body weight for the squat exercise.

Two weight-belt conditions were examined; the subjects squatted with a weight-belt (WB) and without a weight-belt (WOB). The weight-belts used were of heavy construction and consisted of three layers of leather 11 mm thick and 100 mm wide over the entire length. Competitive power-lifters and more serious recreational weight lifters generally use this type of belt.

At least 2 d prior to testing, the 8RM was determined for each subject. The 8RM load was determined without a weight-belt to help ensure that at least eight

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repetitions would be completed for each condition. The subjects performed eight repetitions at their 8RM load, which corresponds to approximately 75–80% of their one repetition maximum effort (25). These conditions were chosen in order to represent typical training routines and weight-belt usage by many weight lifters.

Subjects were allowed their normal warm-up prior to testing. The order of performance for the two weight-belt conditions was assigned randomly; two subjects used the best first and three subjects performed without the belt first. All data were collected for a subject on the same day while allowing for adequate rest (at least 1 h) between each set of eight repetitions.

Instrumentation

Cinematographic. A Locam high speed 16-mm camera was used to film all trials. The camera was placed 10.0 m from and perpendicular to the primary sagittal plane of motion with the optical axis set at a height approximately midway through the subjects' range of motion (1.5 m). All trials were filmed at 50 ± 1 fps. A reference measure and subject identification board were included in the field of view.

Force platform. A Kistler force platform was located in the center of a raised (30 cm) lifting platform and safety rack. Eight raw voltage signals representing the vertical (4-Z), anteroposterior (2-X), and mediolateral (2-Y) forces from the force platform were input to eight charge amplifiers. The amplifiers were interfaced to a MC68000 10-MHz based microcomputer via an analog-to-digital (A/D) converter. The sampling frequency used was 200 Hz.

Pressure transducer. A balloon catheter was inserted approximately 10 cm into each subject's rectum in order to measure IAP. The catheter was connected to a Gould:Statham pressure transducer. The signals (200 Hz) were amplified and output to the computer via the A/D converter. The pressure transducer was calibrated by pressurizing the transducer while concurrently measuring pressure with a mercury manometer and the voltage outputs from the A/D. A/D voltage outputs were then plotted vs the pressure readings from the manometer to obtain the calibration curve for the pressure transducer.

Electromyographic (EMG). The EMG signals (sampling rate = 200 Hz) from four primary muscle groups that were expected to be affected by the use of a weight-belt were examined. All electrodes remained in place for the duration of the experiment.

The external oblique (EO) was chosen to represent the muscles that aid in constricting the abdominal cavity. The electrodes were placed slightly superior to and 15 cm away from the umbilicus and at an angle along the line of muscle fibers. The erector spinae (ES) muscle group was also examined, and the electrodes were placed 5 cm away from the midline of the spine at approximately the level of L3/L4. During WB, the erector spinae electrodes were in some cases partially covered by the weight-belt.

Two lower body muscle groups were examined. The vastus lateralis (VL) muscle was chosen to represent the knee-extensor group and the bicep femoris (BF) for the hip-extensor/knee-flexor group. VL electrodes were placed near the motor point and over the bulk of the muscle approximately 15–20 cm superior to the center of the knee joint. BF electrodes were placed in a similar manner. Although the BF is both a hip-extensor and knee-flexor, its primary function during the squat exercise is as a hip-extensor acting eccentrically during the down phase and concentrically during the up phase.

The surface electrodes were placed 5 cm apart in each case. The EMG signals were preamplified near the site and further amplified (CMMR>90 db, 10 MOhm). Lastly, the signals were interfaced to the computer via the A/D converter.

Data Reduction

Cinematographic. The film was digitized using a GRAF/PEN sonic digitizer interfaced to the computer system. The head of the second metatarsal, the ankle, knee, hip, and shoulder joints were digitized. Only the left side of the subject was digitized. The film, force platform, IAP, and EMG data values were synchronized by means of a voltage pulse that illuminated a light-emitting diode in the camera field of view while simultaneously sending a voltage signal to the A/D converter.

The digitized position-time data were smoothed using an optimizing low-pass digital filter program. The digital filter began at a low cut-off frequency and continued to filter the data in +0.5-Hz increments until the residuals analysis revealed the optimal smoothing value. The kinematic data generated included the absolute limb angles and the relative joint angles. Lander et al. (15) found a good correspondence between critical variables in the vertical force-time curve and 2.36 rad (135 degree) and 1.57 rad (90 degree) knee angle positions. These selected critical kinematic variables were used to divide the lift into six functional periods (P). The downward phase of the lift consisted of P1 through P3 while P4 through P6 comprised the upward phase. P1: Start of the lift (based on the first change in the Z-force) to 2.36 rad (135 degree) knee angle, P2: 2.36 rad knee angle to 1.57 rad (90 degree) knee angle, P3: 1.57 rad knee angle to minimum knee/thigh angle, P4: minimum knee/thigh angle to 1.57 knee angle, P5: 1.57 rad knee angle to 2.36 rad knee angle, and P6: 2.36 rad knee angle to the end of the lift (when the Z-force returned to baseline). Critical events (maxima and minima) and mean values were calculated based upon the six functional periods and two phases of the lift for the kinematic as well as all of the remaining variables.

Force platform and IAP. The force platform voltage outputs were summed and scaled to obtain the three orthogonal forces (X, Y, Z). Summation and division of the eight raw force platform channels allowed for the calculation of the center of pressure of the feet on the force platform in the anteroposterior (COPx) and mediolateral (COPy) directions. IAP values were obtained by sealing the A/D voltage values based upon the calibration curve.

Electromyographic. EMG voltage outputs were mathematically full wave rectified. The mean value (mEMG) was determined for each phase (down and up) and each period (1 through 6) of the lift. The mEMG values were normalized for each subject based upon the maximum value (100%) observed during the six defined periods of the lift and across all 16 repetitions that a subject performed during both conditions (WB and WOB). For example, if a subject's greatest mEMG value occurred during P4, then it was assigned 100% and all other period values were proportionately smaller (e.g., 75%). The mEMG values for the up and down phases of the lift were calculated in a similar manner. This allowed for the comparison of mEMG values between subjects.

Statistical Procedures

The eight repetitions were combined into four pairs of trials for ease of analysis and presentation (i.e., pair 1 = trials 1 and 2). Individual trial data were used to determine the minima, maxima, and mean values. All critical events and values based on the six periods and two phases of the lift were statistically evaluated using a two-way repeated measures ANOVA with planned comparisons. The comparisons examined included WB vs WOB for each of the four pairs of repetitions and comparisons between the pairs of repetitions within each weight-belt condition.

RESULTS

Primarily, the data presented are for the up and down phases of the lift as defined earlier by the relative knee joint angle. Some additional parameters are also included where appropriate, e.g., maxima, minima, and period mean values.

Temporal

In general, WOB trials were of longer duration than WB trials, although not all comparisons were significant (Table 1). The down phase appeared to be rather similar across repetitions with no pattern present in the data. But, the overall, up phase, and P5 time all increased significantly by the last repetitions. P5 showed the greatest increases in duration (WB = +84.8%, WOB = +95.6%), indicating that this was the most critical portion of the lift. The elongation of P5 can be seen graphically in Figure 1.

TABLE 1. Temporal mean values and statistical comparisons.

	Pairs of Repetitions					
	1	2	3	4	Change	Differences
Overall time (s)						
Belt	2.69 (0.12)	2.79 (0.07)	3.14 (0.11)	3.34 (0.09)*	24.2%	1–34, 2–34
None	2.77 (0.13)	2.92 (0.10)	3.28 (0.17)	3.56 (0.17)	28.5%	1–34, 2–34
Down phase time (s)						
Belt	1.18 (0.08)*	1.14 (0.05)	1.13 (0.04)	1.15 (0.05)*		
None	1.25 (0.08)	1.17 (0.04)	1.12 (0.03)	1.27 (0.10)		3–4
Up phase time (s)						
Belt	1.52 (0.05)	1.65 (0.03)	2.01 (0.08)*	2.20 (0.07)	44.7%	1–34, 2–34
None	1.52 (0.06)	1.76 (0.08)	2.15 (0.16)	2.30 (0.09)	51.3%	1–34, 2–34
Period 5 time (s)						
Belt	0.66 (0.04)	0.78 (0.03)	1.06 (0.08)*	1.22 (0.06)*	84.8%	1–34, 2–34
None	0.68 (0.06)	0.82 (0.06)	1.19 (0.14)	1.33 (0.09)	95.6%	1–34, 2–34

Standard errors are in parentheses. Change is the percentage increase or decrease from pair 1 to pair 4. Differences are the significant comparisons between pairs of repetitions ($P < 0.05$).

Significance level for the comparison between the weight-belt (WB) and without weight-belt (WOB) conditions: * $P < 0.05$.

Kinematic and Force Platform

No significant differences were observed between WB and WOB for the force platform (Fig. 1) and kinematic variables. These data show that a similar technique was employed by the subjects regardless of belt usage. However, the degree of forward trunk lean increased with each repetition. The minimum trunk angle value was approximately 0.89 rad (51 degrees) in the early repetitions and decreased to about 0.80 rad (46 degrees) by the last repetitions, which resulted in an average change of −10.9%. Similarly, the mean trunk angle during the up phase decreased 6.0% by the latter repetitions.

Intra-Abdominal Pressure

IAP has been shown to provide a significant amount of relief to the lumbar spine during the lifting of heavy objects. This is accomplished by pressurizing the abdominal cavity in order that it may bear some of the load normally born by the spine. High correlation values have been reported in the literature between IAP, lumbosacral moments, spinal compression force, and back muscle force (16,21). In the present study, all comparisons between WB and WOB were found to be statistically significant ($P < 0.05$). The use of a weight-belt increased the IAP by approximately 25–40% (Table 2).

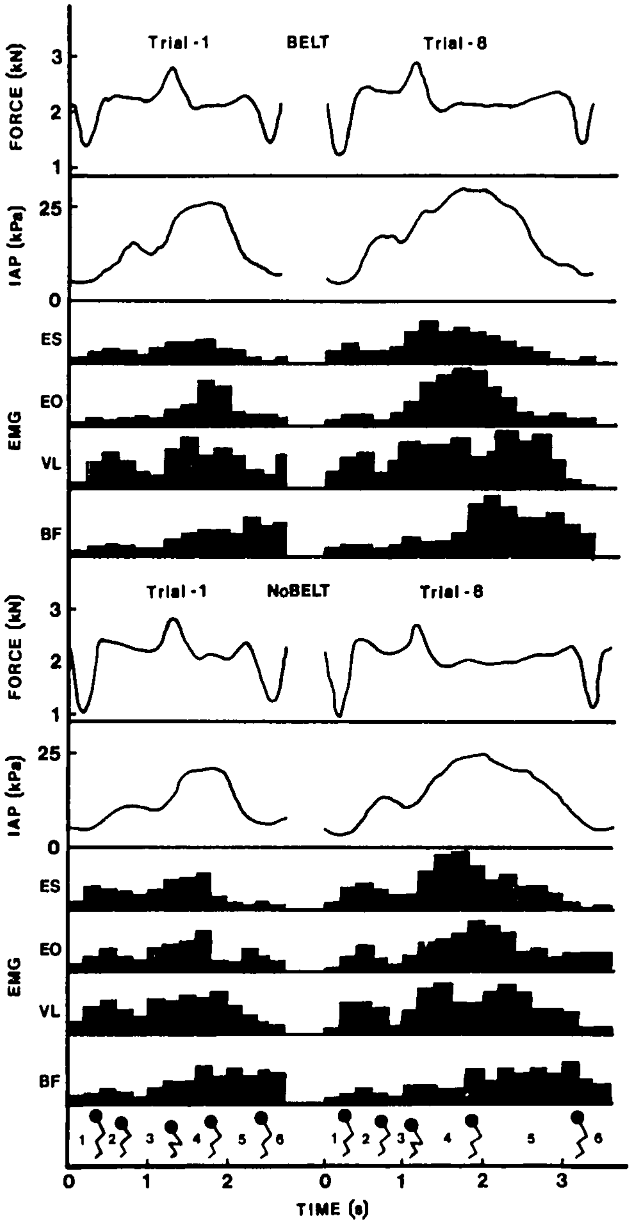

Figure 1—Sample trials of force (vertical ground reaction), IAP, and EMG: ES (erector spinae); EO (external oblique); VL (vastus lateralis); BF (bicep femoris). The EMG has been integrated over 200-ms periods for clarity.

Maximum values and down phase mean values exhibited few differences across repetitions. In contrast, the overall and up phase mean values did show significant increases in later repetitions. Undoubtedly, the up phase increases of approximately 11.5% were responsible for the observed increases in the overall mean values. A typical set of repetitions is shown in Figure 1.

TABLE 2. IAP values and statistical comparisons.

	Pairs of Repetitions					
	1	2	3	4	Change	Differences
Overall mean						
Belt	14.63 (0.82) *	15.87 (0.93) *	16.20 (1.02) *	16.73 (0.92) *	14.4%	1–234
None	11.04 (0.65)	12.14 (0.58)	12.75 (0.61)	12.91 (0.89)	9.7%	1–234
Maximum value						
Belt	25.29 (1.42) *	26.37 (1.39) *	25.85 (1.39) *	27.29 (0.98) *		1–4
None	19.63 (1.11)	20.83 (0.95)	21.10 (1.15)	20.53 (1.46)		
Down phase mean						
Belt	11.25 (0.81) *	12.01 (0.82) *	11.63 (0.73) *	12.03 (0.78) *		1–4
None	7.96 (0.57)	8.17 (0.54)	8.42 (0.63)	8.66 (0.66)		
Up phase mean						
Belt	17.30 (0.92) *	18.66 (1.09) *	18.85 (1.19) *	19.26 (1.12) *	11.3%	1–234
None	13.60 (0.80)	14.85 (0.66)	15.13 (0.74)	15.21 (1.01)	11.8%	1–234

Pressures are expressed in kPa. Standard errors are in parentheses. Change is the percentage increase or decrease from pair 1 to pair 4. Differences are the significant comparisons between pairs of repetitions ($P < 0.05$).

Significance level for the comparison between the weight-belt (WB) and without weight-belt (WOB) conditions: * $P < 0.05$.

Electromyographic

EMG was collected from two trunk muscles that were representative of the abdominal constrictor (EO) and back extensor (ES) muscles. Also, knee extensor (VL) and hip extensor (BF) muscles were examined. The EMG values are graphically depicted in Figure 1; for clarity, the EMG has been integrated over 200-ms periods of time. Results for the EMG variables are presented in Table 3.

No differences were observed between WB and WOB for ES mEMG values. Up phase mean values were only up to 11% greater than the corresponding down phase values suggesting similar effort in trunk extension. Increases across repetitions varied from 7.8% for the down phase to 19.2% during the up phase of lift. This may indicate a greater effort (force) being exerted or else local fatigue in the muscles.

No weight-belt differences were observed for the EO mEMG. Also, no pattern across repetitions was observed during the down phase. In contrast, increases of 16.7 and 20.7% were observed in the up phase mean values between the first and last repetitions. Also, up phase values were nearly twice as great as down phase values. This indicates a much greater abdominal effort when raising the weight.

VL mEMG values are consistently greater for WB, although not all comparisons were statistically significant. Most of the differences were concentrated in P5 where the WB values were up to 18% greater than WOB values. This may indicate a greater reliance on knee-extension when using a weight-belt. Increases between first and last repetitions varied from 7.4 to 14.7% for the variables examined. The down phase showed no consistent pattern across repetitions. Up phase mEMG

TABLE 3. mEMG values and statistical comparisons.

	Pairs of Repetitions					
	1	2	3	4	Change	Differences
Erector Spinae Group						
Down phase mean						
Belt	69.3 (5.4)	72.7 (4.6)	75.3 (5.6)	76.1 (4.8)	9.8%	1-34
None	70.5 (4.9)	70.3 (4.6)	74.9 (5.0)	76.0 (5.8)	7.8%	1-4, 2-4
Up phase mean						
Belt	71.9 (3.7)	80.1 (3.2)	79.5 (3.9)	81.4 (4.1)	13.2%	1-4
None	71.4 (5.0)	81.1 (4.2)	82.1 (1.8)	85.1 (3.2)	19.2%	1-234
External Oblique						
Down phase mean						
Belt	38.9 (6.5)	44.5 (7.9)	37.2 (5.7)	40.0 (6.3)		2-3
None	39.0 (6.1)	36.8 (5.5)	42.0 (6.5)	37.6 (5.5)		
Up phase mean						
Belt	63.9 (8.3)	65.5 (9.2)	71.4 (9.7)	74.6 (10.2)	16.7%	1-4
None	58.9 (8.3)	66.8 (9.5)	71.5 (10.1)	71.1 (10.6)	20.7%	1-34
Vastus Lateralis						
Down phase mean						
Belt	57.6 (4.3)	68.9 (4.0)	61.4 (2.8)	62.5 (2.9)		1-2
None	56.1 (2.3)	60.3 (2.9)	58.9 (3.6)	60.5 (3.0)		1-34
Up phase mean						
Belt	84.2 (2.3) *	87.4 (2.1)	91.6 (2.2) *	90.4 (4.7)	7.4%	1-3
None	75.5 (1.7)	85.3 (3.0)	82.1 (1.9)	85.2 (1.7)	12.8%	1-234
Period 5 mean						
Belt	70.7 (4.3) *	73.0 (3.3) *	78.2 (2.8) *	76.5 (2.8) *	8.2%	1-3
None	59.8 (1.3)	65.1 (2.2)	66.7 (1.9)	68.6 (2.6)	14.7%	1-34
Bicep Femoris						
Down phase mean						
Belt	26.3 (2.8)	31.6 (3.7) *	30.2 (3.8) *	31.4 (4.0) *		1-24
None	26.5 (3.2)	28.9 (2.9)	27.6 (3.6)	27.5 (4.4)		
Up phase mean						
Belt	61.9 (3.1)	68.9 (3.7)	80.0 (3.9)	88.2 (5.3) *	42.5%	1-34, 2-34, 3-4
None	60.0 (4.8)	69.6 (3.9)	73.8 (3.6)	78.9 (4.1)	31.5%	1-234, 2-4

All values are expressed as a percentage of the standardized mEMG for periods or phases. Standard errors are in parentheses. Change is the percentage increase or decrease from pair 1 to pair 4. Differences are the significant comparisons between pairs of repetitions ($P < 0.05$).

Significance level for the comparison between the weight-belt (WB) and without weight-belt (WOB) conditions: * $P < 0.05$.

values were approximately 50% greater than the down phase values.

Several differences were observed in belt usage for BF mEMG values. Up phase WB values were up to 9.3% greater, especially during the later repetitions, indicating greater reliance on the BF for hip-extension. Differences across repetitions were only present during the up phase with up to a 42.5% increase by the last repetitions. In general, up phase values were over twice as great as down phase values (Table 3; Fig. 1).

DISCUSSION

Lifters typically use multiple repetitions in their training routines. The effects of wearing or not wearing a weight-belt could reasonably be expected to change across repetitions as fatigue becomes a bigger factor in performance. Hunter et al. (10) found physiological differences in belt usage over time in several different types of activities. Blood pressure increased during 6 min of cycling on an ergometer and during a 2-min isometric dead-lift. Heart rate also increased during cycling.

Surprisingly, excluding duration, the lifters in this study showed no appreciable differences in technique across repetitions as determined by force platform and kinematic variables. It could logically have been assumed that technique would have degraded with time, but this appeared not to be the case. It is likely that determination of a more accurate 8RM load may have resulted in the degradation of technique across repetitions. However, there was no way to ensure that a subject would fail exactly during a particular repetition. Many temporal variables were found to be statistically different. The major trend was an increase in the duration of the defined periods and phases by the later repetitions. Differences were also observed between the WB and WOB conditions. In general, the WB repetitions were performed more quickly than the WOB repetitions. This finding could mean that the subjects felt more comfortable and safe while squatting with a weight-belt. All subjects used weight-belts at various times in their training routines.

IAP has been shown to be a good indicator of forces acting on the spine during the squat exercise (15,16). IAP will increase in response to greater demands placed upon the spinal structures. If IAP is voluntarily increased *a priori*, it provides for even greater protection and relief of spinal structures. In this study, the use of a weight-belt resulted in greater IAP values ranging from 25 to 40% in the variables examined. This is somewhat greater than previous research on the squat that showed an increase of approximately 17% for single repetitions (16). Harman et al. (9) in a study examining the dead lift exercise showed that using a weight-belt increased IAP by approximately 13%. The magnitude of the IAP values and the loads employed in the previous two studies compared well with the present study. It was hypothesized that subjects would take advantage of the weight-belt by pushing against it to a greater extent as fatigue increased in the later repetitions. However, there were no interactions observed in the IAP results of this study. The IAP mechanism appeared to operate in a similar manner with the weight-belt as without, but at a greater level of pressure. Across repetitions, up phase IAP values increased to approximately the same extent as the EO, ES, and VL mEMG values, but not as great as the BF mEMG.

In the squat, it is desirable for the trunk muscles to act isometrically to maintain the proper trunk posture. During this study, little or no trunk flexion and extension were observed. EMG for both the back extensors (16) and abdominal muscles (16,21) has been shown to decrease when a weight-belt is worn. No differences were observed in the present study in either the ES or EO mEMG values. In previous studies (4,6,7,13,16,24) back muscle EMG has correlated highly with either load or calculated back muscle force. For this reason, the increased IAP values observed in this study should have resulted in a decreased ES mEMG. It is possible that the greater speed of performance counteracted any possible decrease. A similar decrease should have been observed for the EO mEMG. Possible explanations may be that the subjects actively pushed against the weight-belt or else the greater speed of movement led to the increased EO mEMG values.

Results of the VL and BF mEMG data suggest that the subjects utilized greater knee and hip extensor musculature with a weight-belt than without. Previous research has also shown similar results (16). More-skilled lifters use more knee extension that their unskilled counterparts who rely more upon hip extension (18). Also, the BF results may have been influenced by its dual role as a knee flexor. It is possible that the BF was just reacting to a stretch imposed by the knee extensors. It is also interesting to note that the BF mEMG values across repetitions increased at a much greater rate than the ES, EO, VL, and IAP values. This suggests that the BF becomes more important during the later repetitions.

In summary, using a weight-belt resulted in greater IAP, VL, and BF values. Also, subjects performed more quickly with a weight-belt than without. No differences were observed between WB and WOB for the ES and EO mEMG values.

The use of weight-belt clearly increased IAP during the squat exercise and in all likelihood reduced spinal compression and shear forces. It appeared as though the subjects felt more secure when using a weight-belt because of the increased speed of performance. The lifters also appeared to use the knee extensor muscles to a greater extent, suggesting a more skilled performance.

Interestingly, the lifters in this study appeared to maintain their technique even in the presence of fatigue during the later repetitions. The only technique-related difference was the increase in duration of the up phase of the lift. However, this does not guarantee that technique would be maintained when performing more than eight repetitions or that a different exercise would yield the same results.

Based on the findings of this study, the use of a weight-belt appears to provide an added degree of protection during submaximal repetitious lifting. A rather consistent difference in IAP across trials between the belt and no belt conditions showed that there was no increase in this benefit as more repetitions were performed. It is possible that performing more than eight repetitions and/or performing to exhaustion may yield different results. Even in this case the use of a weight-belt could only help the situation.

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