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EFFECTS OF RANDOM WHOLE-BODY VIBRATION ON BACK STRENGTH AND BACK ENDURANCE

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Whole-body vibration (WBV) has been implicated as a cause of low-back pain in the industrial workforce. The U.S. Bureau of Mines conducted two studies to determine whether random, low-intensity WBV had an effect on maximum back extensor strength and on back endurance. In the first, maximum back strength was measured before and after 30-min periods of vibration while seated in four different seats. In the second, back endurance was measured before and after 30-min periods of vibration while positioned in eight different seating postures. Results from the two studies indicated that back muscle function is not compromised by WBV at the intensity and duration studied.

INTRODUCTION

Exposure to shock and whole-body vibration (WBV) is quite common for operators of mobile underground coal mining equipment. Minimal research has been conducted on the exposure of underground equipment operators to WBV, or on the design of appropriate seating. A previous Bureau of Mines research contract (Remington et al., 1984) conducted a limited evaluation of mobile underground coal mine equipment operators to WBV. The data indicated that 55% of the operators were exposed to vertical vibration levels that exceeded the International Standard Organization's (ISO, 1974) fatigue-decreased proficiency criterion (intended to preserve working efficiency) and 22% exceeded the exposure limit (intended to protect workers from physical injury or illness caused by daily exposure at work).

A review of the Mine Safety and Health Administration's accident statistics for a 6-yr period (1981-86) indicated that a total of 1688 lost-time injuries occurred to coal haulage (shuttle car) operators. Of these injuries, a total of 25% involved the back, 15% involved the neck. Various research studies and reviews have indicated that WBV can affect the musculoskeletal, cardiovascular, and gastrointestinal sytems of exposed workers (Carlsoo, 1982; Wilder et al., 1982; Chaffin and Anderson, 1984; Wilder et al., 1985). In addition to these physiological and physical effects, other studies have investigated effects on performance and the subjective evaluations to WBV exposure (Soule, 1973; Weaver, 1979; Oborne and Boarer, 1982; Meister et al., 1984; Bobick et al., 1988).

A comprehensive review of the WBV literature (Seidel and Heide, 1986) indicated that only 5 of a total of 185 studies reviewed dealt with the effects of WBV on the function of the trunk musculature. This is surprising considering the importance that the trunk muscles have in the function of the vertebral column. Wilder et al. (1982) found a frequency shift in the raw EMG signals that suggested a fatigue in the erector spinae and the oblique musculature from sinusoidal vibration.

In view of the limited amount of information relating to the effects of vibration on trunk muscles, the Bureau of Mines conducted two studies to determine whether random, low-intensity WBV had an effect on maximum back extensor strength and on back endurance.

METHOD

Subjects

A. Maximum back strength. Eight healthy men (35.5 yr of age ± 6.5 SD) volunteered to participate in a pilot study that examined the effects of vibration, seatback angle, and the presence or absence of foam padding on maximum back extensor strength. The subjects were employees of the Bureau of Mines Pittsburgh Research Center and were minimally familiar with the test protocol. Potential subjects were advised of the nature of the investigation and signed an informed consent form before undergoing the screening medical exams. They received a thorough physical examination and graded exercise tolerance test (American College of Sports Medicine, 1980) prior to participation.

B. Back endurance. Eight healthy male underground miners (37.0 yr of age ± 5.5 SD) participated in a study that examined the effects of eight different seat postures on their back endurance. The subjects were paid volunteers from a low-seam coal mine in Pennsylvania and had experience with WBV from mobile underground coal mining equipment. Similar to the first study, potential subjects were advised of the nature of the investigation and signed an informed consent form before undergoing the screening medical exams. They received a thorough physical examination and graded exercise tolerance test (American College of Sports Medicine, 1980) prior to participation.

Experimental design

A. Maximum back strength. The independent variables in the first study were (1) presence or absence of random, broad-band vibration, (2) seatback angle of 90° or 130°, and (3) presence or absence of foam padding material (2 in thick) on the seatpan and seatback. The dependent variable was the maximum back extensor strength.

Each subject was tested on two separate days. Half of the subjects were vibrated on their first day, and their second day was non-vibrating. The reverse was true for the other half of the subjects (their first day was non-vibrating and the second day was vibrating). The order of whether the first day was vibrating or not was randomized among the subjects.

During each test day, the subjects were exposed to four different seat configurations (seatback angle of 90° or 130°, and padded or steel seat) for a 30-min period in each configuration. Each subject had the same order of seat configurations for his two test days so data collected could be compared between the vibrating and non-vibrating days. However, the order of testing the seat configurations among the subjects was randomized and counterbalanced to control for bias due to the order of testing.

B. Back endurance. The independent variable in the second study was the configuration of the eight seats evaluated. Eight different seat conditions were tested: (1) 110° seatback angle with 1 in padding, (2) 110° seatback angle with 2.5 in padding, (3) 110° seatback angle with the subject sitting on two bags of rock dust [rock dust, which is pulverized limestone, is commonly used in underground coal mines to prevent an explosive condition by keeping fine coal dust out of suspension in the air; bags of rock dust are commonly used by mobile equipment operators as seat pads instead of sitting on steel seats], (4) 140° seatback angle with 1 in padding, (5) 140° seatback angle with 2.5 in padding, (6) 140°

seatback angle with two bags of rockdust, (7) 170° seatback angle with 1 in padding, subject lying on his back, and (8) 170° seatback angle with 1 in padding, subject lying on his left side.

The dependent variable was the total time that the subject could pull at 70% of his maximum back exertion, which was measured at the beginning of each test day. The order of testing the eight seat configurations among the subjects was randomized and counterbalanced to control for bias due to the order of testing.

Apparatus

Figure 1 presents a schematic of the shake table used in both studies. Shown is the seat configuration for the first experiment. The seatback was adjustable to the 90° and 130° angles, and the 2 in padding could be easily attached to the seatpan and back. In the second experiment, three separate seats were constructed and were bolted in place for the testing. The 1 in and 2.5 in pads were attached to the seatpan and back of the 110° and 140° seats, and the rock dust bags were strapped in place on these two seats. The 170° configuration was modified with 1 in pads only.

The various seats were bolted to the electrohydraulically powered, computer-controlled shake table. While the subjects were seated in the different configurations, they wore headphones through which static (pink noise) was played to mask extraneous auditory signals. The foam material was designated as Pudgee[1] and manufactured by Dynamic Systems, Inc.

[1]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

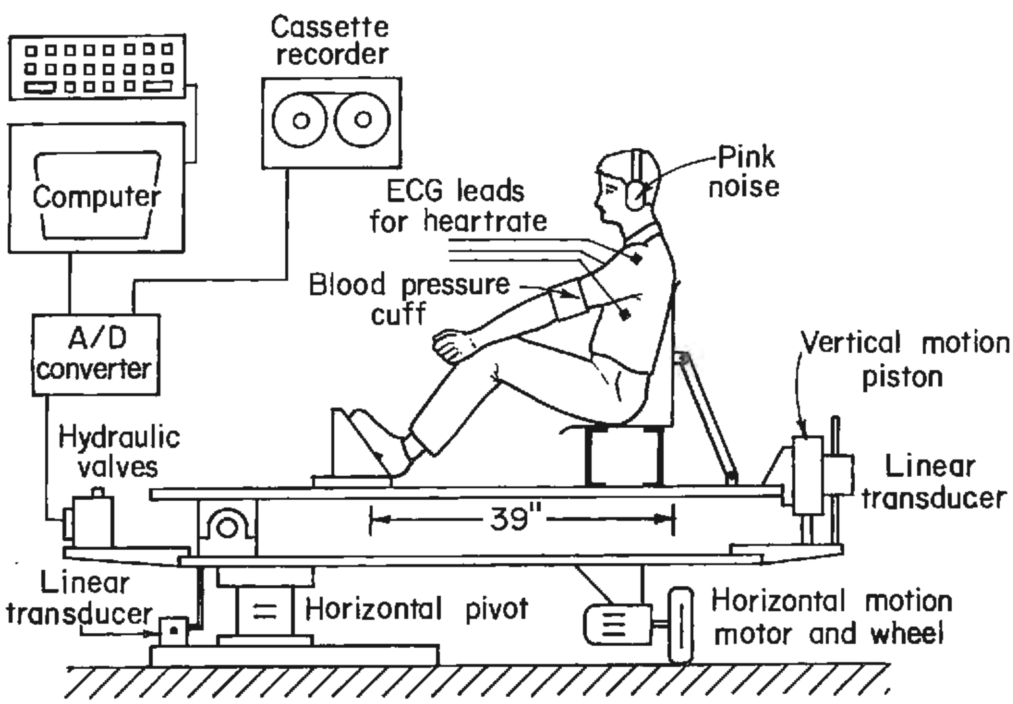

Figure 1. Schematic of experimental test equipment (horizontal motion apparatus was not utilized in these studies).

Experimental task

Figure 2 provides a typical one-third-octave-band power spectrum of the vibration generated by the shake table. This spectrum is an average of the four segments of the normal cycle that a coal haulage vehicle (shuttle car) undergoes when moving coal from the mining face to the dumping point for removal to the surface. These segments are (a) loading coal into the haulage vehicle, (b) tramming loaded to the dump point, (c) unloading the coal, and (d) tramming empty back to the mining location.

Data were collected during actual shuttle car operation underground. Vertical vibration signals were collected via a uniaxial accelerometer that was attached to the machine frame directly beneath the operator's seat. These data were processed so the computer-controlled vibration platform would approximate the signals gathered from the shuttle car during operation.

Figure 2 indicates that the composite vibration spectrum to which the subjects were exposed was broad-band and very low intensity. The acceleration levels of the spectrum were greater than 0.03 m/sec^2 (approximately 0.003 g) from 3.15 Hz to 80 Hz. The maximum values of acceleration were approximately 0.3 m/sec^2 (approximately 0.03 g) at 10 Hz and slightly less than 0.4 m/sec^2 (approximately 0.04 g) at 12.5 Hz. This spectrum is compared to the ISO 2631 fatigue-decreased proficiency criteria for 4-, 8-, and 16-hr exposures.

In the first experiment, the subjects' maximum back extensor strength was evaluated before and after 30-min periods of vibration. Before the testing began, the subjects practiced providing a maximum voluntary isometric back exertion via a test-retest procedure that followed the Caldwell regimen (Kroemer, 1987). After the subject had sufficient

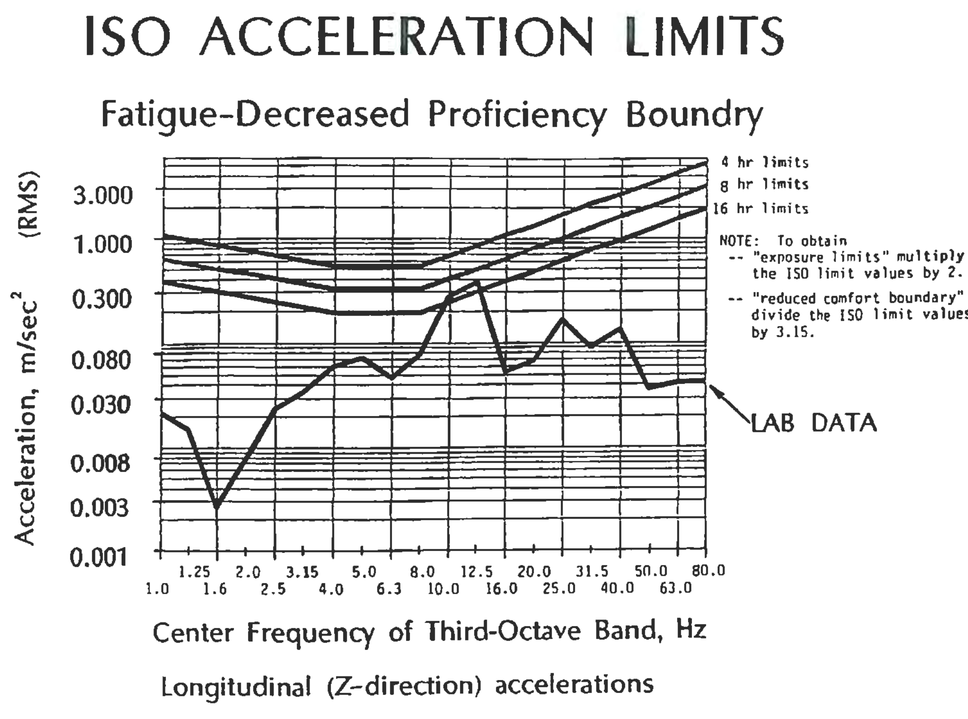

Figure 2. One-third-octave-band power spectrum of vibration generated by shake table compared to ISO 2631 Fatigue-Decreased Proficiency criterion.

practice (perhaps three to five exertions) to duplicate the maximum value, the pre-vibration measurement was collected. Back extensor strength was measured with a strain gage type of load cell, manufactured by the Prototype Design and Fabrication Company. It was used in conjunction with the Model ST-1 Force Monitor. The subject was required to stand facing the load cell with the pelvis positioned against a padded board located anterior to the hip joint. A strap that was connected to the load cell was looped around the subject's shoulders. The subject was instructed to exert a steady rearward force (not a jerk) against the strap, using the back muscles while pushing the hips forward against the padded board. The knees were to be kept straight, the hands were to be at the sides of the legs, and the feet were to be flat on the platform. The maximum exertion was to be held for five seconds. At the completion of the vibration, the maximum back strength (single exertion) was again measured to determine whether any decrement had occurred.

In the second experiment, the endurance of the subjects' trunk extensors was evaluated before and after 30-min periods of vibration. The endurance test was similar to the maximum exertion test described above. The subject was required to pull for as long as possible at 70% of his maximum exertion, which was measured at the beginning of each test day. The same apparatus and same procedure, which were described previously, were used to measure a subject's maximum back exertion.

A computer program was written that would monitor the force output of the strain gage. The program would activate a low-pitched tone when the force was less than 65% of the maximum exertion for that subject, and activate a high-pitched tone when the force was more than 75% of the maximum value. The subject was instructed to keep the tension against the shoulder strap so no tone would be generated, thus keeping the force at 70% ± 5%. In addition, an analog force monitor was incorporated into the output of the strain gage so the subject had immediate visual feedback as to whether he was pulling too hard or not hard enough.

The simultaneous visual and auditory signals provided excellent feedback for the subject to quickly settle into the force that kept the tone quiet. When the subject began to fatigue, the low-pitched tone would be activated; the computer program terminated the test when this tone was activated for three consecutive seconds. The total time of pulling was recorded as that subject's back endurance value. At the completion of the 30-min vibration period, the back endurance test was repeated to determine if the vibration adversely affected the endurance of the trunk extensors.

<u>Data treatment</u>

The results of data collected for the two experiments were analyzed using an analysis of variance with repeated measures (ANOVR) statistical package (Games et al., 1980). For the first experiment, a 2 x 2 x 2 (vibration or not x seatback angle x seat material) analysis was utilized. In the second experiment, a 1 x 8 analysis (eight seat configurations) was utilized. Because of a wide variation in body size and corresponding back strength among the subjects, each test subject served as his own control. Relative differences in maximum back strength and back endurance (total time pulling) were computed for the before- and after-vibration measurements. Critical alpha levels were 0.05 in all cases.

RESULTS

Table 1 provides a summary for the relative differences in maximum back strength for the eight subjects. Comparing the data for the eight test conditions indicates that there is very little difference in the relative strengths when the subjects were vibrated or not. The average of the four summary values for vibrating condition is 96.15% and the average of the

Table 1. Summary of relative differences in maximum back strength for all test conditions for all test subjects (n = 8).

Vibration				No Vibration			
90° foam	90° st	130° foam	130° st	90° foam	90° st	130° foam	130° st
96.2% ±9.3%	94.8% ±9.5%	95.6% ±10.7%	98.0% ±12.6%	100.2% ± 9.1%	95.8% ±10.5%	96.6% ±6.3%	97.3% ±5.0%

foam = 2 in padded mat'l; st = steel seat; 90° and 130° = seatback angle values are mean ± standard deviation.

four summary values for the no-vibrating condition is 97.48%. The slight decrease (1.33%) in relative back strength during the vibrating condition is certainly not significant statistically. In fact, the results of the repeated measures analysis of variance indicated that none of the independent variables had a significant effect on the maximum exertion of the subjects. Whether the subjects were vibrated or not (p= 0.331), or whether they were positioned with the seatback at 90° or 130° (p= 0.936), or whether they were sitting on the padded or steel seat (p= 0.804), none of these conditions had a statistically significant effect on the maximum back strength exertions measured after the 30-min test periods.

Table 2 provides a summary for the relative differences in the back endurance (total time pulling at 70% of maximum back exertion) for the eight subjects. The results of the repeated measures analysis of variance indicated that none of the eight seat configurations listed in Table 2 had a statistically significant effect on the subject's back endurance. There was some indication that the 170° posture that required the subjects to lie on their side caused a decrease in the total pulling time, but the result was non-significant (p= 0.355).

Table 2. Summary of relative differences in back endurance (total time pulling at 70% maximum exertion) for eight seat configurations for all test subjects (n = 8).

110°thn	110°thk	110°rdb	140°thn	140°thk	140°rdb	170°thn,back	170°thn,side
113.1% ±40.3%	116.8% ±42.5%	108.5% ±21.8%	107.1% ±22.7%	106.6% ±18.2%	113.3% ±14.9%	103.1% ±13.7%	91.8% ±14.4%

thn = thin (1 in) mat'l; thk = thick (2.5 in) mat'l; rdb = one rock dust bag on seatback and one on seatpan; 170° back = subject lying on back; 170° side = subject lying on left side; values are mean ± std. deviation.

DISCUSSION

The results from the present studies indicate that WBV (at the duration and intensity investigated) does not compromise back muscle function. The decrease in back strength was not significantly different whether the subjects were vibrating or not. In addition, back endurance was not affected by the vibration or the eight different seating configurations studied. It is important to realize that a limited population of test subjects was studied in these two experiments. A larger sample size may produce different results. In addition, longer periods of vibration over extended time periods may have some effect on muscular function. This finding suggests that other causes are responsible for the incidence of low-back pain when miners are subjected to WBV.

McKenzie (1981) has stated that the most important factor to be considered in the etiology of low-back pain is the sitting posture. A good sitting posture is one that maintains the spinal curves that occur normally when standing erect. Sitting postures that reduce the normal lumbar lordosis will stretch the spinal ligaments and will eventually produce low-back pain. In addition, a slumped sitting posture will cause the fluid intervertebral disk to migrate rearward, putting pressure on the posterior longitudinal ligament and on the nociceptive receptors that are located primarily in this region. Immediately adjacent to this are the nerve roots and the spinal cord. Thus, this increase in pressure will deform the free nerve endings and, after repeated instances, will lead to chronic low-back pain.

When considering the loss of normal lordosis and mis-alignment of the vertebrae, along with repeated impacts from vibration and shock loading to the buttocks and lumbar spine, the rate of disk deformation and ligamentous stretching may be accelerated. Over time, micro-fractures may also develop that may lead to a weakening of the annulus. This may increase the likelihood of a lost-time low-back injury from some normal work activity that may be unrelated to operating mobile equipment, but causes a sudden loading to the ligaments and other soft tissues of the lumbar spine, producing low-back pain.

Partly responsible for low-back pain reported by mobile equipment operators is the inadequate seat design of typical underground mining equipment, which fails to maintain correct lordosis in the lumbar spine. Some models of underground mining equipment have padded seats, but the materials tend to wear out rather quickly in the harsh underground environment. Many models of mobile equipment have seats that are only a bent steel plate. In addition, the seat is usually attached directly to the machine frame since vibration-isolation systems are difficult to install because of space limitations. Thus, the operator is subjected to almost constant vibration and shock loading during normal operation.

To prevent the effects from poor sitting postures that have been described, seats that are incorporated into mobile underground mining equipment should be modified to include a lumbar support. In addition, these workers should be encouraged to use a series of simple exercises to counteract the effects of prolonged flexion, and increase the muscle tone of the abdominals and back musculature.

CONCLUSIONS

These two studies determined that low-intensity, short-duration exposures of whole-body vibration did not adversely affect the maximum back strength or the back endurance of the subjects studied. In addition, this research has indicated that episodes of low-back pain, which occur quite regularly with mobile equipment operators, seems to be a function of postural and mechanical effects related to the structures of the spine, rather than a weakening of the trunk musculature.

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