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Project Title: Unexpected Trunk Loading Following Seated Vibration

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List of Abbreviations:

EMG: Electromyography or Electromyographic

FDP: Fatigue, Decreased Proficiency

Hvib: Horizontal (Lateral) vibration

ISO: International Standards Organization

RMS: Root Mean Square

VHvib: Combined Vertical and Horizontal (Lateral) vibration

Vvib: Vertical vibration

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vertically and horizontally, laterally (VHvib). If the means of the differences in this matched pair presentation were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Change in Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Change in Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Static): it was significant ($P<.025$) in the "x-" or " Change in Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Change in Normalized Peak EMG" axis.

Figure 10. Characteristics of muscle response to unexpected load applied before and after five minutes of walking following: entry into the study (Entry), sitting still (Sit), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If changes in the means were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Sit): it was significant ($P<.05$) in the "x-" or "Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Normalized Peak EMG" axis.

Figure 11. Changes in characteristics of muscle response to unexpected load applied before and after five minutes of walking following: entry into the study (Entry), sitting still (Sit), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If the means of the differences in this matched pair presentation were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Change in Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Change in Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Sit): it was significant ($P<.05$) in the "x-" or " Change in Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Change in Normalized Peak EMG" axis.

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Significant Findings:

The information/advice to take away from this study is as follows: It is a good idea to walk around for five minutes after driving (for 40 minutes) before bending over or lifting anything.

The back is at risk, for several reasons, if one chooses to bend over or lift immediately after driving. The reason for this is because the response of the back muscles to an unexpected load is affected by the loading environment immediately preceding the sudden load application. Separate forty-minute exposures to vertical (5 hertz) and side-to-side (2 hertz) sinusoidal vibration, at the International Standards Organization (ISO) 8-hour, Fatigue Decreased-Proficiency (FDP) limit, significantly increased the erector spinae total reaction time and peak muscle EMG activity. In other words, the muscles take more time to respond and generate greater predicted forces following those relatively short (when compared to an 8-hour day) vibration exposure durations. This work questions whether the ISO 8-hour FDP vertical vibration limit is conservative enough to protect the disc from mechanical damage.

Walking for five minutes is beneficial because it tends to "reset" the system. The effect of walking on subjects who had been vibrated from side-to-side showed a trend of decreasing reaction time and peak EMG activity, but it did not reach the $p<.05$ level of significance. Walking after vibrating up-and-down tended to shorten the back muscles' reaction time and significantly ($p<.005$) decreased the peak muscle EMG activity, hence predicted forces generated and applied to the intervertebral disc.

Usefulness of Findings:

The human lumbar intervertebral disc has not yet evolved to be able to accommodate the amount of seated vibration exposure it now experiences. For this reason, this study provides firm reasons for walking after driving, as a control measure, before bending over or lifting.

This work provides further justification for minimizing the jolt/vibration energy reaching the driver. From the "Work=Kinetic Energy" relationship in physics, it can be shown that a 10% decrease in either the vibration amplitude or exposure duration time can decrease the work performed on the body's tissues by 19%. Decreasing both the vibration amplitude by 10% and the exposure duration by 10% can decrease the work performed on the body's tissues by 37%. Relatively small changes can lead to significant improvements and hence risk reduction.

With the aim of reducing the loads on the lumbar disc, the implications of this work further justify designing vehicle seats with adjustable seat pans, adjustable seat backs, lumbar supports and arm rests, and vehicle cockpits laid out so the driver can operate the controls while seated in these optimal postures.

It is clear that work of this sort has been having an effect on vehicle and work task redesign.

Abstract:

This work studied *in vivo*, the effects of common loading environments on the mechanical response of the seated human. The eventual goal of this work is to evaluate and control the occupational health hazard of low back pain, a musculoskeletal injury, by establishing an "envelope" of loading conditions which should not be exceeded if the spine is to avoid mechanical damage. Proceeding from prior *in vitro* findings of short-column buckling in the lumbar spine following vibration exposure, this proposal evaluated how the supporting trunk musculature responded to an unexpected load application after a 40-minute vibration or static load intervention [seated vertical vibration, seated lateral vibration, seated lateral and vertical vibration or sitting still (as a control)]. This simulated the sudden and unexpected shift of an object in the hands of the car or truck driver who has driven for 40 minutes at an exposure level consistent with the 8-hour, Fatigue, Decreased Proficiency level of the ISO 2631 (1985) guideline on human exposure to whole-body vibration. Normal walking (as a break) for five minutes, prior to an unexpected load application, was also tested to determine if it would serve as a reasonable control measure. This would allow lumbar discs to return, via creep behavior, to the upright posture orientation where the facets are more firmly engaged.

Separate forty-minute exposures to vertical (5 hertz) and side-to-side (2 hertz) sinusoidal vibration, at the International Standards Organization 8-hour, Fatigue Decreased-Proficiency limit, significantly increased the erector spinae total reaction time and peak muscle EMG activity in response to an unexpected load. In other words, the muscles take more time to respond and generate greater predicted forces following those relatively short (when compared to an 8-hour day) vibration exposure durations. This work questions whether the ISO 8-hour FDP vertical vibration limit is conservative enough to protect the disc from mechanical damage.

Walking for five minutes is beneficial because it tends to "reset" the system. The effect of walking on subjects who had been vibrated from side-to-side showed a trend of decreasing reaction time and peak EMG activity in response to an unexpected load, but it did not reach the $p<.05$ level of significance. Walking after vibrating up-and-down tended to shorten the back muscles' reaction time and significantly ($p<.005$) decreased the peak muscle EMG activity, hence decreasing the predicted forces generated and applied to the intervertebral disc.

The results show that one should walk around for five minutes after exposure to vertical, and also probably horizontal whole-body vibration prior to placing oneself in a condition to be exposed to an unexpected load.

Body of Report with Conclusions:

Background and Significance

The significance of this study lies in its ability to further the understanding of the numerous factors (anatomic, industrial, environmental) which may influence both the severity of low back complaints, as well as the resultant disability. In particular, the focus on load exposure history as a significant risk factor has particular promise, because to some degree its effects can be minimized through passive control systems (for example seating arrangements), as opposed to factors which are less controllable (for example spinal anatomy). The importance of this work is apparent when one considers that low back pain is one of man's most important disabling health problem. (Kelsey et al., 1979) The medical, industrial and socio-economic consequences of low back pain (LBP) syndromes are staggering. (Kelsey et al., 1979) Low back pain is the leading cause of industrial disability payments; the second most common medical cause of work loss in industry resulting in eight million workers being affected. Two million are chronically disabled from these processes. The cost of lost wages alone comes to nearly 4 billion dollars per annum (Frymoyer et al., 1983) and thus can be anticipated to be far more than that in the 1990's. Hence even partial solutions to the low back pain problem could provide significant societal benefits.

Epidemiology: The frequency of low back complaints appears to be increasing, as well as the attendant disabilities. Although complex societal and economic forces may account for part of this increase, there is suggestive evidence that industrialized environments may be of significance. Such data suggest the need to define carefully the industrial risk factors associated with low back pain as the first step to designing programs of prevention. Epidemiologic work (Frymoyer et al., 1983) indicates significant association of the low back complaint with exposures to both industrial and nonindustrial (particularly vehicular) vibration. The Centers for Disease Control (1983) concur that back pain and vertebrogenic pain may be associated with whole body vibration.

Heliovaara (1987), has studied the apparent ill effects of man in the machine age and Kelsey et al (1984) found an increased incidence of herniated discs with long term exposure to automobiles and trucks.

Various industrial workers exposed to vibration including shipyard workers, sheet metal workers, miners and those using vibrational hand tools have demonstrated abnormal changes in the musculoskeletal, cardiovascular and G.I. systems. (Armstrong et al., 1982). Gearhart (1978) found that helicopter vibration can cause changes in the musculoskeletal system. Investigators have suspected or have found associations between truck or tractor vibration environments and early or unusual degenerative changes in the spine (Christ (1974); Gruber (1974); Rosegger (1970)). In a previously reported study of 3,920 patients (Frymoyer et al., 1980), it was determined that the complaint of low back pain was more common in individuals exposed to vibration, e.g., truck and tractor driving and heavy construction equipment operation. In the New York City Subway system, lateral vibration was associated with a high prevalence of low back pain (Johanning et al, 1990). This corroborates the effects on the spine found in other railroad environments, attributed to vertical and horizontal vibration (Arnautova-Bulat, 1979; Louyot et al, 1954).

Mechanical Characteristics: Extensive studies have been performed assessing the mechanical characteristics of the lumbar motion segment. Reviews of this work (Kazarian (1972); Panjabi and White (1978); Schultz (1974); and Tencer, et al., (1981)) show that the lumbar motion segment is viscoelastic, absorbs energy, moves with six degrees of freedom (three translations and three rotations), exhibits coupled motion (motion in one direction affects motion in others), has limited fatigue tolerance and depends upon its boney and ligamentous components for mechanical tasks.

Early work concentrated on the effects of single loads or torques applied to the motion segment. Researchers have been studying the three dimensional effects of loads and torques applied (Panjabi and White, 1978) in three dimensions (Edwards, et al., 1983; Laborde et al., 1981; Panjabi, et al., 1976; Panjabi, et al., 1977; Pope, et al., 1977; Schultz, et al., 1979; Berkson, et al., 1979; Tencer, et al., 1982; Tencer and Ahmed, 1981; Tencer, 1981; and White, 1969). Testing of this type is important, as it is difficult to assess directly all the loads and torques experienced by the motion segment in vivo (Dimnet, et al., 1984a and 1984b). If the stiffness characteristics of the motion segment are known, this task is simplified. The forces ([F]) can be obtained by applying the motion segment's stiffness characteristics ([k]) to its in vivo motion ([Δx]) characteristics: [F]=[k][Δx]. Fortunately, six degree-of-freedom movements of the in vivo motion segment are easily obtained by biplanar or stereo radiography (Brown, et al., 1976; Pope, et al. 1977; Frymoyer, et al., 1979; Stokes, et al, 1980; and Stokes, et al., 1981).

A limitation in the use of the flexibility matrix for reporting the mechanical characteristics of the motion segment is that it is specific to the point at which the load was applied to obtain it. Therefore, it is possible to obtain different flexibility matrices in response to different load rates, magnitudes and point of application. Using a consistent load range and load rate allow the use of a linear flexibility matrix. A way to solve the problem of load application location is to find a point which demonstrates a consistent mechanical response (Dimnet, et al., 1984a and 1984b). Both Rolander (1966) and Lin, et al., (1978) found these points and called them the "balanced position of the load" and an "operational centroidal axis" respectively. They were both defined as that point, where, when a vertical load was applied, the segment would move only vertically.

Three groups have studied the six degree of freedom (3 translations and 3 rotations) response to applied loads and torques of the minimally constrained vertebral body (Tencer, 1981; Tencer and Ahmed, 1981; Panjabi, et al., 1977; Tencer, et al., 1982; Berkson, et al., 1979; and Schultz, et al., 1979). These studies have defined the mechanical response by means of main and coupled stiffness characteristics. Loads and torques applied to motion segments along or about the anterior-posterior, lateral and axial axes have produced main and coupled translations and rotations with which to generate the motion segment's complex flexibility characteristics. Using the main and coupled flexibility characteristics, it was presumed that a generalized stiffness matrix could be developed (by inversion of the flexibility matrix) which would describe the behavior of the segment. Determining this matrix would be of great benefit as it would permit comparison of segment properties as affected by loading, environmental or disease history. One limitation of these works is that there is no description of a mechanically based reference at which the specimens are loaded. Except for the point of application of preload in the study by Panjabi, et al., (1977) and the description of the balance point in the work by Tencer (1981) and Tencer and Ahmed (1981), loads are applied to the motion segment over geometrically based reference locations. All of the above-mentioned unconstrained testing applied loads either in line with the geometric center of the upper vertebral body or along an axis collinear with the line segment connecting the geometric centers of both centra of the upper and lower vertebral bodies of the motion segment.

Wilder (1985) and Wilder, et al (1986, 1988, 1989) have loaded specimens at the balance point where both coupled flexion-extension and coupled lateral bend rotations are minimized. The balance point offers a good, mechanically based loading reference. Loading a specimen at its balance point allows the determination of a flexibility matrix at a unique, mechanically based reference and may have bearing on trunk musculature control strategies.

Etiology: The seated vibration environment is associated with the production of low back pain (Sandover, 1981). There are several mechanical factors which contribute to stress the posterior portion of the intervertebral disc in the lumbar spine when one sits.

1) Sitting flattens the lumbar lordosis and shifts the line of force of the spine to a point posterior to the effective pivot point of the ischial tuberosities. (Chaffin and Andersson, 1984) In a vibration environment, the load transmitted by the spine, applied along the moment arm created by the anterior offset of the ischial tuberosities, may induce an additional rocking motion in the pelvis and may amplify the vibration motion transmitted to the spine.

2) Sitting also causes an increase in the posterior disc height which may mechanically strain the posterior and postero-lateral collagen fibers of the anulus fibrosus where they are thinner and fewer in number. (Farfan, 1973; Krag, et al., 1987; Panjabi and White, 1978; Galante, 1967)

3) Additional strains are created in forward flexed motion segments because the facets disengage and allow an increase in the anterior-posterior translation compliance. (Panjabi, et al., 1977; Schultz, et al., 1979; Tencer, et al., 1982)

4) Lumbar intradiscal pressures are significantly greater in the seated posture. This has

a tension increasing effect on the disc collagen fibers analogous to increasing the tension in a taut wire by pushing on it from the side. (Andersson, 1974; Nachemson and Morris 1964; Okushima, 1970; Schultz, et al., 1979; Belytschko, et al., 1974; Nachemson, 1960).

5) Polymers such as rat and human medial collateral ligaments (Fung, 1981) have been shown to become softer and weaker due to vibration loading (Weisman, Pope and Johnson, 1980), a fatiguing type response. (Hertzberg and Manson, 1980; Riddell, Koo and O'Toole, 1966).

6) Physical changes and disc herniations have been caused in motion segments by exposure to cyclic loading. (Adams and Hutton, 1983; Brown, et al., 1957; Liu, et al., 1983; Wilder, et al., 1982).

7) Whole body vibration studies have established that the seated human has a resonant frequency close to those frequencies produced in common working and vehicular environments. A structure vibrating at its resonant frequency is more likely to fail. (Bastek, et al., 1977; Pope et al, 1987; Seidel, et al., 1980; Wilder, et al., 1982). In vivo whole body vibration studies have established the motion characteristics of the lumbar region during vibration exposure. (Panjabi, et al., 1984; Hagena, et al, 1986; Kaigle et al, 1990)

8) A vehicle driver's disc is at risk for mechanical damage while unloading the vehicle after driving as back muscles fatigue with some vibration exposure (Wilder et al, 1984; Magnusson, et al, 1988), lumbar balance point locations shift posteriorly following sustained sitting, thereby decreasing the erector spinae moment arm, and increasing the load requirements of the erectors and increasing the imposed loads on the disc (Wilder, et al., 1987), trunk fatigue results in increased coupled (out of plane) torques (Parnianpour, et al, 1988) and muscles overcompensate for unexpected loads (Marras, et al, 1987); all behaviors which would enhance the motion segment's tendency to buckle after seated vibration exposure (Wilder, et al, 1988).

9) The combination of imposed lateral bend vibration and the flexion-extension response due to vertical vibration potentially poses the most severe mechanical environment for the lumbar disc (Wilder et al, 1990; Wilder et al, 1982), due to the greater potential for stretching the postero-lateral region of the disc with its subsequent mechanical fatigue.

Work Needed: From the existing epidemiologic and etiologic literature, it is evident that the lumbar motion segment is particularly at risk in both static and vibration seating environments which: 1) increase its internal disc pressure and 2) increase its flexibility, while: 3) decreasing its resistance to buckling, 4) stressing the posterior region of the disc and 5) load it in the form of static or vibration load environments. It is also evident that there is a risk associated with lifting (Damkot, et al., 1984) and unexpected loads (Marras, et al, 1987). These findings suggest that a systematic study is needed of the effect of load history upon the trunk musculoskeletal system soundness. If lumbar region response characteristics could be obtained from this sort of work, the cause and effect relationship between seating environments and mechanical response changes in the trunk could be established. This would be a valuable contribution as there is now no such firm relationship.

Experimental Design and Methods

Specific Aims

This work studied in-vivo, the effects of common loading environments on the mechanical response of the seated human. The eventual goal of this line of work is to evaluate and control the occupational health hazard of low back pain by establishing an "envelope" of loading conditions which should not be exceeded if the spine is to experience minimal mechanical damage. Proceeding from prior in-vitro findings of short-column buckling in the lumbar spine following vibration exposure, this project evaluated how the supporting trunk musculature responds to an unexpected load application after a forty-minute load intervention (seated lateral vibration, sitting still). This simulated the sudden and unexpected shift of an object in the hands of the driver, who has driven for 40 minutes. Normal walking (as a break) for five minutes, prior to an unexpected load application, was tested to determine if it would be a reasonable control: allowing lumbar discs to return, via creep behavior, to the upright posture where the facets are more firmly engaged.

Trunk muscle activity (via surface electromyography) and main and coupled mechanical driving point impedance (via brief vibration exposures for mechanical response assessment) of the subjects was recorded and used as the outcome measures of the tests. 22 subjects were tested. Outcome measures were obtained before and after exposure to specific loading environments. Trunk muscle activity was also monitored during a sudden, unexpected flexion load applied to the subject, performed before and after sustained exposure to the specific loading environments.

The following hypotheses were tested using a matched pair t-test:

1) There are significant differences in trunk muscle activity during unexpected load application within subjects with different load exposure histories (seated vibration or sitting still)

2) A walking break for 5 minutes "resets" the system.

By using these hypotheses, it was possible to differentiate the effects of static and vibration loading and sitting postures on the trunk's neuromuscular control system. The overall goal was to establish the mechanical effect of load history on the lower back and to determine whether load history increases the likelihood of significant mechanical derangement following a sudden mechanical overload. This will begin to establish whether the International Standards Organization (ISO, 1985) vibration exposure criteria are reasonable limits for minimizing mechanical changes in the lumbar region.

Experimental Design

Test Matrix: Four, 40-minute Load Environment Simulations:

Attitude: Seated:

Loading Mode:

Static: Flexion due
to sitting

Vibration: Flexion due to sitting
with sinusoidal vertical, lateral and combined vibration
at the 8-hr ISO FDP level (ISO, 1985)

Comparisons Made:

Response to an unexpected load following a 40-minute exposure to static sitting and sitting in a sinusoidal vertical, lateral or combined vertical and lateral vibration environment (where the vibration is equivalent to that at the International Standards Organization: 8-hour, Fatigue, Decreased Proficiency level (ISO, 1985))

Materials and Methods

Subjects

Twenty two subjects were tested: 9 males and 13 females of whom 16 were normal controls and 6 right-handed subjects (3 male and 3 female) had diagnosed chronic back trouble (2 with disc herniation, 2 with spinal stenosis, 1 with disc degeneration and osteophytes, and 1 with facet arthrosis). The normal subjects had no history of low back pain, and were solicited by advertisement.

Measurement System / Outcome Measures

Two basic measurement systems were used for this work: 1) mechanical vibration response and 2) trunk muscle electrical activity.

A servo-hydraulic shaker (Figures 1 - 4), upon which was located an AMTI Biomechanics Force platform (which can sense 3 forces and 3 torques), was used to a) impart the 40-minute sinusoidal, vibration exposures (at a level of the International Standards Organization 8-hour, Fatigue Decreased-Proficiency limit) to subjects and b) assess

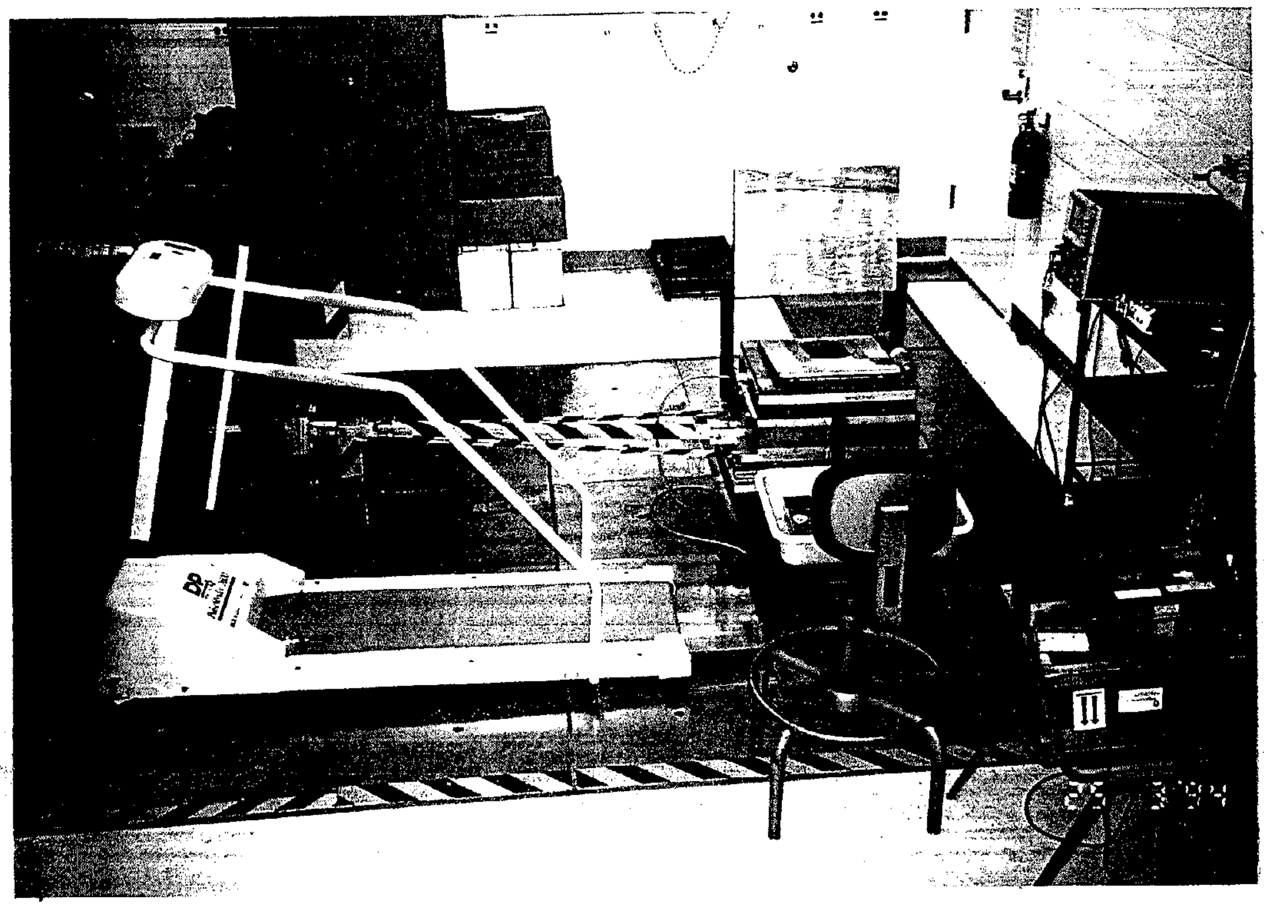

Figure 1. Overview of whole-body vibration lab. Note treadmill in foreground. Vibration system is capable of producing vertical and horizontal (lateral) vibration.

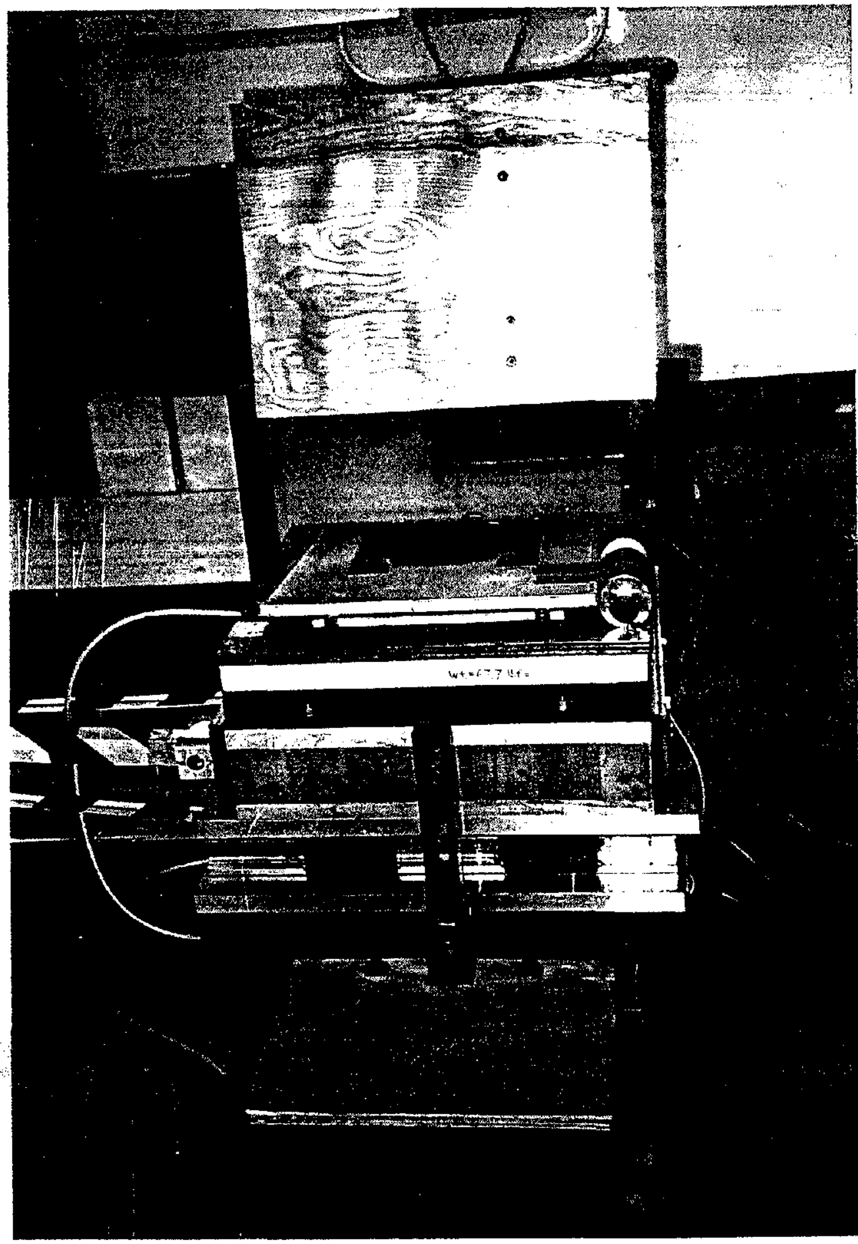

Figure 2. Front view of seat used in the study. Seat is fixed on top of an AMTI Biomechanics force plate. A Bruel & Kjaer human vibration monitoring system was used to monitor vibration levels applied to subjects. Note the (red) button available to the subject for stopping the test.

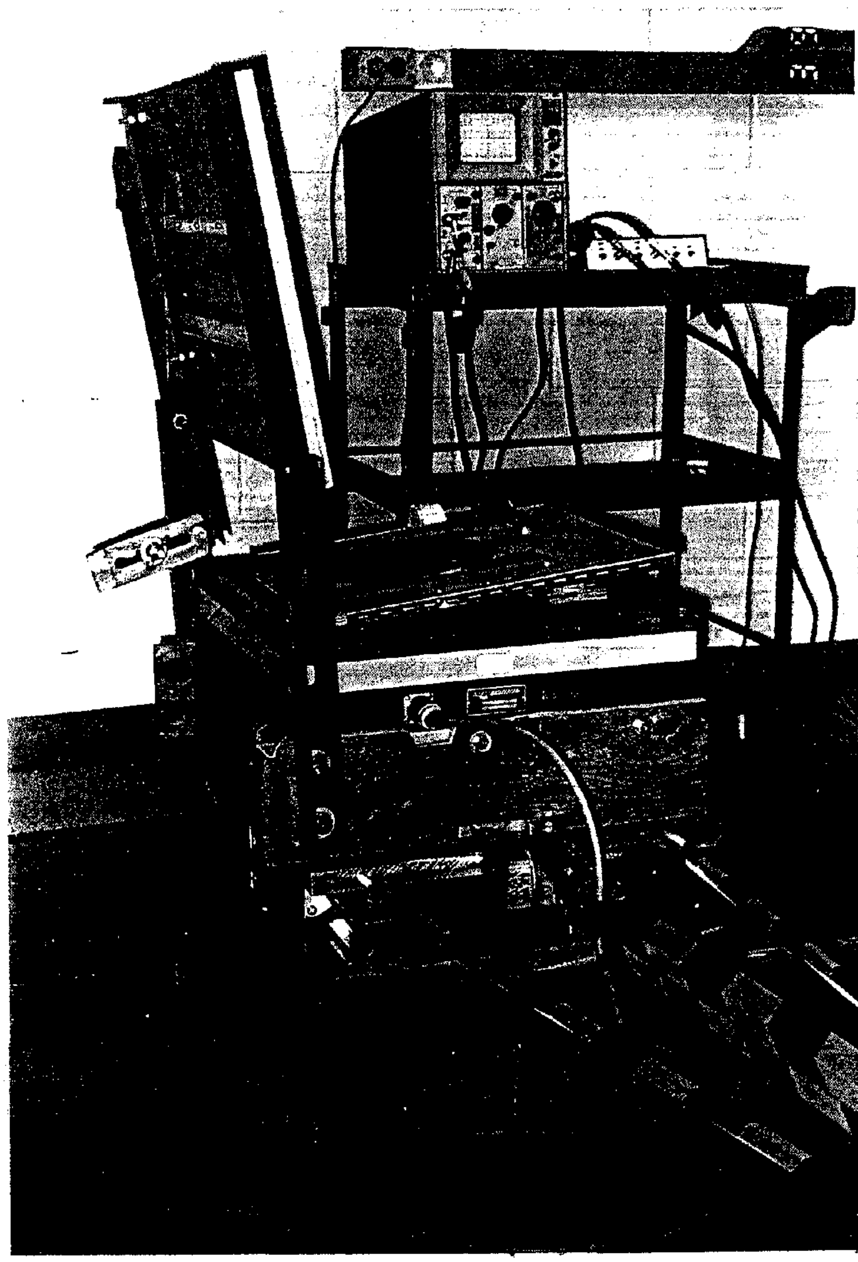

Figure 3. Side view of the seat used. The seat pan was used in a position 5 degrees up from the horizontal. The seat back was oriented 100 degrees from the horizontal or 10 degrees back from the vertical. Note the linear bearings used to enable lateral motion. The oscilloscope was used to monitor the quality of the EMG signals.

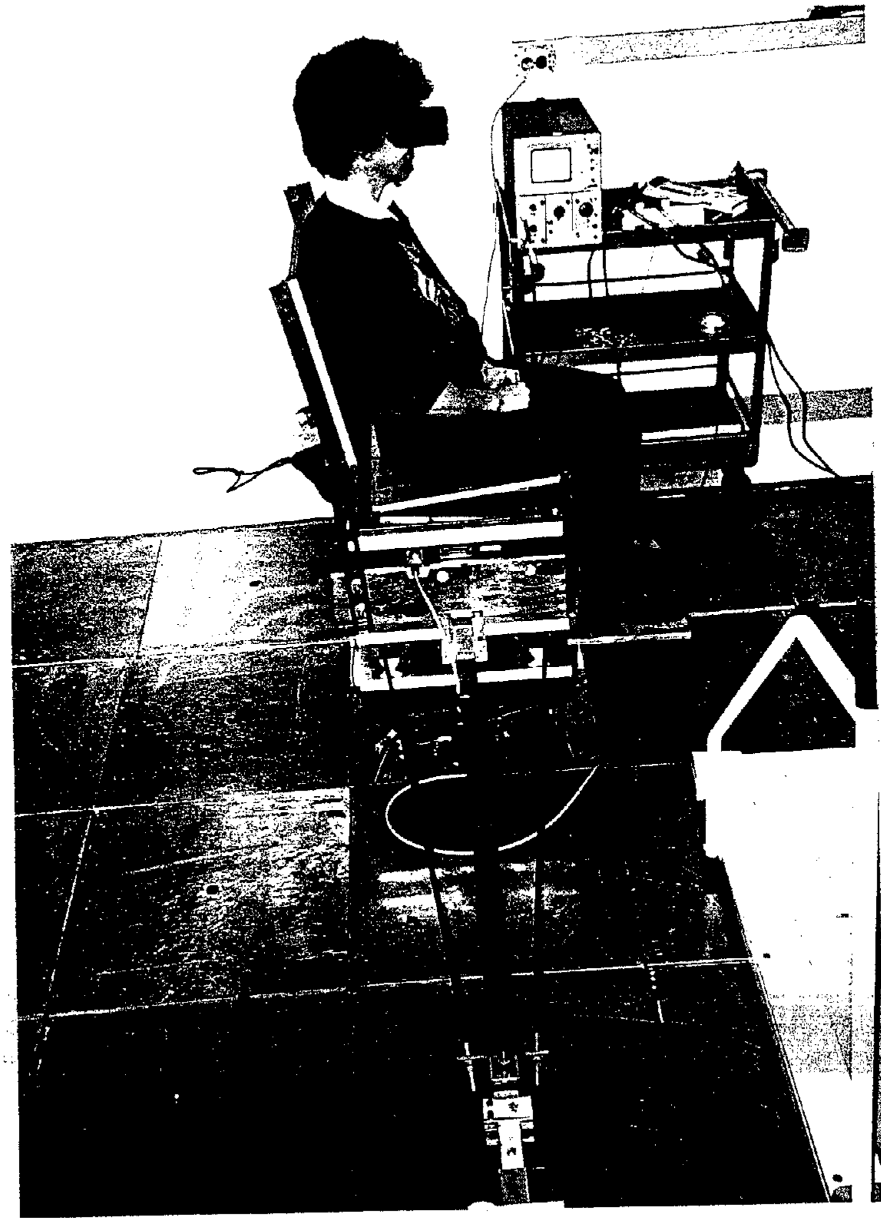

Figure 4. Subject on seat. Note that the foot support moved with the seat. This subject's back was not firmly against the seat back. Subjects were requested to keep their hands in their lap, supporting their forearms by their legs.

mechanical changes in the subject via swept-sine, driving point impedance evaluation (Wilder, et al., 1982). Software was written to perform the swept-sine, main and coupled mechanical driving point impedance evaluation. The subject was vibrated for 5 seconds at discrete, integer frequencies, in a random order, from 1 to 15 hertz. Steady-state vibration response data were gathered for 4 seconds. Immediately following each 5 second vibration, the shaker was stopped and 4 seconds worth of static response data were gathered. This was done to obtain the differences between the vibration and static responses. 8 channels of data were gathered at 1024 hertz, using a Data Translation model 2821 data acquisition board. The data gathered were:

1 Seat position
2 Seat acceleration
3 Fore-aft reaction force
4 Vertical reaction force
5 Side to side reaction force
6 Flexion-extension reaction moment
7 Lateral bend reaction moment
8 Axial rotation reaction moment

Data were smoothed, ensemble averaged, smoothed and scaled. Subjects were not affected by the data processing time as it took only 4 additional seconds to process and store the data (8 channels at 1024 hertz for 4 seconds) to computer Random Access Memory and later to non-volatile memory. The ensemble averaged force and torque data will be divided (in the time domain) by the computed velocity (based on the seat displacement and acceleration data) to obtain main and coupled mechanical driving point impedances (Hixson, 1976). Flexion-extension and lateral-bend moments will be divided by vertical reaction forces to obtain data for calculating center of pressure on the force platform.

Surface electrode pairs, with Davicon (model AE-106) preamplifiers, were used to collect muscle electrical activity data from the erector spinae muscle groups at the L3 level, 3 cm from the midline (Figure 5). This was chosen in order to determine muscle responses due to the moment applied due to flexion-extension and lateral bend responses (Seroussi and Pope, 1987; Marras et al., 1987; Andersson, et al., 1980). During the unexpected load application, the data channels 1 and 2 gathered right and left latissimus dorsi responses (Marras, et al., 1987).

EMG - moment correlations were carried out in the same general format as we have used in the past (Seroussi, et al., 1989), but no attempt was made to predict forces in individual muscle groups.

During the unexpected load application event (Figure 6), conducted in a manner after Marras, et al. (1987), the following data were recorded:

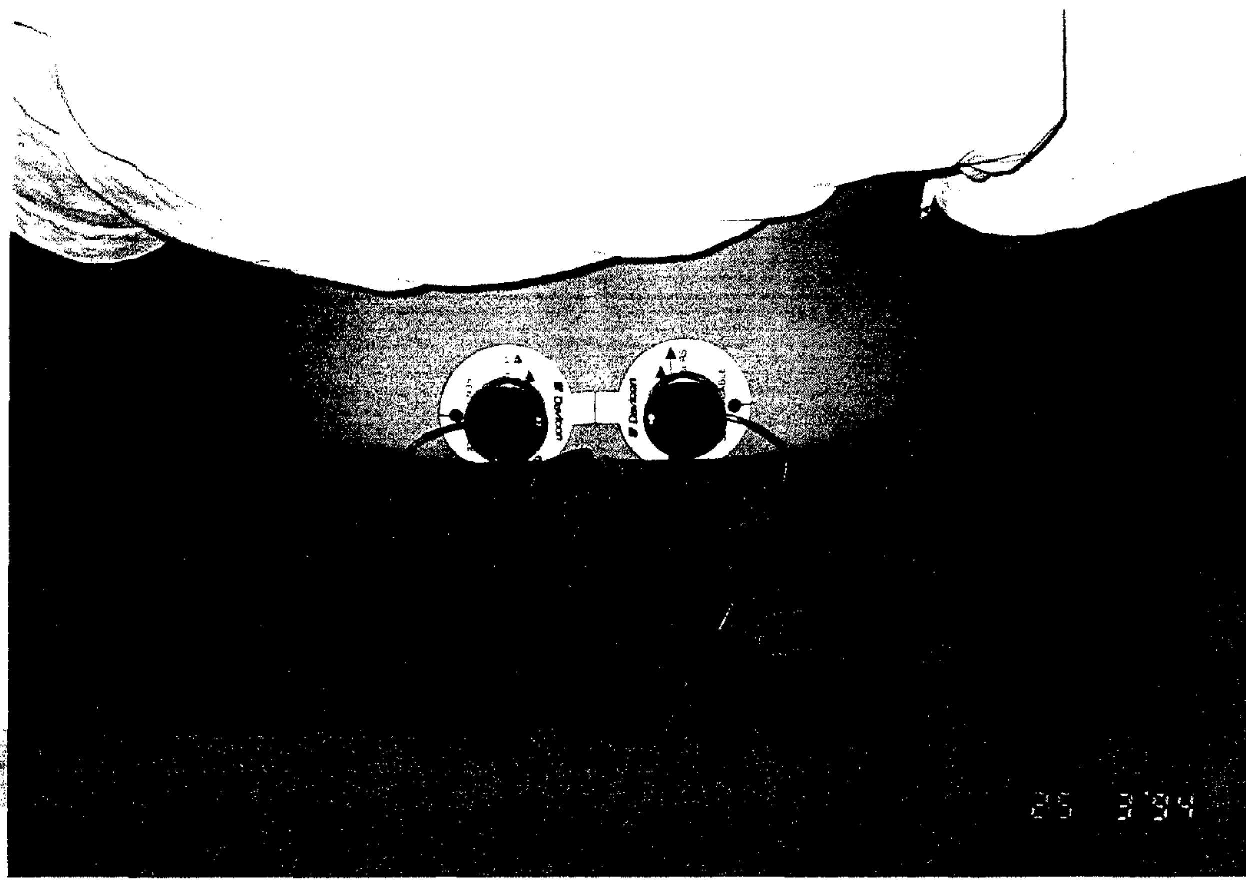

Figure 5. Davicon AE-106 active electromyography (EMG) electrodes in place over the erector spinae muscle groups.

Figure 6. Subject holding instrumented pan in place prior to impact by the unexpected load. The drape blocked visual cues and the vibration system's hydraulic power supply masked aural cues of the load's descent.

1 Right erector spinae electrical activity
2 Left erector spinae electrical activity

EMG data were processed in a manner similar to that described by Marras, et al. (1987): instantaneous RMS maximum, normalized to each muscle's peak activity during all the unexpected loading. In addition, the elapsed time between load impact in the box held by the subject and muscle activation (above resting level activity) was determined.

Environmental Exposure Simulation: Vibratory or Static

Each of the subjects was assigned to all of the four loading exposures. Ultimately there were sixteen subjects exposed to each of the four, 40-minute loading regimes.

Load was applied to the lumbar spine of the subject via the musculoskeletal system's response to the posture held and the presence or absence of vertical, lateral or combined vibration to simulate sitting in either a static or vibration environments such as found in either an office or factory chair or driving, respectively. Computation of the root mean square vibration acceleration applied to the seated subject was based upon the acceleration levels found in the International Standards Organization limits for "Fatigue, Decreased Proficiency" boundaries (ISO, 1985), during an 8-hour exposure of a seated individual to a sinusoidal vibration applied vertically, laterally or in combination.

It was assumed that the magnification of the lateral acceleration transmitted to the head of a seated individual while being vibrated within the average range of resonances for seated individuals, occurred in a manner similar to that for vertical vibration and is due to the relative motion observed in the lumbar region (Wilder, et al., 1985; Pope et al, 1986). Amplifications of transmitted vertical acceleration on the order of 2.5 have been observed to be imparted to an accelerometer attached to a bite-bar or to a tightly fitting helmet. It was assumed that the lumbar motion segments experience at least that amount of acceleration.

The sinusoidal vertical and lateral vibration load exposures lasted for 40 minutes so the subject's approximately 5 hertz vertical natural frequency and 2 hertz lateral natural frequency response exposed the lumbar region to approximately 12,000 vertical and 4,800 lateral load cycles. The vibratory loading exposure was expected, as other work has shown, (Adams and Hutton, 1983; Liu, et al., 1983; Wilder, et al., 1982, 1985, 1986, 1987, 1988; Kazarian, 1972; Weisman, et al., 1980; and Brown, et al., 1957); and Adams and Hutton, 1982) to produce mechanical changes in the disc.

Environmental Exposure Simulation: Unexpected Load Event

A short-duration, combined flexion-compression load, called the unexpected load event, was applied, according to Marras, et al. (1987), to the subject simulating the effect on the spine of a sudden shift of a load being handled. It was thought that a simulation of a trucker (or a car driver) unloading a truck (or car) would be a useful experiment for studying the mechanical response of the spine's supporting musculature in the trunk. However, the simulation covers only one very specific (potential) condition during the lifting process. That condition is the rapid load application to the spine which might be experienced as the driver is trying to catch or compensate rapidly for a suddenly shifting load carried in the hands.

As an example of how someone can unexpectedly load the spine, assume a person is carrying a 360 N (80.9 lbf) box with a center of gravity located 0.52 meters in front of the center of the person's L3-4 intervertebral disc. Assume also that the person slips and does not fall, but the load free falls for 0.26 seconds. It takes the person ½ second to stop the fall of the box. What load is imposed on the disc?

The velocity at the end of the box's fall is:

$$v = at = 9.81 \text{ m/s}^2 \times 0.26 \text{ s} = 2.55 \text{ m/s}$$

From impulse and momentum, the force applied at the hands to arrest the box's fall in ½ second is:

$$\Big|_{t_1=0}^{t_2=1} F(t_2-t_1) = m(v_2-v_1) \qquad \text{when } t_1=0,\ v_1=0$$

$$F = (mv_2) / t_2 = ((W/g)v_2) / t_2$$

$$F = ((360 \text{ N}/9.81 \text{ m/s}^2)2.55 \text{ m/s}) / 0.5 \text{ s} = 187.2 \text{ N}$$

To balance this load (187.2 N) at the hands, 520 mm anterior to the disc's center, the erector spinae muscles become active with a center of effort 52 mm posterior to the disc's center. By balance of moments, the erector spinae muscles pull with a force of 1,872 N. Allowing for the findings by Marras, et al. (1987), the muscles will over-compensate for the unexpected load by 70% and produce a muscle force of 3,182 N. This leaves a summation of vertical forces on the disc of 3,370 N.

A load lower than that described above was used, a tennis ball, filled with lead shot, weighing 6.4 newtons and falling approximately 1.81 meters. The protocol followed was similar to that of Marras, et al. (1987): that of dropping bags of lead shot into a box held by the subject.

Environmental Exposure Simulation: A 5-minute Walking Break to "Reset" the System

As the intervertebral disc is a viscoelastic structure and exhibits creep (Kazarian, 1975; Burns, et al., 1984; and Kaleps, et al., 1984; Wilder, et al., 1987), subjects will take a break, walking for five minutes at four points in the protocol in order to allow the disc to return, enhanced by the vibrocreep of walking, to an orientation where the facets are engaged, the disc pressure is lower (with respect to a seated posture) and the lumbar lordosis is regained. It is hypothesized that this 5 minute walking break is what should be performed prior to any lifting or bending over after driving.

Test Sequence

The following were main steps to the testing of each subject:

1) Upon entry into the lab and after being consented and connected to the EMG electrodes, the subject walked on the treadmill (DP, Fit for Life, Pulse Strider, model 21-2600, Diversified Products, Opelika, Alabama) for 5 minutes (to be used as an initial conditioning);

2) the initial, "mechanical and trunk muscle responses" were determined;

3) the subject was exposed to each of a sustained loading regime, in a random order, to simulate common load environments (vertical, lateral, or combined vibration while sitting upright, sitting statically);

4) the intermediate "mechanical and trunk muscle responses" were determined;

5) The subject walked on the treadmill for 5 minutes;

6) the final, "mechanical and trunk muscle responses" were determined;

7) go to step #3 until all load exposure types were used and outcomes measured.

Test Protocol Outline

General Flow Chart of Experiment:

Explain Experiment to subject, obtain consent
Attach surface EMG electrodes around trunk at L3 level
Obtain standing EMG-bending moment correlations in:
Flexion-extension

General Test:

Walk for 5 minutes
Mechanical assessment (outcome measure) of subject
Environmental exposure (Static, vertical, lateral or combined vibration load) for 40 minutes
Mechanical assessment (outcome measure) of subject
Walk for 5 minutes
Mechanical assessment (outcome measure) of subject

To perform the mechanical assessment (outcome measure) of subject:

During brief vibration exposure:
Complex driving point impedance (swept sine) with brief seated vibration exposure
From force plate (vibrating seat), obtain 3 reaction loads and 3 reaction torques
Calculate main and coupled driving point impedance
From forces and torques, calculate center of pressure

During the unexpected load application (while standing on force plate):
Trunk Muscle Electromyographic parameters from 2 erector spinae muscles at L3
Response timing, recruitment patterns, magnitudes
Indications of main (flexion-extension) and coupled (out of plane) responses

Due to these conditions:

5-minute walking break
Environmental exposure (40 minutes):
Simulate static, seated environment (sitting in a chair), OR
Simulate vertical, vibration, seated environment (driving a vehicle) OR
Simulate lateral, seated environment (sitting in a chair), OR
Simulate vertical and lateral vibration, seated environment (driving a vehicle)
5-minute walking break
Repeat until all exposures tried

Data Analysis

The following hypotheses were tested using a matched pairs t-test:

1) There are significant differences in trunk muscle activity during unexpected load application within subjects with different load exposure histories (seated vibration or sitting still)

2) A walking break for 5 minutes "reset" the system.

An additional question to be asked of the results are:

1) Are the ISO (1985) Fatigue, Decreased Proficiency limits for lateral vibration exposure sufficient to prevent significant change in muscle response or mechanical response?

These hypotheses were tested using a matched-pair t-test. By using these hypotheses, it was possible to differentiate the effects of static and vibration loading and sitting postures on the trunk's neuromuscular control system. The overall goal is to establish the mechanical effect of load history on the lower back and to determine whether load history increases the likelihood of significant mechanical derangement following an unexpected, sudden mechanical overload.

Safety Considerations:

As per local IRB guidelines, the experiment was fully described to the prospective subject, emphasizing the points in the experiment where the greatest risk would be present. The prospective subject then made the choice to participate or not. Physical risks were minimized by vigilant attention to the subject by the investigator. Physical risk to the subject due to malfunction of the vibration simulator and/or controlling computer was minimized by use of 1) a load-abort manifold, designed to stop the shaker in the event it sensed excessive load, 2) an independently powered, peak acceleration and jerk sensor, designed to stop the shaker if it detected excessive motion and 3) a 1500 watt uninterruptible power supply, designed to continue supplying power to the computer, vibration controller and load-abort manifold regardless of electrical powerline problems such as sags, surges, noise, spikes, brown-outs or blackouts. Vibration was "turned up" slowly to the full test amplitude, while the investigator spoke to the subject and asked how he felt about it. The test would have been discontinued at the first sign of subject distress or desire to end the test. This had been an appropriate and effective technique in the past. Subjects were free to withdraw from the study at any time without prejudice to them. Although not present during the test, physicians were available with a phone call.

The risks were low as they constituted physical loads one would experience while driving over a rough road or catching an unexpectedly falling object. The subject was informed of the risks and was able to select whether to participate or not. It was explained that there was great potential benefit to the findings from this study as it could lead to recommendations about lifting restrictions immediately following sustained sitting or driving.

Results:

Total reaction times and reaction magnitudes (as detected by peak EMG activity using a moving 10 ms rms window) have been obtained from the responses of the right and left erector spinae groups from the 16 normals tested, from the first of six unexpected loads applied following each seated vibration/no vibration exposure and each bout of 5-minutes of walking. A group of 4 individuals (Wilder, Magnusson, Aleksiev, Luotto), experienced in analysis of EMG signals evaluated the responses and concurred on the instant and magnitude of the peak response (Figure 7). To detect the effect of the seated exposure intervention, both the means of the differences and the difference of the means of responses to unexpected loads before vs following the 40-minute exposure were calculated. To detect the effect of walking as a control measure, both the means of the differences and the difference of the means of responses to unexpected loads before vs following the five-minute walking control measure were calculated. Responses across all 16 subjects and both right and left erector spinae groups were pooled in the analysis.

In all cases (Figures 8 - 9), seated exposure for 40 minutes, to pure vertical vibration significantly increased the pooled erector spinae muscle reaction time and amplitude. In the matched-pair condition, pure lateral (horizontal) vibration significantly increased the pooled erector spinae muscle reaction time and amplitude. Exposure to the combination of vertical and horizontal (lateral) vibration had no significant effect but tended to decrease the reaction time and increase the EMG response. Static sitting significantly decreased reaction time ($p<.025$) and tended to decrease reaction amplitude, non-significantly.

In all cases (Figures 10 - 11), walking following entry to the study and seated vibration exposure decreased the total reaction time of the musculature to the unexpected load, but not to a significant level. Walking following entry to the lab and exposure to pure vertical and pure horizontal (lateral) vibration decreased the muscle response amplitude, but was significant ($p<.005$) only following entry to the study and pure vertical vibration. Walking following exposure to the combination of vertical and horizontal vibration produced a non-significant trend decreasing reaction time and increasing response amplitude. Walking after sitting statically produced no significant change in EMG amplitude, but did lead to a significant ($p<.05$) increase in total reaction time.

Results for the chronic low back trouble patients: Under all conditions there was a reaction time difference between the erector spinae muscle groups to the right and left sides of the lumbar spine averaging 73-108 msec. There was no significant effect of side

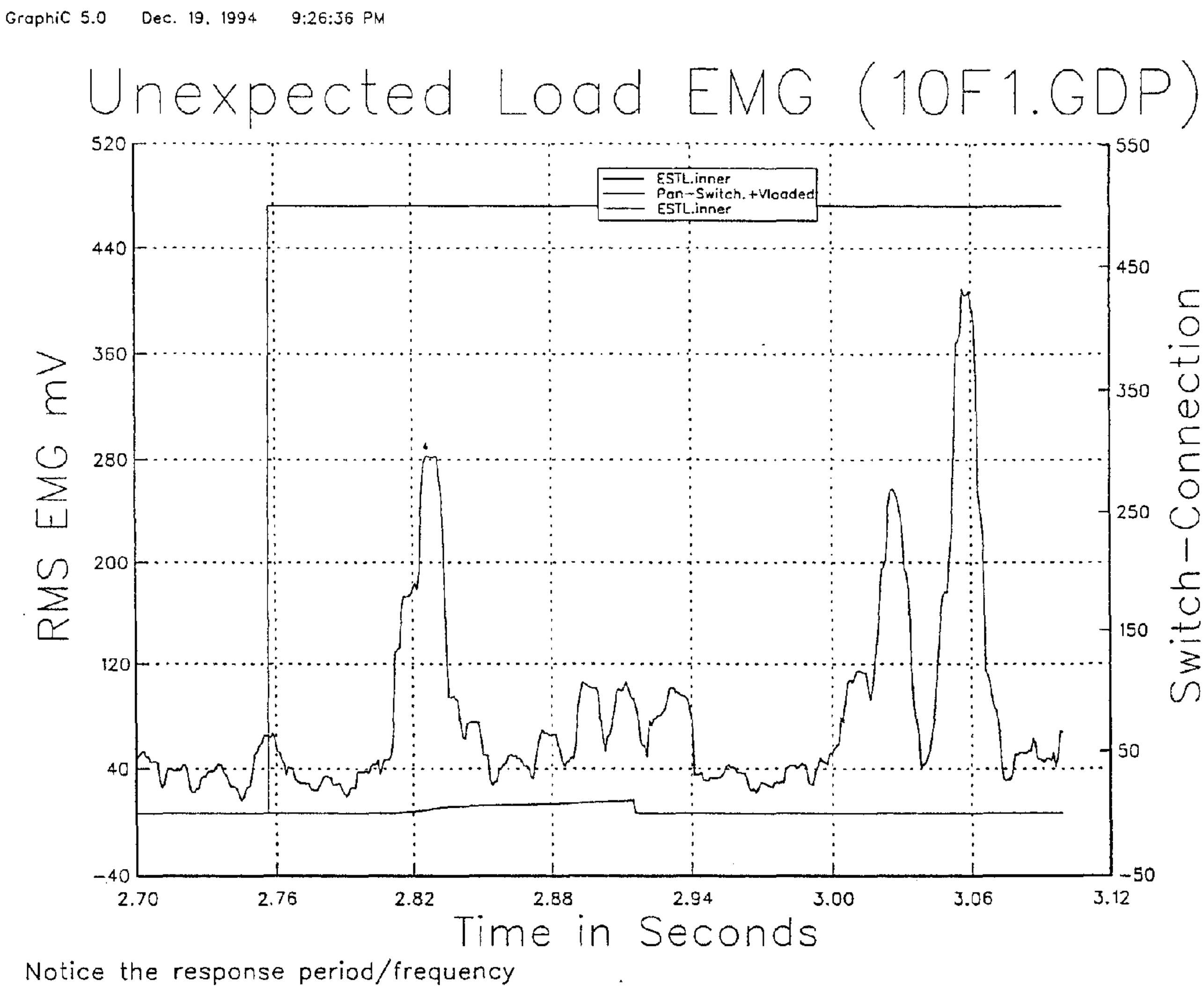

Figure 7. Typical results. The step function indicates the instant of switch closure due to the load hitting the instrumented pan. The other line indicates the EMG activity of the erector spinae muscle.

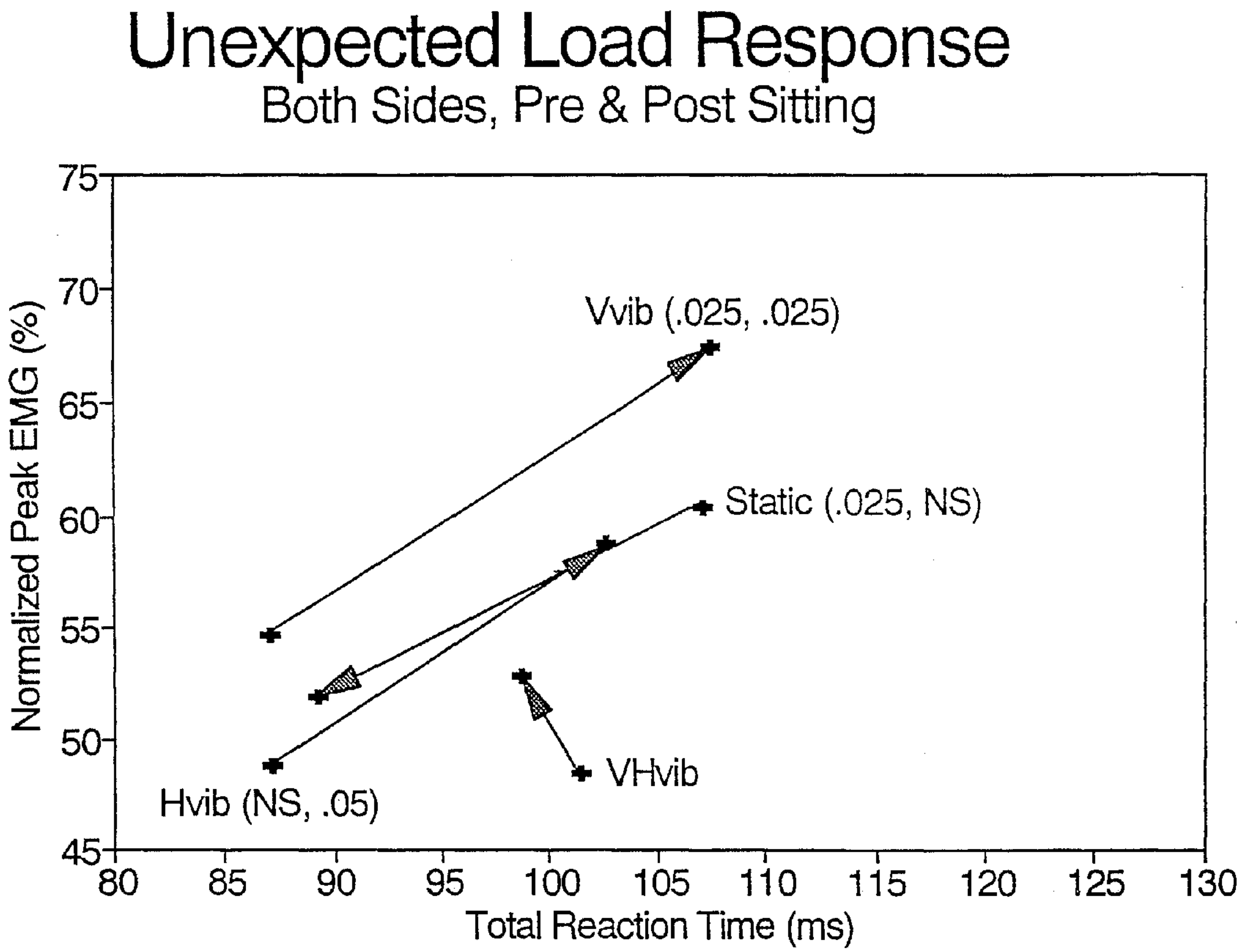

Figure 8. Characteristics of muscle response to unexpected load applied before and after 40-minute exposure to sitting still (Static), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If changes in the means were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Static): it was significant ($P<.025$) in the "x-" or "Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Normalized Peak EMG" axis.

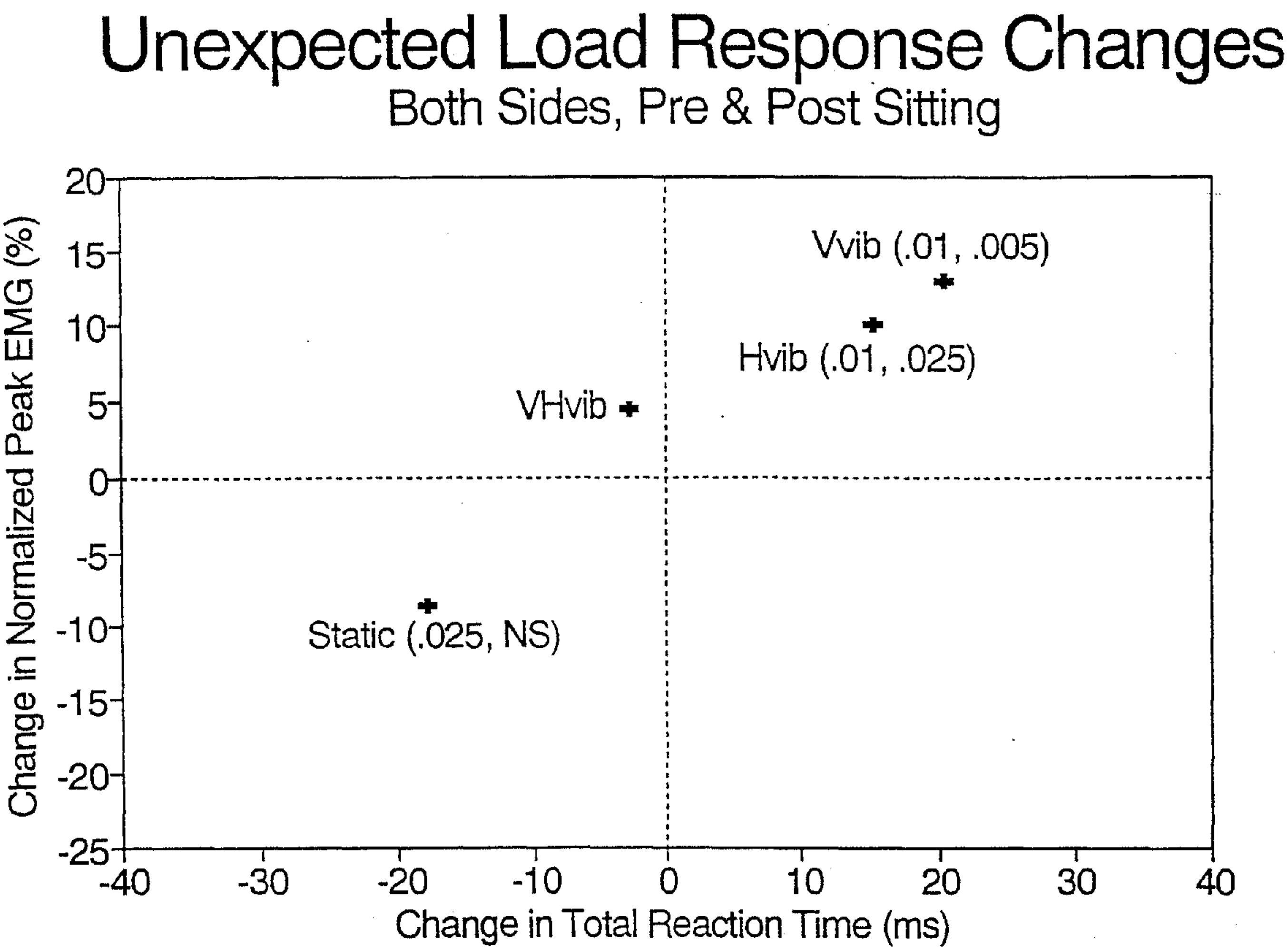

Figure 9. Changes in characteristics of muscle response to unexpected load applied before and after 40-minute exposure to sitting still (Static), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If the means of the differences in this matched pair presentation were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Change in Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Change in Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Static): it was significant ($P<.025$) in the "x-" or " Change in Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Change in Normalized Peak EMG" axis.

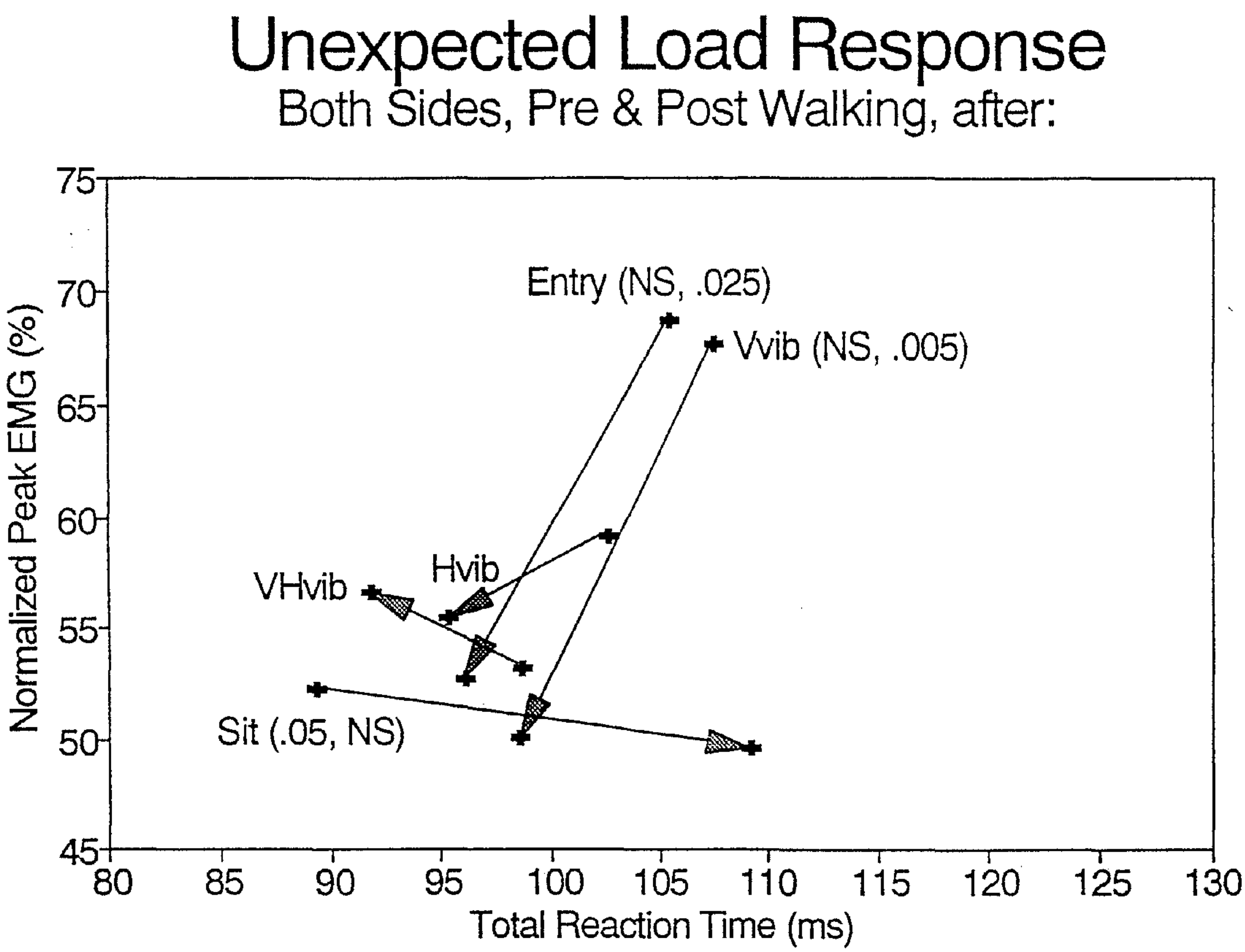

Figure 10. Characteristics of muscle response to unexpected load applied before and after five minutes of walking following: entry into the study (Entry), sitting still (Sit), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If changes in the means were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Sit): it was significant ($P<.05$) in the "x-" or "Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Normalized Peak EMG" axis.

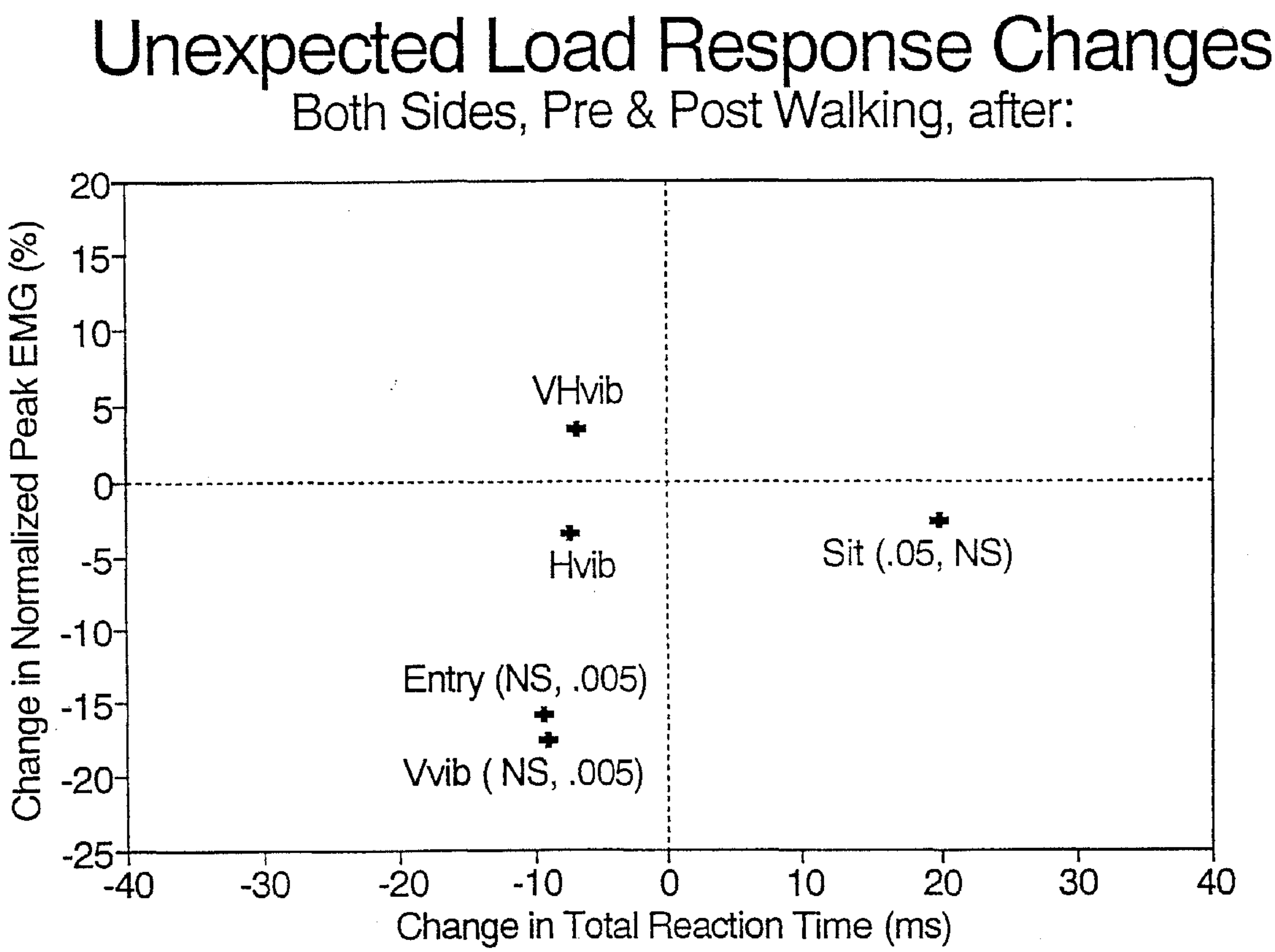

Figure 11. Changes in characteristics of muscle response to unexpected load applied before and after five minutes of walking following: entry into the study (Entry), sitting still (Sit), sitting while vibrating vertically (Vvib), sitting while vibrating horizontally, laterally (Hvib), sitting while vibrating both vertically and horizontally, laterally (VHvib). If the means of the differences in this matched pair presentation were significant, they were indicated as one of a coordinate pair. The first set of characters indicate significance of the change in the "x-" or "Change in Total Reaction Time" axis. The second set of characters indicate significance of the change in the "y-" or "Change in Normalized Peak EMG" axis. For example, muscle response changed due to static sitting (Sit): it was significant ($P<.05$) in the "x-" or " Change in Total Reaction Time" axis, but was not significant (NS) in the "Y-" or "Change in Normalized Peak EMG" axis.

in the responses. However, there was a trend ($p<.07$) for the left side to respond faster than the right side after exposure to seated vertical vibration. Walking for 5 minutes, following the initial muscle/flexion-moment calibration significantly shortened the muscle reaction time on the right side ($p<.025$). But, with the same prior activity, there was only a reaction time decreasing trend ($p<.10$) on the left side. Walking tended to decrease the reaction time after the initial calibration and after vibration exposure. Walking tended to increase the reaction time after static sitting.

Discussion:

The data presented support the mechanical effect of seated exposure to pure vertical vibration and pure horizontal (lateral) vibration. Reaction times have been increased due to these conditions, likely due to fatiguing effects and increase of lower frequency components of muscle activity (Magnusson et al, 1988; Parnianpor et al, 1988; Wilder et al, 1994). The increased EMG response amplitudes, controlled for the over-compensation reported by Marras et al (1987), corroborate the in-vitro finding that the balance point or effective fulcrum of the motion segment has moved posteriorly (Wilder et al, 1988, 1989) due to the combined effect of maintaining a flexed position in a vibrating environment (inducing vibro-creep in the disc). When the effective fulcrum within the intervertebral disc moves posteriorly, the moment arm over which the erector spinae muscles can act decreases, requiring greater forces (hence greater EMG activity) to cope with the same externally applied moment. Greater muscle forces lead to greater loads imposed on the disc.

It is encouraging that the combination of vertical and horizontal vibrations had little effect. It implies that their combined action may prevent the loss of water from, and material softening in, the anterior anulus.

The effect of static sitting is more encouraging. The total energy (kinetic + potential + strain) imposed on the lumbar region is much less. The resulting decrease in reaction time implies the opposite effect of muscle fatigue. It appears that the high frequency response components are enhanced, probably due to the recovery provided by sitting still for 40 minutes. The trend of decreased EMG activity after sitting implies that the effective fulcrum has moved anteriorly, thereby increasing the moment arm over which the back muscles operate, and reducing the loads on the disc. This serves as a further mechanical reason for minimizing vibration reaching a vehicle operator.

The significant effect that walking has is to reduce the EMG response to an unexpected load, most importantly following seated exposure to vertical vibration. It implies that walking can move the effective fulcrum anteriorly, increasing the moment arm over which the erector spinae act, and decreasing the load on the disc, during an unexpected load event. Walking also tends to decrease the muscle reaction time, implying recovery from the fatigue induced by the seated vertical vibration exposure.

Walking after sitting still increases reaction time, without affecting reaction amplitude. The implications of this result require further investigation, but may imply some muscle fatigue.

The information/advice to take away from this study is as follows: It is a good idea to walk around for five minutes after driving (for 40 minutes) before bending over or lifting anything.

The back is at risk, for several reasons, if one chooses to bend over or lift immediately after driving. The reason for this is because the response of the back muscles to an unexpected load is affected by the loading environment immediately preceding the sudden load application. Separate forty-minute exposures to vertical (5 hertz) and side-to-side (2 hertz) sinusoidal vibration, at the International Standards Organization (ISO) 8-hour, Fatigue Decreased-Proficiency (FDP) limit, significantly increased the erector spinae total reaction time and peak muscle EMG activity. In other words, the muscles take more time to respond and generate greater predicted forces following those relatively short (when compared to an 8-hour day) vibration exposure durations. This work questions whether the ISO 8-hour FDP vertical vibration limit is conservative enough to protect the disc from mechanical damage.

Walking for five minutes is beneficial because it tends to "reset" the system. The effect of walking on subjects who had been vibrated from side-to-side showed a trend of decreasing reaction time and peak EMG activity, but it did not reach the $p<.05$ level of significance. Walking after vibrating up-and-down tended to shorten the back muscles' reaction time and significantly ($p<.005$) decreased the peak muscle EMG activity, hence predicted forces generated and applied to the intervertebral disc.

Implementing this recommendation can be done with some thought. One oil delivery company has directed their drivers to walk around and take care of their paperwork before handling the heavy hoses needed to offload the product. Package delivery operations should make greater use of lifting/carrying aids if there is time pressure for deliveries, the driving time exceeds 40 minutes and the vertical vibration meets or exceeds that discussed above. A future direction for this work is clearly to study the effect of walking times less than five minutes.

Conclusions:

The human lumbar intervertebral disc has not yet evolved to be able to accommodate the amount of seated vibration exposure it now experiences. For this reason, this study provides firm reasons for walking after driving, as a control measure, before bending over or lifting.

This work provides further justification for minimizing the jolt/vibration energy reaching the driver. From the "Work=Kinetic Energy" relationship in physics, it can be shown that a

10% decrease in either the vibration amplitude or exposure duration time can decrease the work performed on the body's tissues by 19%. Decreasing both the vibration amplitude by 10% and the exposure duration by 10% can decrease the work performed on the body's tissues by 37%. Relativly small chnges can lead to significant improvements and hence risk reduction.

With the aim of reducing the loads on the lumbar disc, the implications of this work further justify designing vehicle seats with adjustable seat pans, adjustable seat backs, lumbar supports and arm rests, and vehicle cockpits laid out so the driver can operate the controls while seated in these optimal postures.

By implication, this work also questions whether the ISO 8-hour FDP vertical vibration limit is conservative enough to protect the disc from mechanical damage. Further study is needed.

Conclusions for the chronic low back trouble patients: Avoiding asymmetrically applied loads is important for the long term health of the lumbar spine. This study suggests that due to timing differences in the back muscles' response to unexpected loads, there is the potential for asymmetric loading of the lumbar region. The greater the reaction time, the greater the load application asymmetry between right and left sides. The greater the delay in counteracting the unexpected flexion moment, the larger the muscle force necessary to compensate, hence the greater the load on the intervertebral disc. It is not clear whether these subjects' ability to respond to unexpected loads were the cause or the result of their low back trouble.

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Appendix:

Other, Relevant Work:

The following other work has come out, related to vibration and back problems during this grant funding period:

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Johanning E, Wilder DG, Landrigan PJ, Pope MH: Whole-body vibration exposure in subway cars and review of adverse health effects. J Occupational Medicine 33(5):605-612, May 1991.

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Wilder DG: The Biomechanics of Vibration and Low Back Pain. American Journal of Industrial Medicine 23(4):577-588, 1993

Magnusson M, Wilder DG, Pope MH, Hansson T: Investigation of the long-term exposure to whole body vibration: A 2-country study. Winner of the Vienna Award for Physical Medicine. European Journal of Physical Medicine and Rehabilitation 3(1):28-34, 1993.

Wilder DG, Magnusson M, Fenwick J, Pope M: The effect of posture and seat suspension design on discomfort and back muscle fatigue during simulated truck driving. Applied Ergonomics 25(2):66-76, Feb 94.

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Refereed Proceedings Articles / Proceedings Abstracts:

Wilder DG, Kaigle AM, Beliveau J-GL, Fenwick JW, Tranowski JP, Pope MH: Back muscle response of seated individuals to single and superimposed sinusoidal, vertical vibration. In Proceedings: U.K. Informal Group on Human Response to Vibration, Rheumatology and Rehabilitation Unit, University of Leeds, Leeds, 20-21 Sep 1990.

Wilder DG, Pope MH, Frymoyer JW: The biomechanics of lumbar disc herniation and the effect of overload and instability following vehicular vibration exposure. In proceedings of the Canadian Society of Mechanical Engineers FORUM 1992 "Transport 1992+", 1-5 Jun 92, Montreal.

Pope MH, Wilder DG, Magnusson M, Hansson T: Impact and its effects on the lumbar spine. In Proceedings of the Canadian Society of Mechanical Engineers FORUM 1992 "Transport 1992+", 1-5 Jun 92, Montreal.

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Wilder DG, Kaigle AM, Beliveau J-GL, Huston D, Fenwick JW, Tranowski JP, Pope MH: Back muscle response of seated individuals to single and superimposed sinusoidal, vertical vibration. Acoustical Society of America, San Diego, 26-30 Nov 1990. J Acoustical Society of America, Vol 88, Suppl 1, pp S63, 1990

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Magnusson ML, Wilder DG, Pope MH, Hansson T: Back, shoulder and neck pain in occupational drivers. A two-center screening of long-term exposure. European Journal of Physical Medicine and Rehabilitation, Suppl 2, Vol 2, pp 16, 1992.

Refereed Presentations:

Wilder DG, Kaigle AM, Beliveau J-GL, Fenwick JW, Tranowski JP, Pope MH: Back muscle response of seated individuals to single and superimposed sinusoidal, vertical vibration. U.K. Informal Group on Human Response to Vibration (HRV), Leeds, 20-21 Sep 90.

Wilder DG, Kaigle AM, Beliveau J-GL, Huston D, Fenwick JW, Tranowski JP, Pope MH: Back muscle response of seated individuals to single and superimposed sinusoidal, vertical vibration. Presented at the Acoustical Society of America, San Diego, 26-30 Nov 90.

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Wilder DG, Pope MH, Frymoyer JW: The biomechanics of lumbar disc herniation and the effect of overload and instability following vehicular vibration exposure. Canadian Society of Mechanical Engineers (CSME) FORUM 1992 "Transport 1992+", 1-5 Jun 92, Montreal.

Pope MH, Wilder DG, Magnusson M, Hansson T: Impact and its effects on the lumbar spine. CSME FORUM 1992 "Transport 1992+", 1-5 Jun 92, Montreal.

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Wilder DG, Tranowski JP, Novotny JE, Huston DR, Beliveau J-G, Pope MH: Low back pain and optimal vehicle seating. HRV, Southampton, 28-30 Sep 92.

Magnusson ML, Wilder DG, Pope MH, Hansson T: Investigation of the long-term exposure to whole body vibration: A 2-country study. Winner of the Vienna Award for Physical Medicine. Austria Society of Physical Medicine and Rehabilitation, Vienna, 7 Nov 1992.

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Wilder DG, Tranowski JP, Novotny JE, Huston DR, Beliveau J-G, Fenwick J, Pope MH: Vehicle seat optimization for the lower back. ISSLS, 15-19 Jun 93, Marseilles.

Chapters:

Magnusson ML, Wilder DG, Pope MH, Hansson T: Back, shoulder and neck pain in occupational drivers - A two-center screening of long-term exposure. In: Advances in Idiopathic Low Back Pain. Ernst E, Jayson MIV, Pope MH, Porter RW eds. Blackwell-MZV, Vienna, 1993.

Wilder DG, Wasserman DE, Pope MH, Pelmear PL, Taylor W: Vibration. In: Physical and Biological Hazards of the Workplace. Wald P and Stave G, Eds., Van Nostrand Reinholdt, New York, NY, August 1994.

Pope MH, Wilder DG: Whole body vibration. In: Occupational Musculoskeletal Disorders: Assessment, Treatment and Prevention. Nordin M, Pope MH, Andersson GBJ eds. Pending in Mosby Year Book 1993/1994.

Brinkmann P, Wilder DG, Pope MH: Effects of Repeated Loads and Vibrations. In: The Lumbar Spine. JN Weinstein and SW Weisel (editors), 2nd Edition, International Society for the Study of the Lumbar Spine, W.B. Saunders Co, Philadelphia, In Press.

Invited Speaker:

Wilder DG: Whole-body Vibration in Automotive Seating. General Motors Windows to Technology: Winter Quarterly Review of Seating Technology, CPC Engineering Center Auditorium, 30003 Van Dyke Ave, Warren, Michigan, January 30, 1992

Wilder DG: Vibration and low back pain. Third International Conference on Sound and Vibration in Pregnancy, Dept of Obstetrics and Gynecology, College of Medicine, University of Florida, Gainesville, 7 Feb 1992.

Wilder DG: Biomechanics of Vibration Perception. VDCC Ride Engineering Symposium, General Motors, Manufacturing 'A' Building - Auditorium, Tech Center, 30003 Van Dyke Ave, Warren, Michigan, 23 Jun 1993.

Wilder DG: Ergonomics in Physical Plant: Lower Back Pain and Whole-body Vibration. Reducing the risk of back injury. Northern New England Chapter meeting of the Association of Physical Plant Administrators, University of Vermont, Hampton Inn, Colchester, September 16-17, 1993

Wilder DG: Low back pain and whole-body vibration. In "Seminars in Ergonomics," Dept of Industrial and Operations Engineering, University of Michigan, Ann Arbor, 6 Oct 93.

Wilder DG: Whole-body vibration and low back pain. Solicited for presentation at the Whole-Body Vibration Seminar, **NIOSH**, Cincinnati, 11-12 Aug 1994.

Wilder DG, Pope MH: Review of vibration threshold levels in view of current literature and research. American Conference of Governmental Industrial Hygienists. University of Iowa, 24 Sep 94.

Wilder DG: Sitting in a vibration environment: Biomechanical implications for the lumbar spine and seat design. Graduate Seminar in Biomedical Engineering, University of Iowa, 22 Sep 94.

Wilder DG: Biomechanics of vibration and low back pain. Injury Prevention Research Center Seminar, University of Iowa, 18 Oct 94.

Wilder DG: Sitting in a vibration environment: Biomechanical implications for the lumbar spine and seat design. Iowa Engineering Society, Herbert Hoover Section, 25 Apr 95.

Non-Refereed Articles:

Wilder DG, Pope MH: Vibration weakens backs. Industrial Safety & Hygiene News, Nov 1993, pp 17.

Technical Reports:

Johnson CC, Huston DR, Wilder DG: Active Seat Suspension to Control Low Back Injuries. Final performance report of: Grant Number 1 R43 OH 03018-01, CDC/NIOSH Small Business Innovation Research Program, Phase I. 20 Oct 93.

Present Publications:

The following, funded by this grant, has been accepted for presentation:

Wilder DG, Magnusson M, Pope MH, Rostedt M, Hansson T: Lumbar musculature response to unexpected load in chronic low back pain patients. Accepted for presentation at the International Society for the Study of the Lumbar Spine, Helsinki, 18-22 June 1995.

Possible Future Publications:

Unexpected Trunk Loading Following Seated Vibration. Spine.

Simple measures for reducing the risk of back trouble due to truck driving and heavy equipment operation. J. Occupational Medicine or Am J Ind Med.

Whole-body mechanical property changes due to sitting and walking. Spine.

MUSCLE RESPONSE TO UNEXPECTED LOAD IN CHRONIC BACK PATIENTS. Wilder DG, Magnusson M*, Pope MH, Rostedt M*, Hansson T* Iowa Spine Research Center, University of Iowa, Iowa City, IA 52242, USA; * Dept. of Orthopaedics, Sahlgren University Hospital, S-413 45 Gothenburg, Sweden. Accepted for presentation at the International Society for the Study of the Lumbar Spine, 18-22 June 1995, Helsinki.

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INTRODUCTION A vehicle driver's disc is at risk for mechanical damage while unloading the vehicle after driving as back muscles fatigue with some vibration exposure (Magnusson et al, 1988); the lumbar balance point location shifts posteriorly following sustained sitting and decreases the erector spinae moment arm, thereby increasing the load requirements of the erectors and increasing the predicted loads on the disc (Wilder et al, 1987). Trunk fatigue results in increased coupled (out of plane) torques (Parnianpour et al, 1988) and muscles overcompensate for unexpected loads (Marras et al, 1987). All these behaviors enhance the motion segment's tendency to buckle after seated vibration exposure (Wilder et al, 1988). From the existing epidemiologic and etiologic literature, it is evident that the lumbar motion segment is particularly at risk in both static and vibration seating environments which increase its internal disc pressure and its flexibility, while decreasing its resistance to buckling. It is also evident that there is a risk associated with lifting (Damkot et al, 1984) and unexpected loads (Marras et al, 1987). Patients with ongoing back pain are supposed to have an increased basic muscle tone to protect their backs for unexpected injury that might increase the pain. This increased muscle tone will fatigue the muscles and might lead to an overreaction when the trunk is moved away from a controlled posture. The aim of this study was to study the time lag between the application of an unexpected load and the spinal stabilizing muscles' response to that load in chronic low back patients before and after a fatiguing exposure.

MATERIALS AND METHODS Six right-handed subjects participated in the study. These were three males and three females with age ranging from 31 to 69 years. Their diagnoses were disc herniation (2), spinal stenosis (2), disc degeneration and osteophytes (1) and facet arthrosis (1). At arrival to the laboratory measurements were taken of the subject and calibration of the EMG was done. EMG electrodes were glued to the skin bilaterally at L3-L4 level, three cm from the midline. The subject was then exposed to six repeats of unexpected load. This was done by having a tennis ball filled with lead shot fall into an instrumented tray that the subject was holding in front of the trunk. Measures were taken so as to the subject could not hear or see the triggering of the load. After this first set of exposure the subject walked around for 5 minutes in order to reset the muscles before the second set. The subject was then randomly assigned to quiet sitting or seated vibration for 40 minutes after which the sudden load applications were repeated. This whole procedure was then repeated with the subject in the other seated exposure. The vertical vibration input was 5 Hz and 0.315 ms^{-2} rms, the ISO 8-hour FDP level.

RESULTS Under all conditions there was a response delay difference between the sides averaging 73-108 msec. There was no significant effect of side in the responses. However, there was a trend ($p<.07$) for the left side to respond faster than the right side after exposure to seated vibration. Walking for 5 minutes following the initial muscle/flexion-moment calibration significantly shortened the muscle response lag time on the right side ($p<.025$). But, with the same prior activity, there was only a lag-time decreasing trend ($p<.10$) on the left side. Walking tended to decrease the response lag after the initial calibration and after vibration exposure. Walking tended to increase the response delay after static sitting.

DISCUSSION Avoiding asymmetrically applied loads is important for the long term health of the lumbar spine. This study suggests that due to timing differences in the back muscles' response to unexpected loads, there is the potential for asymmetric loading of the lumbar region. The greater the lag time, the greater the load application asymmetry between right and left sides. The greater the delay in counteracting the unexpected flexion moment, the larger the muscle force necessary to compensate, hence the greater the load on the intervertebral disc. It is not clear whether these subjects' ability to respond to unexpected loads were the cause or the result of their low back trouble.

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