

## JOLTING AND JARRING INJURIES IN SURFACE MINE HAUL TRUCKS

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### ABSTRACT

Powered haulage has been, and continues to be, a major source of severe accidents, injuries, and fatalities at metal/nonmetal surface mines. Between 1986 and 1997, truck drivers accounted for 63% of the lost-time injuries in surface haulage. This project was undertaken to reduce the number and severity of lost-time injuries among operators of these trucks. Shock accelerations were measured on trucks at a western surface mine during representative work cycles to determine the shock environment of the operator. Acceleration data was collected from the floor and seat of two types of haulage trucks. Shock tests were also run at Caterpillar, Inc.'s, proving grounds in Green Valley, AZ, to determine the magnitude of shocks resulting from a rough road and from occasional loading events. A controlled rock drop onto the bed of a haulage truck and a side impact were measured. A system that ties acceleration data with Global Positioning System (GPS) data was developed to aid in identifying haul road problems. A biomechanical investigation revealed that a side impact will cause the erector spinae muscle groups on the side opposite to contract first. Then the near side muscles react approximately 20 ms later, which could increase the likelihood of injury from a side impact.

### INTRODUCTION

Powered haulage has been, and continues to be, a major source of severe accidents, injuries, and fatalities at metal/nonmetal surface mines. Between 1986 and 1997, injuries to truck drivers accounted for 63% of the lost-time injuries. Analysis of MSHA accident data from 1991-1997 in metal/nonmetal surface mine haul truck operator back injuries indicate that out of four hundred events haul truck jarring accounted for 27%; being hit by loader 11%; slips and falls 10%; loading (rock jar) 7%; and vehicle road jarring 8%. In surface haulage between 1986-95 truck drivers accounted for 64% of lost-time injuries and operating a haul truck accounted for 60% of the back injuries. Back injuries are the leading cause of lost time and the most costly class of non-fatal injuries.

The objective of this research is to reduce jolting and jarring injuries among operators of heavy mining equipment, particularly haulage truck drivers. Characterization of the magnitude and frequency of jolts and jars will lead to a better understanding of their causes and enable researchers to evaluate different types of engineering controls that could reduce trauma to operators and lower the incidence of back injuries. The research is part of a project called "Engineering Controls for Reducing Jolting/Jarring Injuries in Surface Mines" at the Spokane Research Laboratory (SRL) of the National

Institute for Occupational Safety and Health (NIOSH). In this project, researchers are investigating the causal factors of jolting and jarring injuries and the effects of long-term exposure to jolting and jarring.

### FIELD TESTS

Data were collected under actual field conditions during representative work cycles at a western surface mine interested in reducing lost-time injuries among its haulage truck operators. These data were obtained from two types of haulage trucks (truck A and truck B) manufactured by different companies.

Jolts and jars were measured using a Dallas Instruments Saver mounted to the pedestal of the driver's seat with a strong magnet at the point where the seat is bolted to the cab floor. This instrument package contains an internal triaxial set of piezoelectric accelerometers, a charge amplifier, and a data logger with 8 megabytes of memory. A Bruel and Kjaer type 4322 seat pad, which also contains a triaxial set of piezoelectric accelerometers, was attached to the driver's seat cushion to measure those accelerations. The three orthogonal directions (x, y, z) were oriented according to ISO 2631 [1]. From the driver's perspective, x is positive forward, y is positive to the driver's left, and z is positive upward.

For truck A, the Saver monitored jolting and jarring for 11 hr, 37 min, between 2:45 p.m. on June 8 and 7:08 a.m. on June 9, 1999. For truck B, the Saver monitored jolting and jarring for 18 hr, 1 min, between 12:47 p.m. on June 9 and 6:48 a.m. on June 10, 1999. The threshold for triggering data collection was determined empirically at 1.5 g's on the z channel of the seat cushion. Seven events above 1.5 g's were recorded on truck A, and five events were recorded on truck B. Other set-up parameters were filter frequency, 200 Hz; range,  $\pm 50$  g's; samples per second, 512; recording time, 8 sec; and samples per event, 4096. The 12 events were converted from the Saver file format to

ASCII and imported into a software program called DADiSP, a product of DSP Development Corp.,<sup>1</sup> for further analysis.

The acceleration shocks for truck A are shown in figure 1 and for truck B in figure 2. Comparing the shocks on truck A with the shocks shown in figure 3 and operators' written logs, the authors determined that shock events A1, A3, A5, and A6 were caused by loading. The other three shock events on truck A (A2, A4, and A7) and all shock events on truck B were caused by rough ground, as determined by comparing figure 4 and operators' written logs. The average peak frequency of the shocks on the seat cushion in truck A was 35 Hz, and the average frequency of the "rough ground" shocks was 1.4 Hz. Interestingly, the average peak frequency of all truck B shocks was also 1.4 Hz.

### FIELD TESTS AT CATERPILLAR PROVING GROUNDS

Caterpillar, Inc. offered us the use of their proving grounds in Green Valley, AZ. We accepted their generous offer and devised three sets of experiments to investigate the possible relation of jolting/jarring to operator injuries. The instruments used in the three tests were the same as those used to collect data at the mine. The set-up parameters were threshold level, 1 g; filter frequency, 100 Hz; range,  $\pm 20$  g's; samples per second, 512; recording time, 4 sec; and samples per event, 2048.

In the first test, a large rock was dropped into the bed of a Caterpillar truck from over 10 ft above the bed surface. The drop produced a distinctive curve (figure 3) in which a significant jolt was registered in the z-direction when the rock struck the truck bed. The jolt due to the rock drop was the most severe jolt that we measured at the test track.

<sup>1</sup>The mention of specific products or manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

In the second test, the truck was hit from the side by a loading shovel (figure 4). The side impact was regarded as rather significant. An observer riding in the truck noted that the side roll and side impact were the most uncomfortable part of his ride. Consequently, side impacts were selected for further investigation.

A third experiment was designed to investigate the effect of different loading conditions of the truck. A comparison of a truck running a bump course empty with a truck running the

course fully loaded was used in that test. The truck was driven along a test course (dirt road) with a series of bumps positioned randomly along the course.

The truck was driven along the course at 5 mph. Figure 5 shows an empty truck going over a bump, while figure 6 shows the same truck going over a bump loaded. The truck suspension, when properly maintained, compensates for the different loads rather well.

**A**

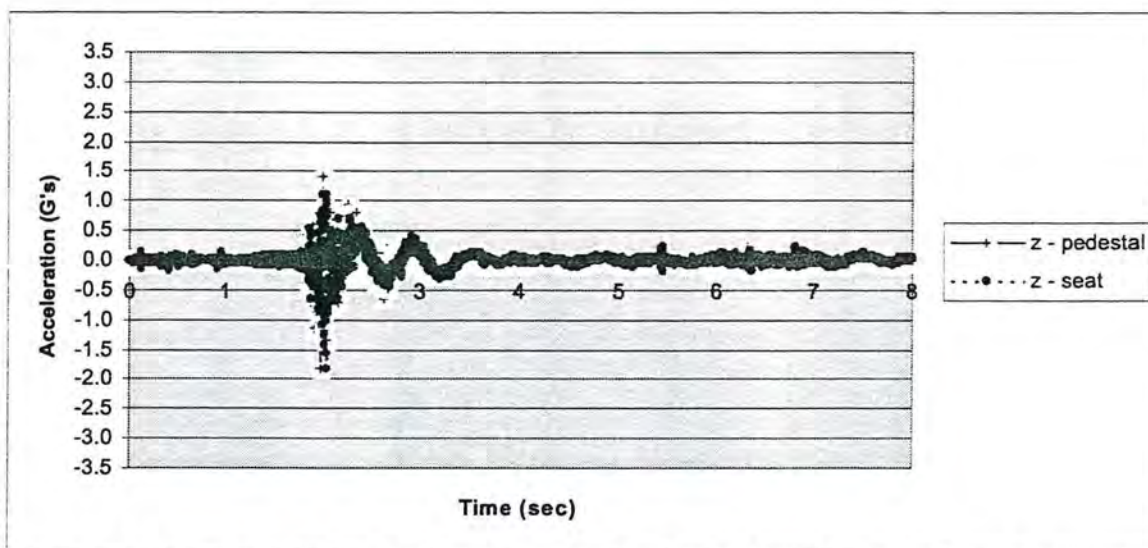


Figure 1.—Truck A shock events (continued). A, Loading event, A1; B, rough ground event, A2; C, loading event, A3; D, rough ground event, A4; E, loading event, A5; F, loading event, A6; G, rough ground event, A7.

**B**

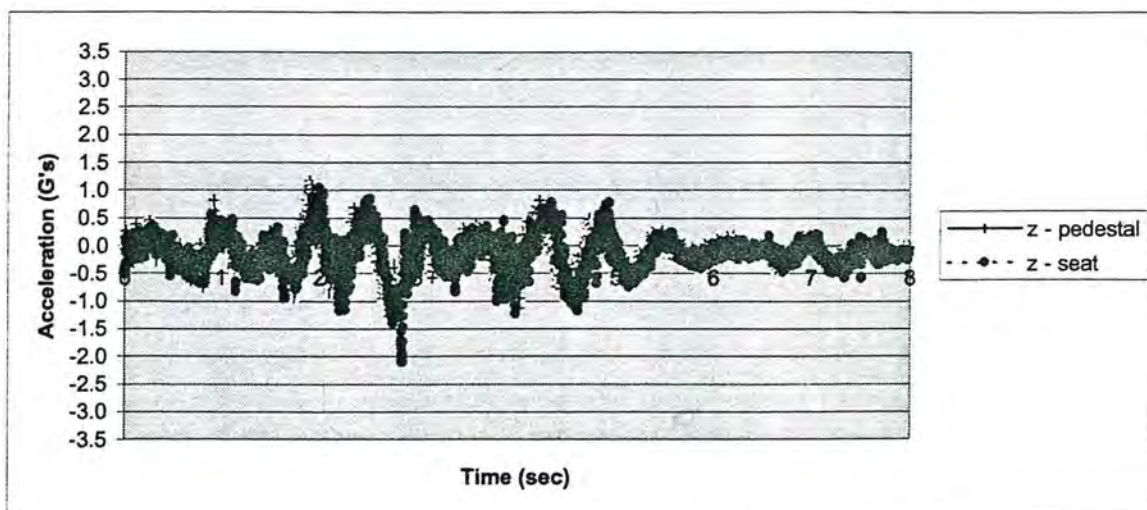


Figure 1.—Truck A shock events (continued). A, Loading event, A1; B, rough ground event, A2; C, loading event, A3; D, rough ground event, A4; E, loading event, A5; F, loading event, A6; G, rough ground event, A7.

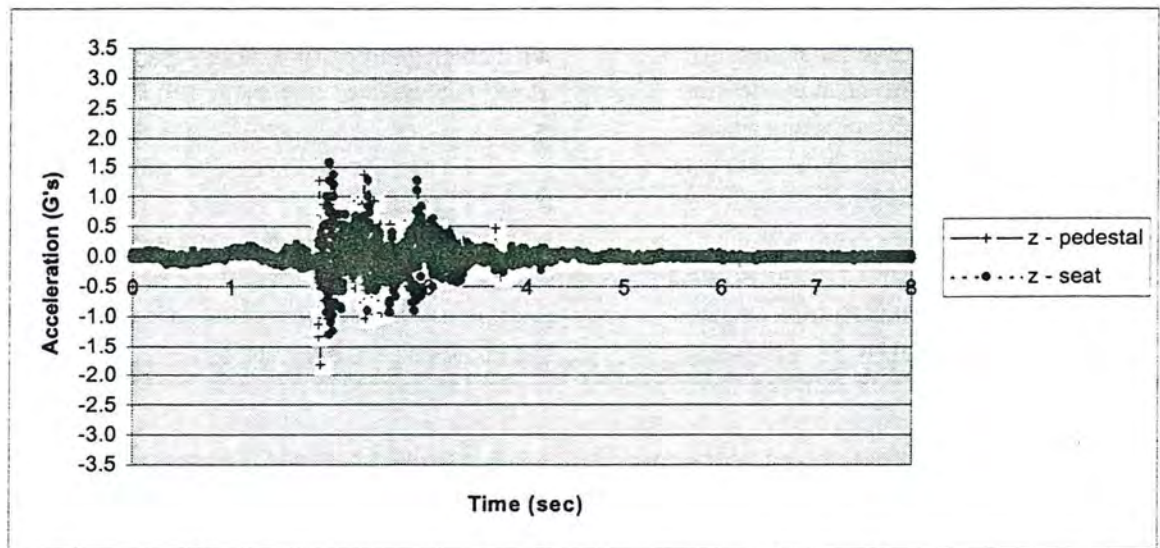
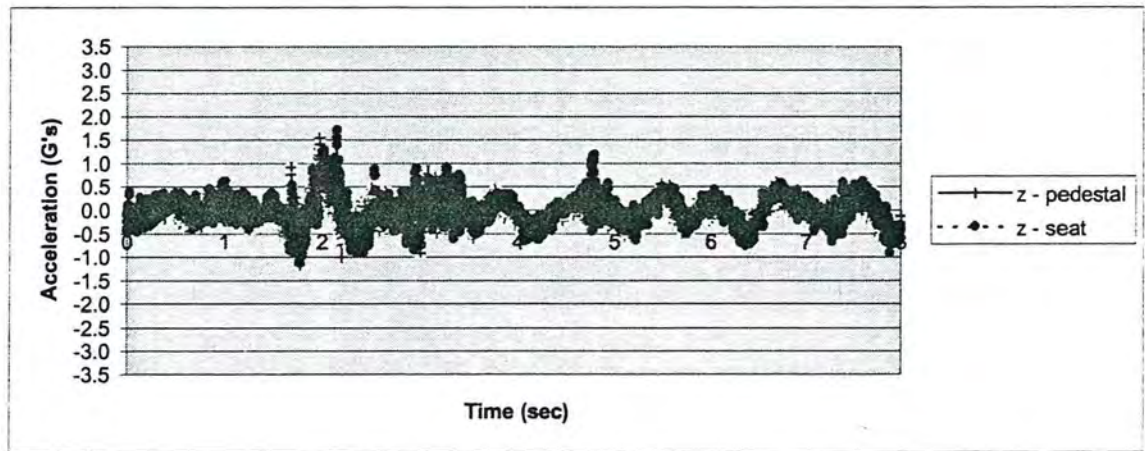
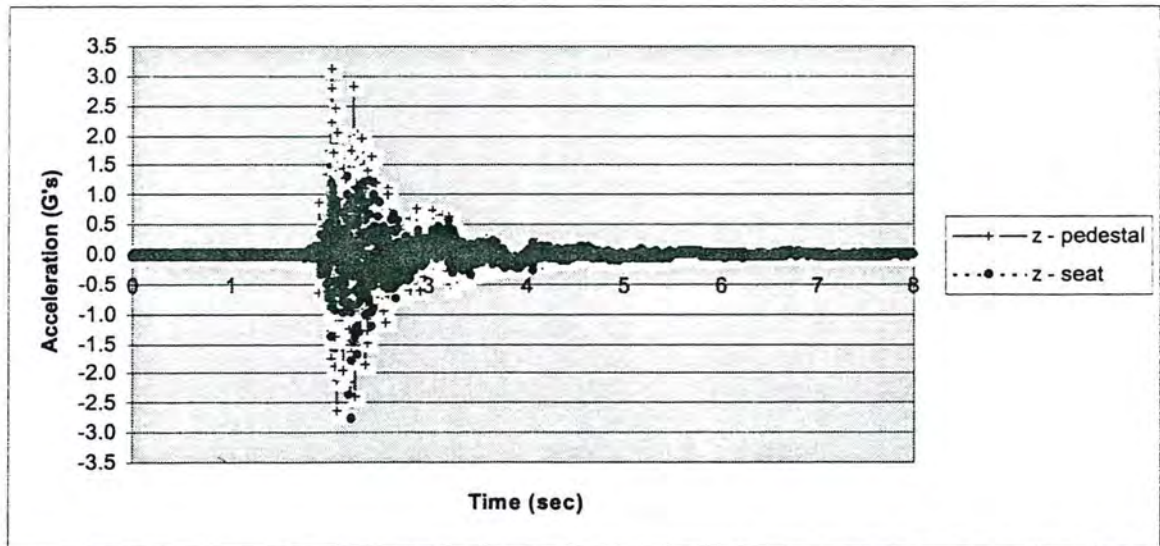
**C****D****E**

Figure 1.—Truck A shock events (continued). A, Loading event, A1; B, rough ground event, A2; C, loading event, A3; D, rough ground event, A4; E, loading event, A5; F, loading event, A6; G, rough ground event, A7

F

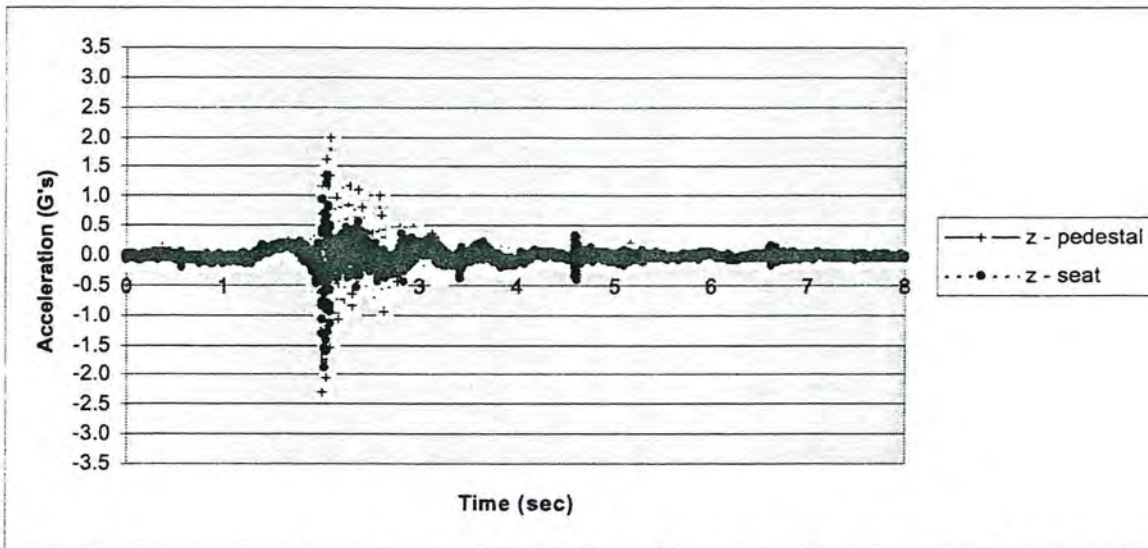


Figure 1.—Truck A shock events (continued). A, Loading event, A1; B, rough ground event, A2; C, loading event, A3; D, rough ground event, A4; E, loading event, A5; F, loading event, A6; G, rough ground event, A7.

G

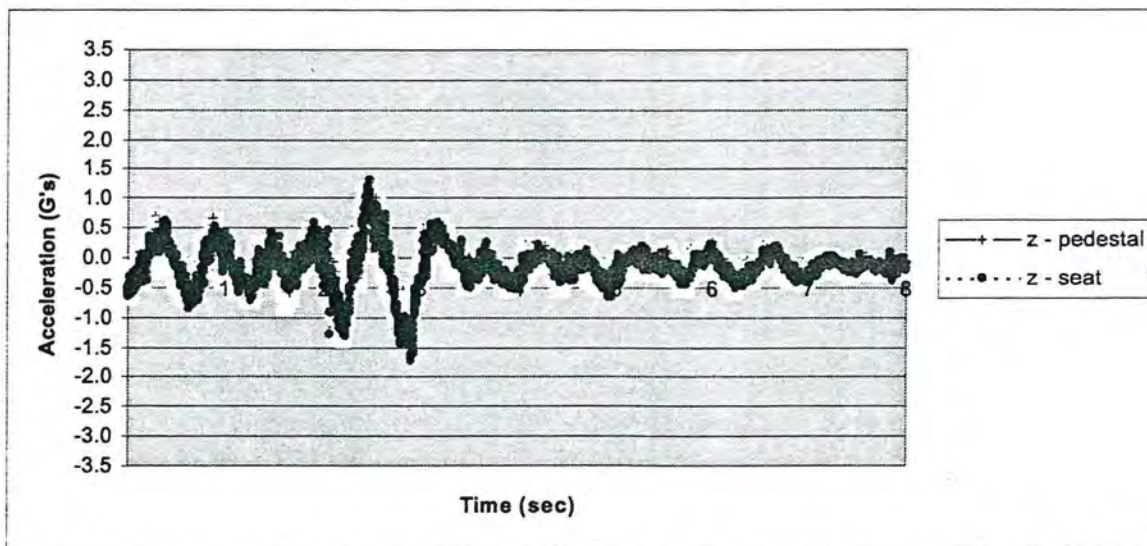


Figure 1.—Truck A shock events (continued). A, Loading event, A1; B, rough ground event, A2; C, loading event, A3; D, rough ground event, A4; E, loading event, A5; F, loading event, A6; G, rough ground event, A7.

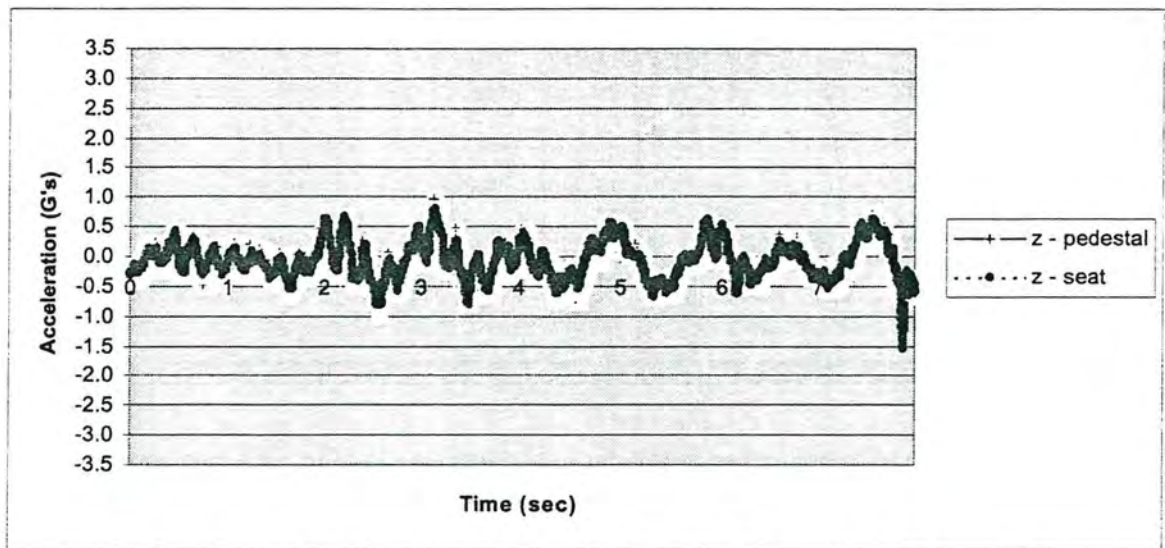
**A**

Figure 2.—Truck B shock events (continued). A, Event 1; B, event 2; C, event 3; D, event 4; E, event 5.

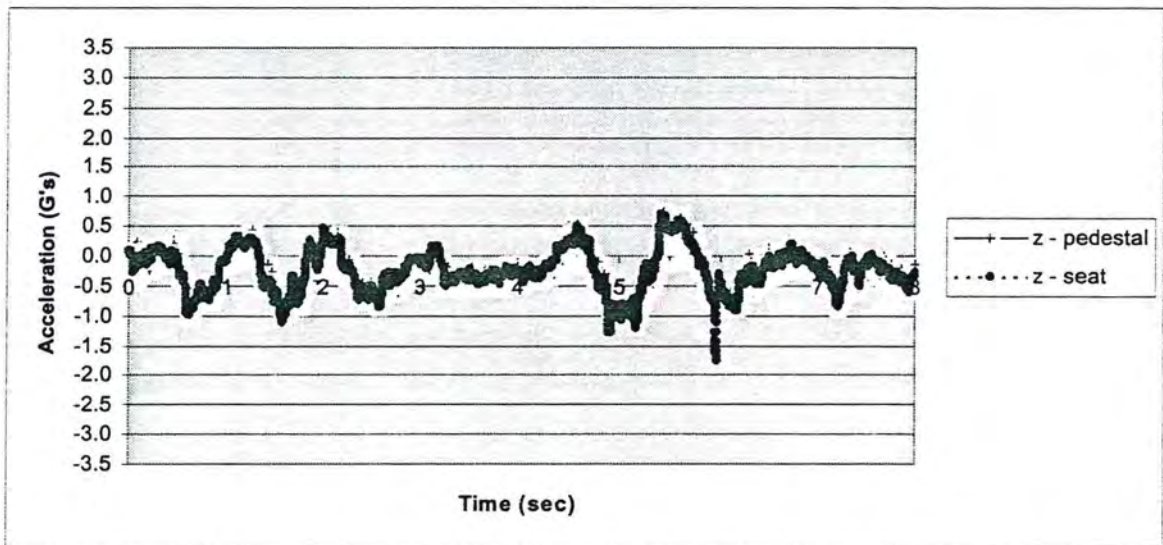
**B**

Figure 2.—Truck B shock events (continued). A, Event 1; B, event 2; C, event 3; D, event 4; E, event 5.

C

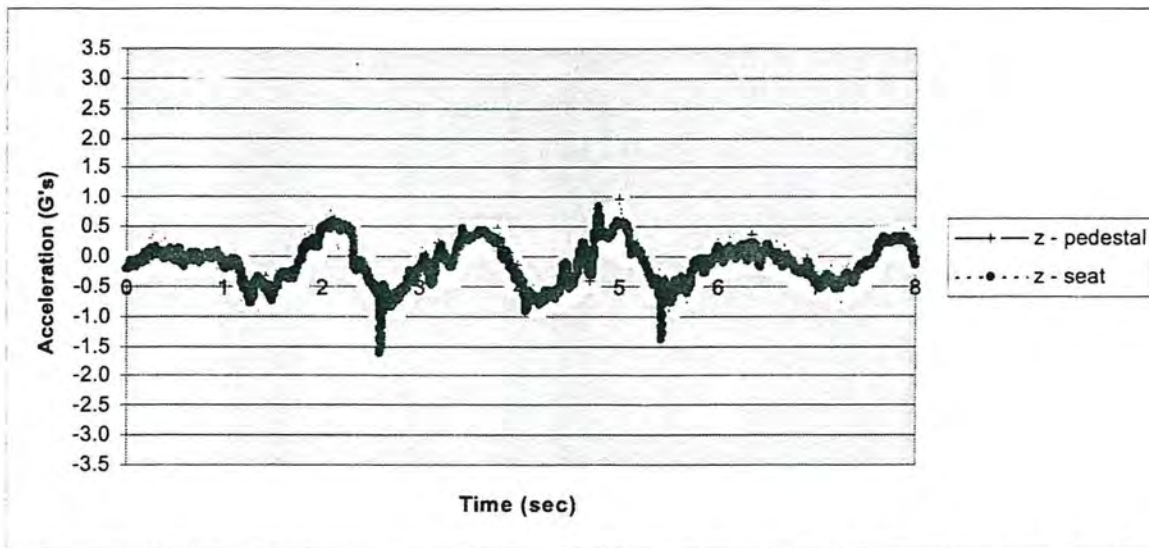


Figure 2.—Truck B shock events (continued). A, Event 1; B, event 2; C, event 3; D, event 4; E, event 5.

D

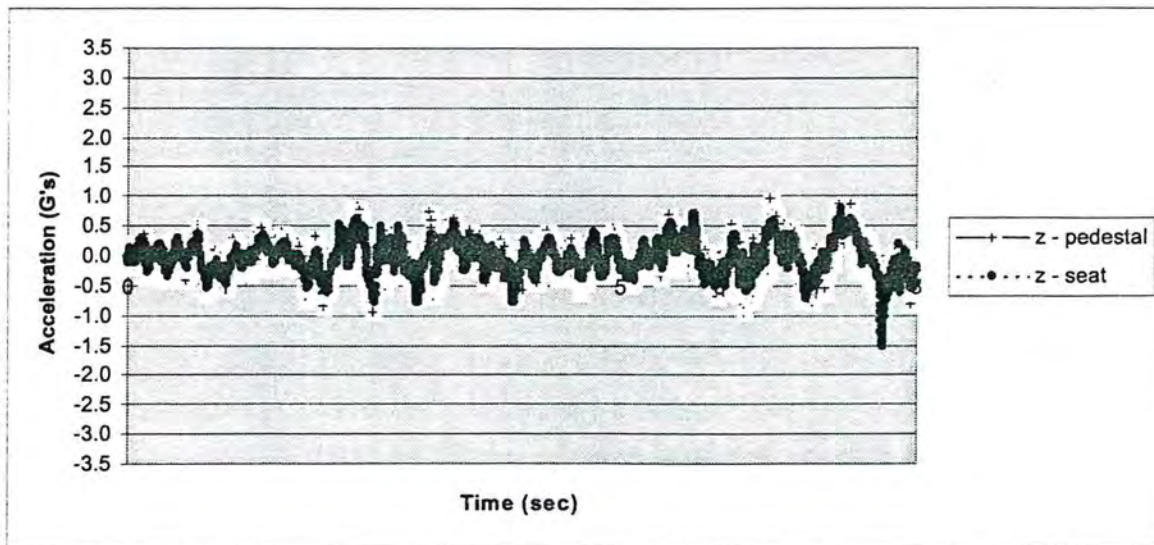


Figure 2.—Truck B shock events (continued). A, Event 1; B, event 2; C, event 3; D, event 4; E, event 5.

E

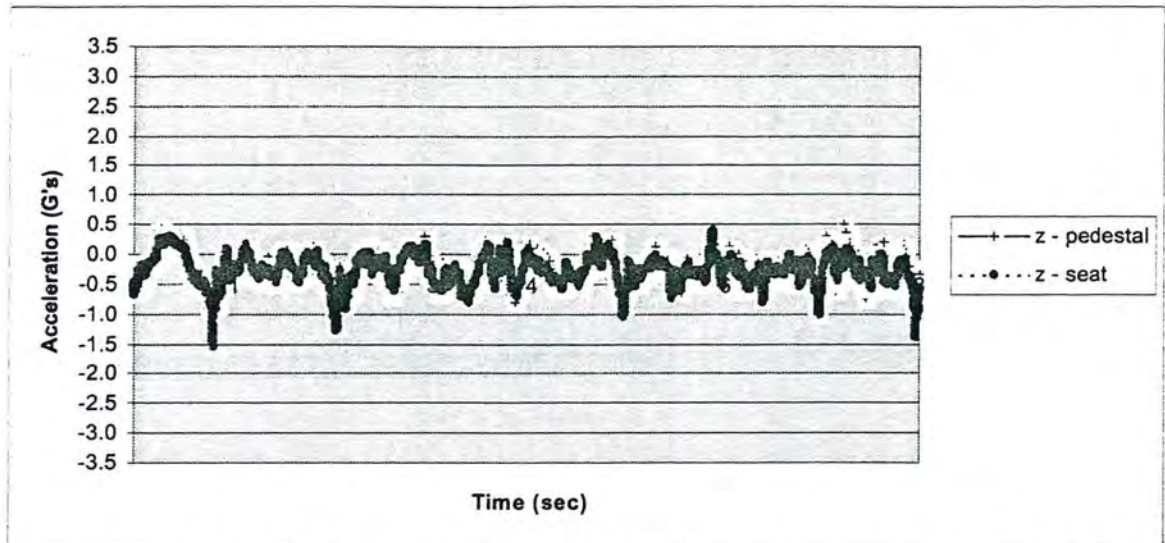


Figure 2.—Truck B shock events (continued). A, Event 1; B, event 2; C, event 3; D, event 4; E, event 5.

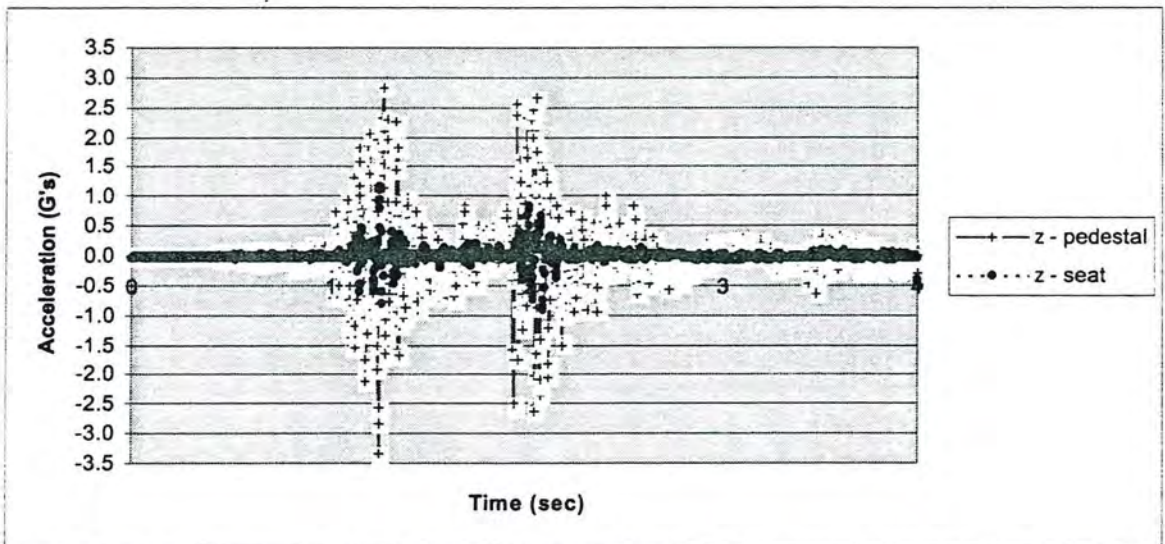


Figure 3.—Acceleration measured after dropping 1-1/2-ton rock from a height of 10 ft onto the bed of a haulage truck.

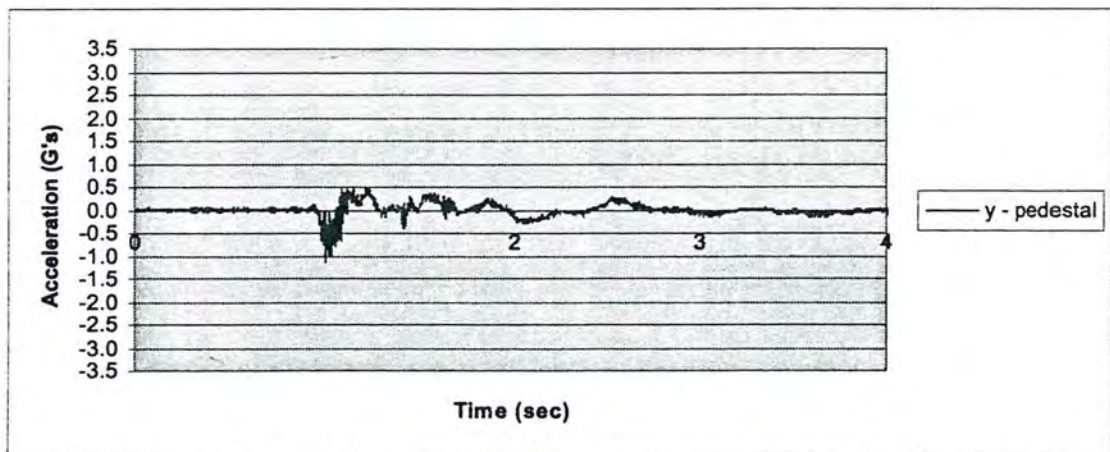


Figure 4.—Acceleration when truck hit in the side by a shovel.

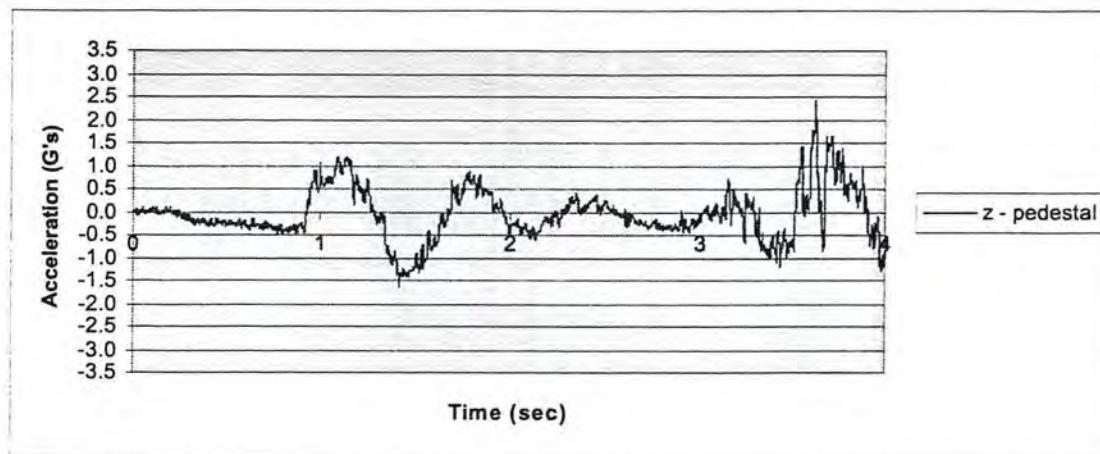


Figure 5.—Accelerations on truck going over course empty.

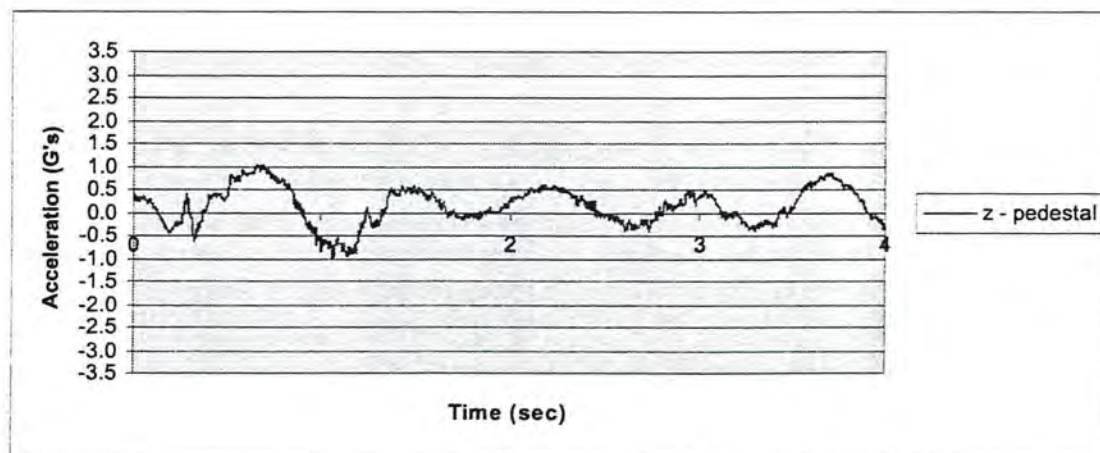


Figure 6.—Accelerations on truck going over course loaded.

### GPS-ACCELERATION STUDIES

A typical epidemiological study involves recording when and where people react to a hazard and plotting the results on a map. To determine the frequency and causes of jolting and jarring, it is necessary to determine when and where these shocks occur, so establishing a relationship between jolt occurrence and location

is important. A system that ties acceleration data with Global Positioning System (GPS) data was developed, assembled, and tested to provide an imprint of the jolts on a mine map (figure 7). This information will be of value in providing feedback to truck operators about how their driving affects jolting and jarring and identifying where haulage problems are.

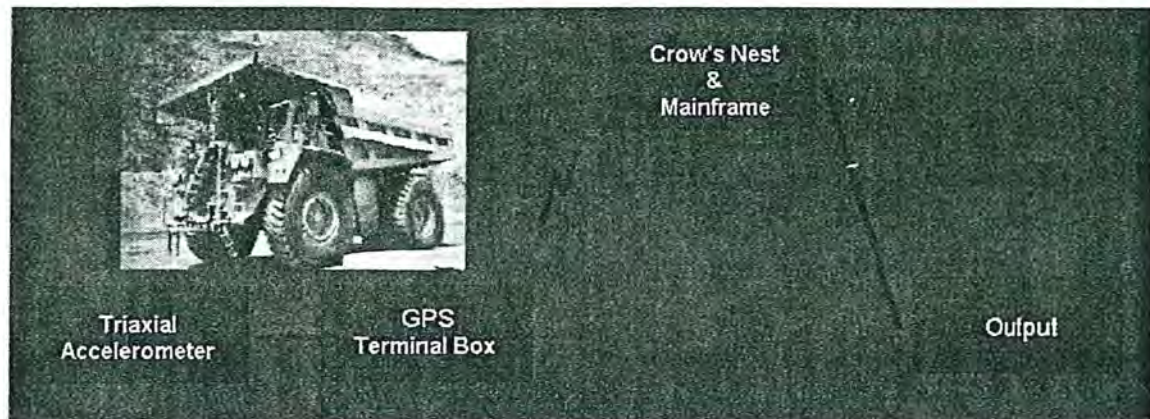


Figure 7.—GPS-acceleration data system

Many verbal reports are available from truck drivers concerning where and how they received injuries while driving, but no way has been available until recently to establish where these injuries occurred. However, recent experiments with GPS by SRL researchers [2] indicate it is feasible to couple an accelerometer on the frame of a truck with GPS. The accelerometer would send signals to GPS hardware. When the truck is jolted or jarred, the shock would appear on the mine dispatcher's screen in real time. When a cluster of jolts in a particular location is displayed on the screen, corrective actions could be taken. One such action might be to provide information to a shovel operator that he or she is loading the trucks in a manner that jolts the operator. A rough spot on a haulage road could be resurfaced. The GPS could lead to refining information about what conditions most frequently cause or contribute to jolting and jarring. Investigations continue on what software components could allow the display of jolts on a computerized mine map in real time.

### HUMAN RESPONSE TO SEATED JOLT AND VIBRATION ENVIRONMENTS

The human response to impact is closely related to vibration, but repeated impacts are fundamentally different in that their acceleration signatures are transient in nature. Vibration is typically present for long periods of time; a worker may be exposed for hours at a time. Impact, on the other hand, refers to a short burst of energy lasting only a fraction of a

second. A large body of literature exists on the response to vibration, and in particular, vertical sinusoidal vibration. However, not much is known about impact response and the potential risks associated with repeated jolts experienced while operating many heavy off-road vehicles, trains, and similar industrial equipment.

The effects of impact on the body are not as well characterized as vibration. In fact, very little is known about the seated impact or sudden load environments in terms of the effect on the spine, the back musculature, or any number of other body systems.(2)

Dr. David Wilder (2), director of the Vibration and Seating Laboratory, Lower Spine Research Center, University of Iowa, has provided extensive data to this project. Understanding the human response to seated jolt, impact, and vibration environments holds significant promise for alleviating back problems in the workplace. The act of sitting can impose significant mechanical risk to the posterior aspect of the lumbar intervertebral disc. Repetitively imposed additional stress and strains from impact, vibration, and unexpected loads can put the posterior disc at increased risk. During a sudden load event, the erector spinae muscle groups in the lumbar region overcompensate for the sudden stimulus, potentially contracting with inappropriately high tension levels, thereby producing high loads on the intervertebral discs in an asymmetric manner. The muscle of the side opposite the impact contracts before the muscle of the near side,

approximately a 20 ms lead [3]. That could enhance the effect of the side impact and contribute to an injury.

Many vehicle operators develop low back problems which may relate to exposure to vibration or repeated impact environments. Although poor muscle tone can be a contributing factor in back injuries, stiffness is not necessarily beneficial. In fact there are some circumstances, such as a driver twisting to look over his shoulder, which would increase the mechanical impedance of the spine and make it more susceptible to injury from a vertical jolt. This investigation has concentrated on factors which appear to be important and changes which could be constructive. Side impact has not yet been taken into account in truck seats as it has in the seat design for race cars.

### CONCLUSION

In the sitting position, the posterior aspect of the lumbar intervertebral disc is placed at greater mechanical risk. Repetitively imposed additional stresses and strains from impact, vibration, and unexpected loads can put the posterior disc at increased risk. Multiple impact exposure challenges the seated individual's ability to prepare and cope. By documenting the body's response to these stresses we can then look at cockpit and design isolation systems and other engineering controls to reduce operator injuries.

1. Driving over rough ground and loading were the primary causes of the jolting and jarring events recorded at the surface mine. Jolting and jarring caused by dumping did not appear in the events recorded.

2. The double-strike hypothesis, where the first jolt sets up the driver for injury by a second jolt, was investigated, but no evidence of the double-strike was seen in the mine data. However, the possibility of its occurrence is evident in the rock drop experiment.

3. GPS can be used as an epidemiological tool for studying and characterizing jolting and jarring.

4. A side impact could cause a back injury.

### REFERENCES

- [1] International Standards Organization. 1997. Mechanical Vibration and Shock. Evaluation of Human Exposure to Whole-Body Vibration, Part 1: General Requirements, ISO 2631-1:1997(E).
- [2] Miller, R., et al. 1999. Tying Acceleration and GPS Location Data To Create a Mine Management Tool. Presentation SME Annual Meeting, Denver, CO, Preprint 99-118.
- [3] Fethke, N. B. Erector Spinae Response to Low Amplitude Single-Strike Lateral Impact. Masters Thesis, Biomedical Engineering, University of Iowa, May 2000

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