An Ergonomic Evaluation of Excavating Operations: A Pilot Study

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Previous studies indicate that operators of heavy construction equipment are afflicted by musculoskeletal injuries of the arms, shoulders, neck, and lower back. These injuries appear to be due to excessive periods of sitting (static posture), work intensity, whole-body vibration, high resistance levers, repetitive motions, and awkward postures.[2–5] Although numerous studies have shown an association between operation of heavy construction equipment and symptoms of musculoskeletal disorders, very little research has been performed that systematically characterizes operating engineers' exposure to ergonomic hazards.

The objective of this study was to systematically characterize the ergonomic hazards associated with excavating operations. As such, the following were performed: (1) vibrations were measured at the operator/seat interface (X, Y, and Z axes), and at the floor of the cab (Z axis); (2) psychophysical ratings of whole-body vibration (WBV) level and overall seat design were obtained; and (3) postural assessments of the job were made.

Methodology

This study evaluated an inexperienced female operator performing excavation, utilizing two different pieces of equipment. The operator was 37 years old, 162 cm tall, and weighed 80 kg. She had approximately 15 hours of operation time (experience) on the equipment evaluated. The two pieces of equipment used were: a Case Super 580E (1986) backhoe/loader, and an Insley H-2000 excavator (1975) (see Figures 1 and 2). More evaluations were performed on the backhoe/loader than on the excavator. The following evaluations were performed on the Case equipment: 1) vibration levels at the seat and floor; 2) psychophysical ratings of the overall seat design and vibration levels (for the task duration, and for an 8 hour duration); and 3) postural assessments. For the Insley equipment, all of the evaluations were performed except vibration measurements. When the evaluations were conducted, the following environmental conditions were noted: the temperature was 31°F, and soil and terrain conditions were rough and frozen.

Whole-Body Vibration

Whole-body vibration was analyzed at the seat/operator interface using a triaxial piezoresistive seat pad accelerometer (Model VT-3), and at the floor level using a single-axis piezoresistive accelerometer (Model 7265A-HS), both from Endevco Corporation (Canton, MA), as well as a field computer system (Model 2100 FCS) from Somat Corporation, to filter and store the data in the field. The vibration measurements were performed in accordance with the ISO 2631 standard.[6] Calibration procedures and mounting of the test equipment were done according to the manufacturers' guidelines.

The field computer system (FCS) was connected to a rechargeable lead-acid battery and the tri-axial (Channels 2–4) and single axis (Channel 1) accelerometers. A laptop was used to calibrate the accelerometers, to start and stop the data collection process, and finally to download the data from the FCS after evaluating each of the activities. Figure 3 shows the location of the accelerometers, and a general schematic of the instrumentation used for data collection.

The vibration data were filtered using a Butterworth filter with a 100 Hz break frequency. The data were sampled at a rate of 500 Hz. A Hanning window was applied to the time domain data. A windowing function is necessary to reduce the leakage in calculating the frequency content of a signal. The crest factors (CFs) were calculated, and then compared with the limit established by the American Conference of Governmental Industrial Hygienists (ACGIH®) standards.[1] Crest factor is defined as the ratio of peak to RMS acceleration, measured in the same direction for X, Y, and Z axes.

A Fast Fourier Transform (FFT) and one-third octave band analysis were performed using the Matlab software. FFT analysis converted the time-domain data into frequency domain data. The data were broken down into one-third octave bands, which provide greater detail than one-octave frequency bands, especially at the lower frequencies. Also one-third octave band analysis of the spectra is needed to use the WBV limits established by ISO/threshold limit value (TLV®) limit.[1] The total vector sum acceleration for the X, Y, and Z axes was calculated using the appropriate axis weighting factors from ACGIH.[1] The total weighted vector sum was then compared with the 8-hour action level of 0.5 m/s^2.

Psychophysical Rating

Psychophysical rating was used to estimate physical strain as perceived by the operator. The ratings (discrete scales) were recorded for the overall seat design,

FIGURE 1
A Case Super 580E Backhoe/Loader.

FIGURE 2
An Insley H-2000 Excavator.

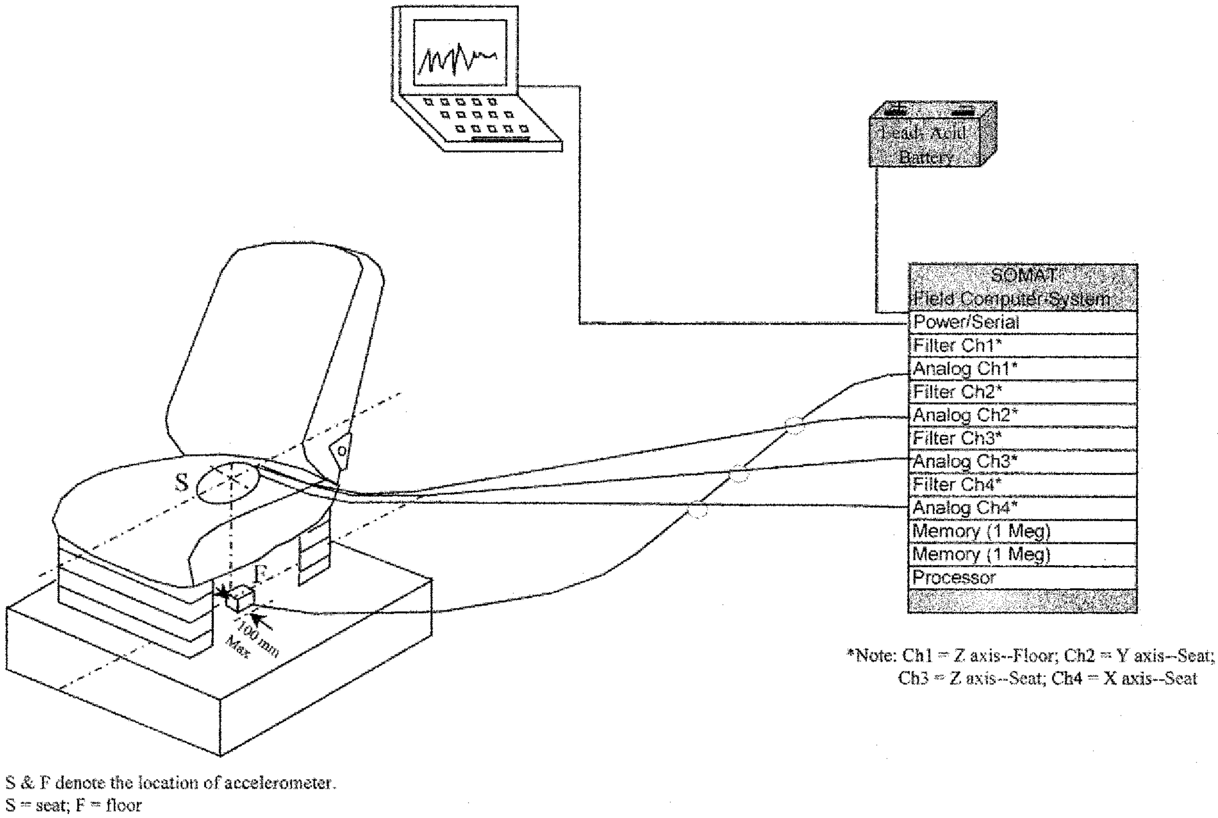

FIGURE 3
A schematic of the instrumentation used for WBN data collection.

and the equipment's vibration level for each task. The operator was asked for a rating after completion of each activity. Responses were recorded for the following questions:

1. The vibration level of the equipment is: (1 = low to 5 = high).
2. The seat design of the equipment is: (1 = good to 5 = bad).

The ratings were compared with the quantitative measurement of vibration at the seat, and the transmissibility of vibration due to the design characteristics of the seat.

Postural Assessment

Postural assessments were performed by videotaping the jobs (digging a trench), and then evaluating it using the real-time postural assessment system.[7] The trunk, right shoulders, and neck were analyzed. For the postural analysis, the operator was observed for 42.3 and 62.4 seconds while operating the Case and Insley equipment, respectively.

Results and Discussion

A Hanning window was applied to the time domain data, and then a Fast Fourier Transform was performed using Matlab software. For the tasks performed by the Case (backhoe/loader) equipment, the overall weighted (vector sum) total RMS accelerations, crest factors, psychophysical ratings, and sample times (for vibration measurements) are provided in Table I.

The digging and riding with load tasks resulted in higher levels of vibration as compared to idling. If these were the WBV levels for an 8-hour day, all tasks except idling would exceed the limit of 0.5 m/s^2 recommended by the European Commission. In general, the seat was amplifying the vibration levels, particularly at lower frequencies. The ratings show that both the digging and riding with a load resulted in a higher rating of perceived vibration from the subject. The operator rated the overall seat design for the Case equipment as a 3. In general, high crest factors were present in both digging and riding with a load. This indicates that the operator was exposed to random jolts and jerks in performing the different activities. When CFs are greater than 6, ISO 2631[6] methodology may underestimate the true effects of WBV, and the results should be used with caution.

The postural analysis of the operator performing the trench digging operation was performed on both pieces of equipment (Case and Insley). For the Case equipment, the trunk was in neutral and twisted 75 percent and 25 percent of the observed time (42.3 seconds), respectively. The neck was in neutral and twisted 45 percent and 55 percent of the

TABLE I
Summary of results for the case equipment

	Idling	Digging	Riding with load
Weighted total RMS accelerations (m/sec^2)	0.053	2.66	6.07
Crest factors (range for all axes)	2.2 to 17.7	13.5 to 26.6	6.2 to 8.8
Sampling times (minutes)	2.05	6.08	0.82
Psychophysical ratings of vibration[A]	2	3 to 5	3 to 5

[A]Note: The psychophysical ratings are for the sampling time and for an 8-hour job.

observed time, respectively. The right shoulder was in elevation (45° to 90°) for a majority of the time period (98%). For the Insley equipment, the trunk was in neutral, flexion (more than 20°), and twisted or bent (more than 20°) 18 percent, 65 percent, and 17 percent, respectively, for the observed time (62.4 seconds). The neck was in neutral, twisted, and severe forward flexion (> 45°) 78 percent, 21 percent, and 1 percent of the time, respectively. The right shoulder was in elevation the majority of the observed time period (77%). The view of the videotape made the analysis challenging for the other body parts. For the Insley, the operator rated the overall seat design as a 3, the vibration level for the task duration as a 3, and for an 8 hour operation of digging the trench the rating was a 5.

Conclusions

This field study was conducted to evaluate the ergonomic hazards associated with the use of construction equipment to perform excavating operations. One female operator performed excavations using two different pieces of construction equipment. Whole-body vibration measurements, psychophysical ratings of the overall seat design and vibration, and postural assessments were performed. The job was broken down into tasks to characterize the vibration levels of each task. The study was carried out in accordance with the measurement and evaluation techniques outlined in the ISO 2631 standard.[6] The machines studied were relatively old, resulting in higher WBV exposures (due to no vibration attenuation), and awkward postures (due to poor cab design). The results revealed that the digging operation and traveling with a load (in the loader-bucket) had higher levels of total weighted acceleration than idling. The seats in the equipment demonstrated that they are not sufficient to protect the operator from long-term effects of vibration exposure. The psychophysical ratings were consistent with the vibration levels. Also, the postural evaluation revealed that the operator assumed awkward postures of the trunk, neck, and shoulders while performing the excavations.

Recommendations

The construction equipment sampled in this study were older pieces of equipment. Newer equipment is expected to be ergonomically designed, yielding better attenuation of vibration and visibility of the job. Some controls for whole-body vibration and awkward postures are as follows:

Whole-Body Vibration

1. Design and select seats based on the transmissibility characteristics, and not solely on the immediate comfort of the operator.
2. Design and select seats that will adequately damp vibration at all frequencies, but importantly, in the lower frequencies (1 to 8 Hz).
3. Properly maintain the equipment to reduce wear and tear that could result in increased vibration.
4. Limit the speed of the equipment when driven, especially over bumpy or irregular surfaces.
5. Workers should avoid jumping off their equipment when exiting, since this introduces a shock to the body that has just been vibrated for several hours.

Awkward Posture

1. Redesign cabs to accommodate better upward and/or downward visibility.
2. Have co-worker or foreman guide the operator (hand signals) when visibly challenging jobs are performed (i.e., jobs below ground).
3. Install mirrors to provide better visibility (sideways, and below ground).

REFERENCES

1. American Conference of Governmental Industrial Hygienists: Threshold Limit Values and Biological Exposure Indices, pp. 126–133, ACGIH, Cincinnati, OH (2000).
2. Bongers, P.M.; Boshuizen, H.C.; Hulshof, C.T.J.; et al.: Back Disorders in Crane Operators Exposed to Whole-Body Vibration. Int Arch Occup Environ Health 60:129–137 (1988).
3. Buchholz, B.; Moir, S.; Virji, M.A.: An Ergonomic Assessment of an Operating Engineer: A Pilot Study of Excavator Use. Appl Occup Environ Hyg 12:23–27 (1997).
4. Burdorf, A.; Zondervan, H.: An Epidemiological Study of Low-Back Pain in Crane Operators. Ergonomics 33:981–987 (1990).
5. Hansson, J.E.: Ergonomic Design of Large Forestry Machines. Intl J Ind Ergon 5:255–266 (1990).
6. International Standards Organization: Evaluation of Human Exposure to Whole-Body Vibration, ISO 2631/1. ISO, Geneva (1985).
7. Keyserling, W.M.: Postural Analysis of the Trunk and Shoulders in Simula ted Real Time. Ergonomics 29:569–583 (1986).