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Jarring/Jolting Exposure and Musculoskeletal Symptoms Among Farm Equipment Operators

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SUMMARY:

This paper discusses a recently completed NORA-sponsored project that examined the vehicle jarring/jolting effects and exposure levels for operators of farming equipment. This research included: collecting and analyzing field data; collecting health and work history data from farm equipment operators. Researchers collected field data at two of the four farms at The Pennsylvania State University. Operations studied included mowing, raking, baling, chiseling, tilling, and road traveling for different model tractors along with spraying using a sprayer machine, and shrub removal using a skid-steer loader. All of the field data operations exceeded the 0.5 m/s^2 action level for overall weighted total RMS acceleration (sum of values for three axes – x, y, and z) recommended by ISO 2631-1 and the Commission of European Communities. Smaller utility tractor mowers (at 3.3 m/s^2) and the skid-steer loader (at 1.7 m/s^2) had the highest acceleration values. Focus group discussions conducted at the 2003 American Farm Bureau Federation Annual Meeting and Convention provided the forum for collecting data from attendees who operated farm equipment. Major findings show 96 percent of participants reported having to bend or twist their necks, although 24 percent reported neck symptoms. Since this is an awkward, yet common, operating posture practiced almost universally by farm equipment operators, it is obvious that the risk of injury relates directly to the severity of and how often bending or twisting of the neck occurs. Injury symptoms in various body parts were reported by 72 percent of participants. Sixty-four percent of participating operators reported experiencing back symptoms.

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INTRODUCTION

Farm tractors and other earth-moving equipment contribute to some of the most common, prolonged, and severe occupational exposures of vehicle vibration among equipment operators. The recognition of potential hazards has resulted in standards concerned with the vibration transmitted by the seats (ISO 5007, 2003) of these vehicles and the vibration exposure (ISO 5008, 2002) of vehicle operators (Griffin, 1990). Pope et al. (1998) described how investigators, using a multifaceted approach, studied the relationship between whole-body vibration (WBV) and low back pain. WBV data shows that the human spinal system has a characteristic response to vibration inputs in a seated posture. Studies have shown that muscle fatigue occurs when exposed to WBV, Wilder et al. (1984), Pope MH et al. (1986), Magnusson et al. (1988). It is significant that muscle response after exposure to WBV takes longer when subjected to a sudden load, such as that occurring during vehicle jarring and jolting.

Exposure to WBV and the postural requirements of the job have been identified as important risk factors in the development of musculoskeletal disorders of the spine among workers exposed to a vibratory environment (Kittusamy and Buchholz, 2004; Kittusamy, 2002; Kittusamy 2000). Adverse health effects of WBV have been reviewed by several investigators (Seidel and Heide, 1986; Wikstrom et al., 1994; Hulshof and van Zanten, 1987; Seidel, 1993). Some acute health effects of WBV include loss of visual acuity, postural stability and manual control. While some of the chronic health effects of WBV are low back pain, early degeneration of the spine, herniated discs, and digestive and circulatory disorders. It has also been reported that long-term exposure to WBV might contribute to the pathogenesis of disorders of female reproductive organs and disturbances of pregnancy (Seidel, 1993; Seidel and Heide, 1986). Furthermore, WBV has a minor synergistic effect on the development of noise-induced hearing loss (Seidel, 1993).

The National Institute for Occupational Safety and Health (NIOSH) compiled a comprehensive body of epidemiological research connecting musculoskeletal disorders with ergonomic exposures, such as repetition, force, posture, and WBV (NIOSH, 1997). A substantial portion of the research gives evidence of a strong association between WBV exposure and back disorders. Similarly, studies concerning agricultural tractor drivers showed that vibration exposure and duration of exposure are associated with lifetime, transient, and chronic back pain and low-back symptoms (Bovenzi and Betta, 1994; Boshuizen et al., 1990a; Boshuizen, et al., 1990b).

This paper highlights a segment of a research project done under the National Occupational Research Agenda (NORA) sponsored by NIOSH. Quantifying the extent and effects of jarring/jolting to reduce injury risk for operators of mobile equipment in agriculture and construction is the main goal of the overall research project. NIOSH laboratories in Pittsburgh, Spokane, and Cincinnati collaborated with the participation of university contractors the Universities of Iowa and Cincinnati. The Spokane Research Laboratory (SRL) had the lead role investigating jarring/jolting for operators of mobile construction equipment. SRL researchers also worked with the University of Iowa, Biomedical Engineering Department to study the back muscle response times and amplitudes to a sudden impact loading event. The NIOSH Division of Applied Research and Technology in Cincinnati worked through the University of Cincinnati, Department of Mechanical, Industrial, and Nuclear Engineering in developing a biomechanical model of the human body that determines the biomechanical effects from increased acceleration levels caused by jarring/jolting. Finally, the NIOSH Pittsburgh Research Laboratory (PRL) focused its efforts in agriculture. This project has allowed researchers a greater opportunity to characterize work exposures.

DEFINITIONS

The following operations are defined with respect to the context of this paper.

Baling – the process of gathering, forming, and packaging cut forages into bales, square-shaped or round. The squares weigh from 18 kg to more than 45 kg (small) and more than 907 kg (large); round bales generally weigh less than 816 kg.

Chiseling – an activity associated with breaking up into finer fragments the ground after it is broken into large fragments from a solid. (Also, concerns an implement of husbandry – a vehicle designed or adapted and determined by departments of highways to be used exclusively for agricultural operations and only incidentally operated or moved upon highways.)

Mowing – the cutting of field crops for appearance (usually once a week) or cutting of forage crops for further processing into bales, loose hay, or haylage.

Raking – the turning of forage crops into windrows and turning windrows to aid in curing.

Roadway – the portion of a highway improved, designed, or ordinarily used for vehicular travel.

Spraying – the activity associated with a usually large machine that distributes some type of solution to a field or vegetation.

Shrub removal – an activity associated with excavating a small shrub and transporting it.

Tilling – the turning of soiling in preparation for planting.

METHODS

The extent to which agricultural vehicle jarring/jolting contribute to operator injury, in terms of magnitude and frequency, was determined through the collection of vehicle vibration (jarring/jolting) data at selected field sites. The collection of health and work history data from farm equipment operators served as another tool for NIOSH researchers to describe the injury issues for these operators and to identify probable causes of these injuries.

Field Data Collection

During field data collection, PRL researchers collaborated with The Pennsylvania State University (Penn State) in University Park, PA and a local farm in Smithton, PA. In the early phase of the project, the local farm provided the opportunity to collect field data for a variety of operating conditions and for a single class 2 farm tractor (see explanation below). Nevertheless, the results reported in this paper concern only data gathered at the Penn State farms. Penn State has a wide variety of farms, farm operations, terrain conditions, and equipment from which to collect data on the effects of equipment operator exposure to jarring/jolting. Penn State has four farm operations: (1) Agronomy Farm (2) Operations and Services Farm (3) Horticulture Research Farm and (4) Animal Facilities Farm. Because of its tractor inventory and different farm operations, researchers selected the Agronomy Farm, primarily, and secondarily, the Operations and Services Farm to collect data.

Researchers collected vibration exposure data on class 1 tractors with an un-ballasted maximum weight of 1,640 kg and class 2 tractors with an un-ballasted weight range from 3,600 to 6,500 kg. Both classes are the most commonly used sizes of agricultural tractors. Data collection involved farm equipment (tractors, a sprayer, and skid-steer loader) performing different operations as follows: Class 1, Equipment No.'s 1 and 3 during mowing; Class 2, Equipment No.'s 2 and 4 through 8 during mowing, bailing, chiseling, ground working, raking, shrub removal, spraying, and road traveling that includes a smooth surface to dirt or gravel transition. Data gathering was accomplished with an 8-channnel, digital data recorder, triaxial accelerometers, signal conditioning amplifiers and in-line, low-pass filters. Researchers collected data to determine the energy entering the seat through the floor from the vehicle frame. Triaxial accelerometers were placed on the floor of the operator's compartment near the base of the seat (frame measurement) and on the seat at the subject/seat interface (seat measurement).

The raw data was initially viewed in terms of root-mean-square (RMS) acceleration, peak acceleration (jar/jolt), crest factor (ratio of peak acceleration / RMS). Of these variables, peak acceleration and crest factor were the most descriptive relative to jars and jolts, although RMS acceleration is necessary to compute the crest factor. Further, the data was analyzed according to ISO 2631-1 exposure limit (weighted vertical or z-axis direction) and total overall weighted RMS acceleration, a single-value computation for all three directions of vibration.

Health and Work History Data Collection

During the American Farm Bureau Federation Annual Meeting held in Tampa, FL in January 2003, researchers collected health and work history data from farmers and farm workers who operated tractors and other mobile farm equipment. Researchers formulated a list of 25 questions for use in focus group discussions that served as the forum to collect data.

The information collected covered eight broad categories and included: general information, work information, job history, information on currently or recently operated equipment, medical history, exercise and hobbies information, injury history, and history of injury symptoms.

RESULTS

Field Work

Tables 1 through 3 provide a summary of results for data analyzed from the Penn State farms. In Table 1, the jars/jolts showing the three largest peak (vertical) accelerations, were obtained for the road travel (33.7 m/s^2), shrub removal (13.8 m/s^2), and mowing (11.3 m/s^2). These peak accelerations were taken from the raw data and not weighted values. Notably, high crest factors were computed also for road travel (16.2), shrub removal (14.2), and tilling (7.3). The data analysis for the small, utility-type, mower tractor (class 1) indicated 3-hours exposure limit as shown in Table 2. The total overall weighted RMS accelerations for all equipment operations ranged from 0.9 m/s^2 to 3.3 m/s^2 thus exceeding the 0.5 m/s^2 action level recommended in ISO 2631-1 (ACGIH, 2002). Among the highest total overall weighted RMS accelerations were those obtained for mowing (3.3 and 2.8 m/s^2), shrub removal (1.7 m/s^2), and road travel (1.6 m/s^2).

Table 1. *Peak acceleration (nonweighted) and crest factor in vertical (Z -direction) for different equipment.*

Equipment No.	Equipment Class	Operation	Peak Acceleration (m/s^2)	Crest Factor
1	class 1	Mowing	11.25	4.91
2	class 2	Mowing	2.93	3.88
3	class 1	Mowing	10.13	4.43
4	class 2	Raking	9.20	6.06
2	class 2	Baling	3.72	6.07
5	class 2	Baling	2.41	3.42
6	class 2	Chiseling	4.55	5.22
2	class 2	Tilling	7.88	7.25
4	class 2	Road	33.69	16.18
7	class 2	Spraying	5.92	6.56
8	class 2	Shrub Removal	13.75	14.18

Table 2. *Exposure limit in vertical or Z -direction for different equipment.*

Equipment No.	Equipment Class	Operation	Exposure Limit* (Hrs)
1	class 1	Mowing	3
2	class 2	Mowing	24
3	class 1	Mowing	3
4	class 2	Raking	5
2	class 2	Baling	24
5	class 2	Baling	12
6	class 2	Chiseling	20
2	class 2	Tilling	11
4	class 2	Road	6
7	class 2	Spraying	17
8	class 2	Shrub Removal	11

*ISO 2631-1

Table 3. *Overall total weighted RMS acceleration (vector sum for 3-directions) for different equipment.*

Equipment No.	Equipment Class	Operation	Vector Sum* (m/s^2)
1	class 1	Mowing	2.84
2	class 2	Mowing	0.87
3	class 1	Mowing	3.26
4	class 2	Raking	1.70
2	class 2	Baling	0.86
5	class 2	Baling	1.03
6	class 2	Chiseling	1.33
2	class 2	Tilling	1.51
4	class 2	Road	1.56
7	class 2	Spraying	0.96
8	class 2	Shrub Removal	1.73

*ISO 2631-1

Focus Group Discussions

The 2003 American Farm Bureau Federation (AFBF) Annual Meeting and Convention provided the forum for collecting health and work history data from attendees who operated farm equipment. To solicit participants for the study, researchers placed an ad in the AFBF convention newsletter and set up a display booth in the section designated for exhibitors. Respondents were volunteers who passed by the booth and signed up to participate. Fifty of 61 potential respondents participated in the study for an 80 percent return rate. Ninety percent of the respondents were owner/operators. Eighty-eight percent (44) were male and 12 percent (6) were female. The average respondent's age was 48 and the average years of experience in operating farm equipment was 33.

A majority of the operators indicated that the cab/workstation design was satisfactory. Sixty-eight percent responded that the seat was adjustable and 96 percent could easily reach and operate the pedals and levers. Moreover, 96 percent reported that they have to bend or twist their neck and 38 percent reported that they jump off the equipment to exit. Furthermore, all of the operators indicated that proper maintenance was performed and that repairs were performed when needed/required (96 percent).

Concerning musculoskeletal symptoms, 72 percent of participants reported symptoms in various body parts. Table 4 shows the affected body parts and percentage of participants who reported symptoms in the particular body part.

Table 4. *Summary of respondents reporting symptoms according to affected body part.*

Body Part	Respondents Reporting Symptoms (percent)
Low back	38
Wrist/hand	28
Knee	28
Ankle/foot	28
Middle/upper back	26
Neck	24
Shoulder/upper arm	24
Elbow/forearm	16
Hip	12

DISCUSSION

Concerning the measured variables for the field data, researchers consider the unweighted RMS acceleration the *least descriptive* of the three measurement parameters in terms of jarring/jolting events for vehicle operators. RMS acceleration reflects a greater time period and includes acceleration levels of far lower levels than peak acceleration, which includes a very short time period and much higher level of energy. With its short time period and higher level, the peak acceleration (the jar/jolt) is perceived by vehicle operators as having a greater impact on them in terms of comfort and health.

The field data analysis showed vehicle operators experienced peak vertical accelerations – indicative of jars/jolts – that could reach accelerations as high as 3.4 g's (where 1 g = 9.8 m/s^2). How often such events occur for the type and class of vehicle is important to note in evaluating operator exposure, severity of exposure, and needed isolation for the seat and possibly other operator cab components. Researchers note that these occurrences were not frequent during data collection. However, owing to the complexities of collecting data in the field, it is not clear how often these conditions could occur and what the cumulative effects of such exposure may have on injury risk. Crest factors exceeding 6 were noted for raking, baling, tilling, spraying, shrub removal and road travel. In these latter two activities, the crest factors more than doubled the ISO 2631-1 guideline. In cases, where crest factors exceed 6, the ISO 2631-1 will underestimate the effects of WBV or jarring/jolting exposure (ACGIH, 2002; ISO 2631, 1997).

The data analysis for the two small, utility-type, mower tractors (class 1) showed the lowest exposure limit at 3 hours whereas the class 2 vehicles showed the highest peak accelerations. The authors believe the lower ISO 2631-1 permissible exposure time of 3 hours for the class 1 compared to the class 2 vehicle concerns several things: the lower mass of the class 1 vehicle; the shorter wheel base 142 to 165 cm; smaller tire diameter and tire construction, e.g. radial versus bias belt; and a lower grade and cost seat with fewer features (e.g., small displacement from seat suspension) for isolating against vehicle vibration, jars and jolts. These factors contribute to a generally rougher ride for the class 1 vehicle. Also, the class 2 vehicles (with greater mass and usually better seating) are used in more "heavy duty" service (raking, baling, tilling, etc.) over generally rougher ground. However, given the "right" speed and "right" rut, pothole, or road surface transition, the class 2 vehicle can generate high vertical accelerations for the seated operator.

The total overall weighted RMS accelerations for all equipment operations exceeded the 0.5 m/s^2 action level recommended in ISO 2631-1. Considering the shortcomings of the ISO 2631-1 concerning multiple-vibration shock, this may not be an accurate indicator of the injury risk from exposure to incidents of jarring/jolting for these vehicles.

Focus group discussions revealed musculoskeletal symptoms in various body parts for the respondents. Nearly all farm equipment operators reported having to bend or twist of the neck showing it is an essential part of pulling equipment and other machinery behind it. Whether or not performing this awkward posture it leads to injury or injury symptoms would depend on how often operators assume this posture and the angular extent of turning the head. More than a third of the respondents reported jumping off equipment to exit. Low back pain is muscular in origin, usually the result of poor posture, or lack of flexibility or strength in the back, stomach, and thigh muscles. Pain, along with stiffness, may begin after lifting a heavy object, a fall (equivalent to jumping off equipment), standing or sitting for a long time, e.g., all-day operation of farm vehicles (Bovenzi et al., 2002). Unfortunately, the limitations of the data collected do not permit the authors to correlate the various injury symptoms with high-risk work practices, awkward postures, and vehicle jarring/jolting.

FUTURE RESEARCH CONSIDERATIONS

NIOSH researchers will complete the analysis of and report on laboratory testing of selected seat suspensions. This will be done in connection with computer-based modeling developed for evaluating seat and seat suspension designs. The purpose of the modeling was to aid in the evaluation and selection of ergonomic and engineering control interventions for decreasing the potential for operator injury from vehicle jarring on farming equipment.

RECOMMENDATIONS

From researchers observations and conversations with tractor operators and farm conference attendees, the following recommendations are offered. First, whenever possible, specify the "better" seat for new tractor purchases or seat replacement (i.e., a "better" seat attenuates jars/jolts and thereby, isolates equipment operators from them). Also, farmers should keep the seats/seat suspensions well-maintained and replace worn or damaged seat padding. One consideration for replacement padding is NIOSH recommended viscoelastic foam padding which has proved effective in mining applications (Mayton et al. 1999, 2003) with vibration environments similar to those found in farming. As the recorded results have shown, operators of small, class 1 utility tractor-mowers can experience rough rides with peak vertical accelerations of 11.3 m/s^2 and an ISO 2631-1 exposure limit of 3 hours. A third recommendation, particularly for the small utility tractor-mowers, is to use larger diameter tires with radial instead of bias belt construction to aid in attenuating ride "roughness." From health and work history data, 24 percent of participants indicated symptoms for the neck. Ninety-six percent of tractor operators bend or twist their neck during operations such as tilling, plowing, raking, etc. Therefore, a fourth recommendation is to use a seat that swivels to reduce the stress on the neck. Finally, during health and work history and field data collection, researchers found the lack of awareness by the participants regarding the potential effects of WBV exposure on a tractor operator. Thus, researchers recommend educating owners/operators of the effects of WBV on the operator during tractor operations. This can be done with safety training sessions during industry conferences and trade shows and by including such information in the owner's manual for the equipment provided by the manufacturer.

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