Quantification of Ergonomic Risk Factors in Southeastern Logging Operations

by

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Abstract

This dissertation aimed to expose and partially fill a gap in logging research regarding ergonomic risk factors associated with operating logging machines in the fully mechanized logging operations typical in the southeastern United States. A review of the existing literature showed that this research was a novel contribution to logging and occupational safety and health research.

A survey was developed to quantify self-reported exposure to ergonomic risk factors encountered in the cab of a logging machine and incidence of neck and back pain and prevalence of musculoskeletal disorder (MSD) diagnosis. Of the 157 machine operators who responded, 10.5% (16) reported a MSD diagnosis, 74.3% (113) reported at least mild back pain over the past year, and 71.7% (109) reported at least mild neck pain over the past year.

These results led to the development of a study to examine the variability of ergonomic risk factors among logging machines and machine operators. The exposures were most pronounced with skidder operators, but further investigation into this proved difficult with the low n (11). Time was the only independent variable with significant correlation to whole body vibration (WBV) exposure.

Limiting time spent operating the skidder would lower lifetime exposure of skidder operators to WBV and likely reduce pain and incidence of MSDs in the logging workforce. However, most crews operate with a single operator per machine and rotation could be problematic due to production demands and the exposure of more employees to higher WBV levels, albeit for less time over a lifetime. An intervention at the design level would be far more effective.

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Chapter 1:

Introduction and Literature Review

Introduction

The forest products industry is a multi-billion dollar industry in the United States. Structures and products made from wood and wood byproducts are so abundant that the process by which all of that wood is collected is often overlooked. Homes, furniture, paper products, and even medicinal extracts are derived from wood. According to the American Forest and Paper Association an average American uses wood and paper products equivalent to 748 pounds in a single year (AFPA 2015). Close to one third of the United States is forested. In the United States, private, working forests support millions of jobs and contribute billions to the gross domestic product.

There is, however, a steep price being paid in the forest. The logging industry is one of the most hazardous in the United States, at times averaging nearly twice the number of injuries per 100,000 workers than that for the total private sector. Over a ten-year period (1980-89), an estimated 1,492 deaths out of 6,400 occurred in the logging industry (CDC 1995). Logging was the second most dangerous occupation from 1992-96, and in 1997 became the most dangerous occupation according to the Bureau of Labor Statistics' (BLS) Census of Fatal Occupational Injuries (BLS 1997). The majority, over 60 percent, of these injuries were the result of loggers being struck by an object, typically a log or tree. Trees can have all sorts of issues that compromise their integrity; heart rot, cracks or breaks, even broken branches caught up in nearby trees, where they can loosen at any moment. These all create the hazard of something falling onto a logger on the ground. Broken branches that get caught in the canopies of the trees are so common that they have been given the nickname, widow makers.

Since 1997, the logging industry has remained in the top five most dangerous occupations in the United States. Fatalities still plague logging, the injury rate of loggers in 2011 was 104.0, nearly 30 times higher than the national fatal occupational injury rate of 3.5 per 100,000 full-time equivalent workers in the same year (Pegula and Janocha 2013). In 2014, fatal injuries rose to 92, the highest total since 2008. Because of these and other startling statistics, much of the focus of logging injury surveillance has been on acute traumatic injuries.

Emerging Issue

The Occupational Safety and Health Administration (OSHA) responded to some of the concerns about fatalities and traumatic injuries in forestry in 1995 with the implementation of a standard detailing regulations for logging operations (29 CFR 1910.266). Suggestions for the reduction of these injuries included the facilitation of the mechanization of logging operations (OSHA 1995). Increased mechanization took loggers off of the ground and into the cab of a machine, protecting them from the logs, trees, and widow makers.

Manufacturers have done a lot with the design of the cab to ensure a worker is safe inside. Increased mechanization has taken place over the past 30 years in the United States, especially in the southeastern United States, and with this increase, the injury rate has reduced dramatically. Since 1996, the annual injury rate as determined by Roberts and Shaffer in 2005, decreased by more than half by 2003 going from 10.0 in the former to 4.9 in the latter.

The injury rate continues to remain at historic lows. However, even with increased focus on the importance of workplace safety, safety training, and improvements in the design of workstations, machines, and equipment across all industries, logging continues to remain one of the most dangerous occupations in the United States. All of the energy, time, and resources aimed at the reduction of traumatic injuries in the logging industry are well spent. However, it is likely as the logging industry has become highly mechanized, health risks have changed significantly and new issues may also need to be addressed.

In 2008, The National Occupational Research Agenda (NORA) released the first formal research and public health practice agenda for occupational safety and health for the industries of agriculture, forestry and fishing in the United States, the National Agriculture, Forestry, and Fishing Agenda. NORA stated that because the type of work in the forest is so strenuous and often requires long hours, forestry workers face health risks, and that these health risks have likely changed with mechanization. One key area for action reported by NORA was a focus on interventions to minimize work-related MSDs. Goals identified by the agenda included improving surveillance within forestry on adverse health outcomes and the health and well being of forestry workers by reducing the occupational causes or contributing factors for chronic disease, and reducing the incidence of MSDs.

Logging operations are very different across the United States. On the west coast, cable logging is more common. Cable logging involves the use of a yarder or grapple yarder, which uses a system of cables to pull or fly logs from the stump to the landing. Logging firms in the southeast almost exclusively operate highly mechanized, full tree harvesting systems. These are predominately small businesses with less than 10 employees (Smidt 2011). Operations typically involve the use of feller bunchers to fell trees, grapple skidders to transport the felled trees from the spot of felling to a landing, and loaders to delimb and cut the trees to length. The loader operator is also responsible for loading the trees onto log trucks that then transport the logs to a wood processing facility. Over the past 30 years, operations have shifted away from clear cutting toward thinning.

Musculoskeletal Disorders

There is evidence to suggest that these modern, highly mechanized logging operations being utilized in the southeastern United States are likely exposing employees to risk factors for the development of chronic injuries such as MSDs. MSDs are one of the most common injuries in private industry in the United States, with work related MSDs making up 33% of all reported occupational injuries (BLS 2013). Recent data available from the BLS shows that the sector that incudes logging had MSD rates at 41.5 per 10,000 full time workers in 2013, second only to the construction industry at 41.9 (BLS 2013).

MSDs as the result of work are not a new concern, it is likely that work related MSDs have been around since the beginning of work. Ramazzini first identified cumulative trauma disorders, which include MSDs in 1700 as workers in similar occupations developed similar injuries (Franco 2001). He observed that a variety of diseases common in workers appeared to be caused by irregular motions and prolonged postures (Ramazzini 1760). Sven Axelsson in 1995 identified the new risks for MSDs emerging with mechanization in logging in Sweden (Axelsson 1995). He described what the European logging workforce was experiencing as "the ergonomic hangover of mechanization". Ergonomics has been a buzzword for more than twenty years in the United States, but it has still not been applied very well in the forest. Axelsson found in his review that musculoskeletal complaints, particularly of the low back, were common among machine operators.

Presently, this issue is only beginning to be looked at in the United States. The delay in ergonomic concerns within logging machines being addressed is almost certainly due to a focus in design on the function and productivity of the machines as opposed to the operator. Other factors playing into the delay are the amount and severity of fatalities and traumatic injuries as well as the belief held by many loggers that logging is hard work, and with hard work comes pain. Pain, however, can be one of the first signs of an MSD.

Americans spend billions on doctor's visits, surgeries, and medications looking for relief from chronic back and neck pain through surgery, unfortunately, the magnitude of that expense does not appear to reduce the amount of sufferers. Estimates for the incidence of neck pain in the general population are between 10.4 and 21.3 percent (Hoy et al. 2010). In several surveys in Sweden, 40-60 percent of logging machine operators (LMOs) reported experiencing pain or ache in the neck or shoulders over the previous year. Swedish loggers have highly mechanized logging also have very high rates of MSDs (Lewark 2005, Synwoldt and Gellerstedt 2003). The annual prevalence of low back pain in the United States has been estimated at more than one-quarter of the population (Deyo 2006). Other reports vary greatly on the incidence of back pain, with ranges from 10-80 percent of the general population (Mortimer et al., 2006, Rubin 2007).

The costs associated with work-related low back pain are high. It has been reported that on average low back pain costs $8,000 per claim, and accounts for one third of workers' compensation costs (Webster 1994). The annual national bill for the care of low back problems has been estimated to be $100 billion. (Katz 2006). Even though low back pain, or any type of chronic pain or injury, does not result in death, it can cause long-term disability, reducing earning potential and quality of life. Pain can keep you from doing the things you love.

The costs of an MSD are not well defined for the logging industry. Logging is already an expensive industry to get in to. To operate a crew in the southeast, an owner would need at least one of each of the machines mentioned above, a feller buncher, skidder, and loader, to run an operation. These machines can easily exceed a million dollars in value. These operations may also need a person to supervise and find and plan the next job, although that person can also operate. Several truck drivers and trucks are also needed to haul wood to the mill. With all of this capital already invested, one single workplace injury could have a significant impact on one of these small crews.

The costs of a workplace injury include direct and indirect costs. Workers' compensation payments and medical expenses are some of the direct costs. The total cost of an injury is likely two times what workers' compensation covers. Workers' compensation rates for loggers vary by state. The most common logging codes have rates ranging from 20 to 50 percent of payroll (Smidt 2011). These rates are relatively high, because the fatality and injury rates for the logging industry are higher than the average rate for private industry. The indirect costs are not as easily quantified, and include lost productivity and the training of a replacement employee.

Literature Review

The majority of logging employees in the United States are machine operators, and while seated in the cab of a machine, they are being exposed to risk factors including physical aspects such as a static seated posture, awkward bent and twisted postures, whole-body vibration (WBV), and repetitive hand and feet movements, as well as other factors including long hours, high productivity demands and job stress (Axelsson 1995, Bentley et al. 2005). Each of these factors has been associated with an increased risk of MSDs with prolonged exposure. Gellerstedt et al. put it well when they stated that work in the cab of a machine is unnatural; the human body is not made for sitting static in a vibrating cab and performing repetitive movements of the head, neck, arms, and feet (Gellerstedt et al. 1999).

As a machine operator, loggers are in a static seated posture in the cabs of the machines. Sitting increases lower back flexion, increasing disc compression, which can result in pain or a MSD, particularly of the low back. This can be aggravated by WBV. Repeated and/or prolonged exposure to WBV can increase the likelihood of structural failure and has been shown to fatigue back muscles thereby increasing the risk of pain or MSD (Calvo 2009, Tiemessen et al. 2008, NIOSH 1997, Bovenzi and Betta 1994, Bovenzi 1996, Bovenzi and Hulshof 1999, Dupuis and Zerlett 1987, Lyons 2001, Seidel 1993).

Various aspects of mechanized logging require the operator to maintain an awkward bent or twisted posture while operating for the duration of a work shift as they twist to look forward and back repeatedly during operation. Skidder operation, in particular, requires the operator to maintain a twisted posture while skidding back and forth from the landing to each load for the duration of a work shift. Twisting either the neck or trunk while seated increases pressure in the discs of the spine, and may increase the risk for the development of a MSD. The sustained twisting of the trunk combined with extended time in a seated position causes lasting muscular activity which may lead to an overload within muscular structures, indicating a higher risk for the development of back pain (Shan et al. 2013). This may be aggravated further by WBV as the muscles of the neck and back may be fatigued from the vibration making them more susceptible to the possible negative outcomes from the pressure in the discs caused by the twisting (Lyons 2001, Shan et al. 2013, Hoy et al. 2004, Jack and Oliver 2008, Palmer and Smedley 2007). This has been found to be particularly harmful to the low back (Hoy et al. 2004; Jack and Oliver, 2008).

Extended exposure to WBV alone has been shown to have a positive correlation to back pain and disorders (Calvo 2009, Tiemessen et al. 2008, Bovenzi and Betta 1994, Bovenzi 1996, NIOSH 1997, Bovenzi and Hulshof 1999). WBV exposure has also been found to contribute to fatigue, central nervous system disturbances, vision problems, and adverse effects to the digestive and genital/urinary systems (Bovenzi and Hulshof 1999, Neitzel and Yost 2002, Seidel 1993).

Operation of controls requires repetitive movements of both the hands and feet. With these movements, the body may not be able to keep up with the processes to prevent injury such as blood flow to remove by products produced by muscle contraction or the lubrication mechanism that operates within tendons. Repetitive movements can also cause fibers within tendons to tear or swell around nerves. These are all possible causes of pain or MSD. There is also evidence that repetitive arm movements when performed in combination with vibration are a significant risk factor for the development of MSDs (Calvo 2009, Norander et al. 2009, CCOHS 2015, Latko et al. 1999, Axelsson, 1995; NIOSH, 1997; Jack and Oliver, 2008; Nordander et al., 2009).

Loggers work outside and are therefore exposed to occasional temperature extremes. Hot and humid environments typical of the southeastern United States cause workers to fatigue more quickly, which increases susceptibility to injury (Lilley et al. 2002, CCOHS 2005). In cold temperatures the muscles and joints lose flexibility and the risk of injury is also increased (CCOHS 2005).

There are also personal risk factors affecting the logging population's susceptibility to MSDs. As with almost every industry in the United States the average age of loggers is increasing. Currently the number of older workers is high since many workers that left the industry in the 2000s were not replaced due the reduction in the logging workforce. With aging comes a gradual decline in muscle mass, degradation in elasticity of connective tissues, slower healing, and accumulated soft tissue damage. These may all contribute to an increased risk of a MSD (Holmstrom and Engholm 2003, Freemont and Hoyland 2007). Body mass index (BMI) is also a contributing factor to the development of MSDs as excess body weight increases the burden on the musculoskeletal system and lowered ability to recover from injuries (Wearing et al. 2006, Viester et al. 2013).

Noise has been reported to exceed recommended exposure limits within the cabs of logging machines. Noise levels greater that 85 dBA can cause noise induced hearing loss (NIHL), a permanent disability, however, noise levels greater than just 60 dBA could negatively impact operator concentration, mood, heart rate, and blood pressure. Some other research suggests that WBV when combined with noise exposure has a synergistic effect on NIHL. Considering around ten percent of noise is conducted by our bones, it may follow that vibration having a certain resonance in our bodies might be impacting how noise affects the bones of the inner ear (Lilley et al. 2001, Axelsson 1995, Jack and Oliver 2008, Seidel 1993, Boettcher et al. 1987, Dauman 2013).

Logging can also be mentally exhausting due to the task monotony, and this combined with a lack of control over the work and pace has been significantly associated with an increased prevalence of low back disorders and neck/shoulder disorders (Hagen et al. 1998). LMOs are also paid less than comparable jobs, and experience a low social standing, and this can impact overall well-being and in turn can impact the ability of a body to withstand injury (CCOHS 2015).

In spite of all these indicators that the hazard is serious, the prevalence of MSDs in loggers specifically, however, is nearly absent from logging injury and illness data. MSDs showed up for the first time in the OSHA recordable injuries for 2008-2009. MSDs accounted for only 4% of reportable cases for equipment operators in 2011 (BLS 2011). In general, underreporting of MSDs within logging is thought to be significant (Morse et al. 2005). The small firms that operate in the southeast United States seldom report and employers are not typically compliant with OSHA or state workers' compensation laws (Smidt 2011). MSDs are also not associated with an acute event, so they are less likely to be reported (Ashby et al. 2001). MDSs, when reported, may also be classified as "other" in workers' compensation claims due to a lack of knowledge/training on the nature of MSDs.

Logging employers have consistently rated finding labor as a top concern (Baker and Green 2008). Working conditions, low pay, and low social status combine to increase the difficulty in labor recruitment (Egan and Taggart 2004). Retention of current workers and improvement in working conditions for future workers is a key component of firm survival and industry health. In addition to the incidence of pain among workers who stay in the industry, there is likely a separation of workers for whom the discomfort is not acceptable. Considerable anecdotal evidence points to job changes or retirement as pain becomes too burdensome for the worker. Since the cost and impact of musculoskeletal injuries is obscure to the forest products industry, decision making with regard to work pace, work hours, machine selection and harvest system is often made with little consideration of risk for the development of MSDs. There is also little incentive to improve what appears to be a good safety record within the crew.

Proposed Research

As previously noted, the United States has had very little research on ergonomics in the context of forestry, and there is no reference to ergonomic considerations in the OSHA logging standard, 29 CFR 1910.266. OSHA also has no ergonomic standard governing these considerations anywhere in its other standards, and the only way ergonomic risks are currently cited is through the general duty clause which states that employers are required to provide their employees with a place of employment that "is free from recognizable hazards that are causing or are likely to cause death or serious harm to employees" (OSHA Section 5(a)(1) 1970). So even if OSHA were providing oversight, which is unlikely due to the small size of the logging firms, the isolation of the worksites, and the amount of inspectors available, they would not have an ergonomic standard to cite.

The National Institute for Occupational Safety and Health (NIOSH) has put out a call for increased research in forestry, and with the shift to a majority of loggers operating machinery in the heavily mechanized world of modern logging, exposure to risk factors for the development of MSDs is likely increasing in this population, creating a need for surveillance data to quantify this problem. Lewark completed a review of the ergonomic situation in mechanized forest operations and believed that the introduction of machines had changed the daily work situation for loggers and that this may be having unforeseen adverse effects. He found MSDs, psychosomatic complaints, and hearing loss were the most common complaints among machine operators (Lewark 2005). It was clear in his review that most of the resources were from European countries.

European countries, unlike the United States, have investigated ergonomic concern in relation to logging operations and have developed an impressive body of work related to the prevention of ergonomic injuries in forestry occupations. Axelsson saw the need for an ergonomic intervention in his review of occupational safety and health in forestry. He wrote that MSDs were emerging with mechanization, and that an ergonomic intervention was needed (Axelsson 1995). The European Union Directive (EUD) is ahead of OSHA with an exposure limit value for WBV set at 1.15 m/s^2. This value is also more restrictive than the International Organization for Standardization (ISO) (EUD 2002, ISO 1997).

Based on the lack of academic research studies pertaining to ergonomic risk factors and the impacts of MSDs in logging operations in the southeastern United States, it is appropriate that surveillance be performed to better define these burdens in an effort to more strategically direct future efforts in research, design, and training.

The goals of this research are to:

1. perform surveillance of LMOs in the southeastern United States.
2. better establish the incidence of neck and back pain and the prevalence of MSDs.
3. quantify exposure to ergonomic risk factors.

Survey Development

Research began with the development and use of a survey instrument to determine the incidence of risk factors associated with the development MSDs in loggers across the United States. This survey was meant to better establish the self-reported incidence of neck and back pain and exposure to risk factors associated with the development of MSDs in representative samples of loggers from across the southeast. Survey research is widely used to obtain information about a workforce and is helpful in indicating trends in attitude and behaviors of a particular population.

Validation of surveys establishing the incidence of MSDs has been performed, and it has found that self-reporting can lead to problems of accuracy and credibility with respondents overestimating their own pain and time spent in a particular position (Viikari-Juntura et al. 1996). This will have to be considered in the use of the data. Several questions from the survey evaluated for validity are very similar to questions that will need to be asked on this survey. Other questions were developed based on recommendations and input from experts consulted for this study, from information provided in the literature, and from the European ergonomic checklists available online (COMFOR 2011, ENFE 2011).

The survey started as two pages long with 19 questions taking respondents less than 20 minutes to complete. The survey was composed of two open-ended questions, two questions requesting respondents select from a list of logging machines, nine multiple choice and six yes/no questions. Most of these questions are aimed at establishing demographics, years in logging, machine(s) operated, time spent exposed to vibration, awkward positions and repetitive movements of the hands and feet, and pain experienced over the last year.

Most of the multiple-choice questions were scales of time. The options were: None, Less than ½ hour, ½ hour - 1 hour, over 1 hour - 2 hours, over 2 hours - 4 hours or more than 4 hours. Selecting None would indicating no exposure/time, Less than ½ an hour a day would indicate mild exposure to the risk factors, and greater than 4 hours a day can indicate full-time status as a machine operator or intense exposure. The other splits in time are not as well defined, but other surveys measuring exposures to risk factors for the development of MSDs used similar scales (Viikari-Juntura et al. 1996). The responses were analyzed with descriptive statistics to summarize facts about the sample and measures and non-parametric statistics to establish any correlations between exposures and pain.

All of the questions were direct response, and because of this, a factor analysis to establish reliability would not be appropriate. Also because of the type of questions, it will be expected that responses to items will be not be consistent. Professors from Auburn University in forestry, occupational safety ergonomics, and education evaluated face validity. A pilot study was performed to check the feasibility of this research and to identify any problems with the survey instrument. A local logging crew with eight machine operators was found to participate in the pilot study. The following summarizes the results of the pilot study and their implications for the research study.

All eight participants returned a completed survey. All were male. The average age of the respondents was 44, ranging from 28 to 52. Average years spent operating a logging machine was seven, with a range from two to 14. Of the eight respondents, half were skidder operators, two operated feller bunchers, and one was a loader operator. One survey respondent selected other, indicating he operated a machine that was not listed, but did not specify machine type in the space provided. Several (three) were exposed to more than four hours of vibration per workday, and only one was exposed to less than a half hour of vibration. All indicated that they had experienced some pain over the past year related to logging.

There were no problems identified with the procedure during the pilot study, but there were some concerns identified about the yes/no questions. Based on the results of this pilot, the survey was adjusted to be 10 sections with a total of 34 items, taking no more than 30 minutes to complete. The scale for pain was adjusted to elicit responses of none, mild, moderate, or severe as opposed to yes or no so that a more meaningful analysis could be performed. Other questions appeared to elicit the appropriate honest response, and once non-parametric tests are performed on a larger sample, some meaningful conclusions about the incidence of risk factors for the development of MSDs in loggers may be able to be made.

Dissertation Development

This dissertation was developed in a manuscript style with the intention of the central chapters being published in peer-reviewed journals. The first research study titled, "What is the Self-Reported Incidence of Risk Factors with MSDs in Loggers across the United States?" involved the distribution of the survey on a larger scale. This research is discussed more thoroughly in Chapter 2. Chapter 2 titled, "Incidence of MSDs and neck and back pain among logging machine operators in the Southern United States" was published in the Journal of Agricultural Safety and Health in 2014 (Lynch 2014).

The second research study was titled, "Survey of Ergonomic Risk Factors among Logging Machines" and involved two parts. The first part is discussed in Chapter 3. Chapter 3, titled, "Noise and vibration exposure in full-tree logging systems in the southeastern United States" was submitted for publication in the Journal of International Forestry Engineering in 2017.

Chapter 4 covers the second part of the research. It is titled, "Impact of speed and terrain on vibration exposure in skidder operators in the southeastern United States". It will be submitted to a journal before the end of 2017.

Appendix A shows a conceptual model of the research study. Approval emails from the Auburn University Internal Review Board for the studies are included in Appendix B. The survey information letter is contained in Appendix C, and the second study informed consent is in Appendix D. Subjects in the second study were also videotaped, a copy of the video release form is in Appendix E. The final survey used for both the survey and the second study is in Appendix F.

Chapter 2:

Incidence of MSDs and Neck and Back Pain Among Logging Machine Operators in the Southern United States

Abstract

There are limited data about the incidence and prevalence of musculoskeletal disorders (MSDs) among loggers in the southern United States despite the risk factors associated with these occupations. Risk factors are both personal (age, body mass index, etc.) and job-related (awkward postures, repetitive hand and foot movements, vibration, etc.). A survey was conducted to estimate the incidence of self-reported pain and diagnosed MSDs and to study the relationship with known risk factors. Respondents were loggers attending training and continuing education classes. Respondents were asked to identify personal attributes, machine use, awkward postures, repetitive movements, and recent incidence of pain and medical diagnoses. All were male with an average age of 44 (range of 19-67) and an average body mass index of 31.3. Most were machine operators (97%) who have worked in the logging industry for an average of 22.9 years. Most machines identified were manufactured within the past ten years (average machine age 6.7 years). For machine operators 10.5% (16) reported a MSD diagnosis, 74.3% (113) reported at least mild back pain, and 71.7% (109) reported at least mild neck pain over the past year. Further analysis attempted to identify an association between personal attributes, machine use, posture and pain. Risk factors related to machine use may be biased since most survey respondents had considerable choice or control in working conditions, as they were firm owners and/or supervisors.

Keywords: Logging, Musculoskeletal disorders, Ergonomics

Introduction

Logging is one of the most hazardous occupations in the United States, at times averaging nearly twice the number of injuries per 100,000 workers than the total private sector (CDC, 1995, BLS, 2010). The surveillance data available accounts for acute traumatic injuries, but in 2011, musculoskeletal disorders (MSDs) were less than 5% of the total reported injuries in logging (BLS, 2012). However, it is likely that MSDs are underreported (Ashby et al., 2001, Azaroff et al., 2002, Morse et al., 2005). Also loggers may expect that the pain they experience is not significant and should not be reported, or part of growing older. Job turnover may also contribute to poor understanding of MSDs in logging since workers may simply leave if the work is uncomfortable or painful (Hagen et al., 1998).

Several studies in North America have measured vibration from typical forest machines, mainly skidders (Cation et al., 2008; Golsse, 1990; Golsse, 1992; Hope and Golsse, 1987; Neitzel and Yost, 2002; Wegscheid, 1994), and there is a general sense that machines have improved over time both in terms of operator comfort and maintenance characteristics (Axelsson 1995). Although reportable and lost time injury rates have declined over time, there is little specific information to attribute a proportion of those improvements to ergonomic risk control. While effort spent on reducing traumatic injury is well spent, MSDs account for a over one-third of work-related injury among all workers in the United States (BLS 2012) and can result in disability, decreased productivity, and time away from work. MSDs can also increase production costs as the result of lost production time and money spent training and compensating replacement workers (Jack and Oliver, 2008).

In logging in the United States, more than 60% of employees are machine operators (BLS, 2010). In the southern United States most of the employees operate equipment as the major function of the job (Roberts et al., 2005). Workers operating forest machines are exposed to risk factors for the development of MSDs, which include whole body vibration (WBV), static and awkward postures, and repetitive hand and feet movements while working (Gellerstedt, 1998; Jack and Oliver 2008). WBV has been shown to have a dose-response relationship to low back pain and disorders in forestry machine operators, tractor drivers and truck drivers (Bovenzi and Betta, 1994; NIOSH, 1997; Tiemessen et al., 2008).

As a machine operator, loggers are also in static and awkward postures in the cabs of the machines. There is conflicting evidence about the impact of static and awkward postures on the development of MSDs, but recent evidence suggests some awkward postures, particularly twisting of the trunk, may increase the risk of back problems (NIOSH, 1997; Shan et al., 2013), and that the combination of awkward postures and WBV may increase risk of injury (Jack and Oliver, 2008). Skidder operation requires the operator to maintain a twisted posture while operating for the duration of a work shift. Also, various aspects of mechanized felling and skidding require an operator to twist to look forward and back repeatedly during operation. Operation of controls requires repetitive movements of both the hands and feet and can lead to strain injuries (Axelsson, 1995; NIOSH, 1997; Jack and Oliver, 2008; Nordander et al., 2009).

Loggers are also exposed to temperature extremes, high productivity demands, and job stress (Axelsson, 1995; Bentley et al., 2005). Each of these environmental and psychosocial conditions has been associated with an increased risk of MSDs with prolonged exposure (Lilley et al., 2002; Axelsson, 1995). Hot and humid environments typical of the southeastern United States cause workers to fatigue more quickly which increases susceptibility to injury (Lilley et al., 2002; CCOHS, 2005). In cold temperatures the muscles and joints lose flexibility and the risk of injury is also increased (CCOHS, 2005).

There are also personal risk factors affecting the logging population's susceptibility to MSDs. As with almost every industry in the United States the average age of loggers is increasing. Currently the number of older workers is high since many workers that left the industry in the 2000's were not replaced due the reduction in the logging workforce. With aging, the risk for the development of an MSD increases (Holmstrom and Engholm, 2003). Body mass index (BMI) is also a contributing factor to the development of MSDs as excess body weight increases the burden on the musculoskeletal system (Wearing et al., 2006).

Overall, workers in logging could be exposed to several risk factors for the development of MSDs. Given that underreporting of MSDs and worker turnover could be significant, additional data is needed to estimate MSD incidence. As pain is one of the first indicators of MSDs, high rates of self-reported pain could be indicative of a future injury. The objectives of this research were to explore incidence rates of self-reported pain and diagnosed MSDs among logging workers in the southeast. These rates were then analyzed to determine if the incidence was related to working conditions.

Materials and Methods

A survey was developed to assess worker demographics, frequency of machine use, machine preference, machine age, time spent in particular postures, and neck and back pain experienced over the past year. The survey included 10 sections with a total of 34 items, taking no more than 30 minutes to complete. The surveys were distributed at nine logging organization meetings and continuing education events across four southern states (Alabama, Georgia, Mississippi and Tennessee). Respondents were most likely owners and/or supervisors who attend to maintain certification. Surveys were placed at each available seat and were completed after a short message about the meaning and relevance of the survey questions. Surveys were returned anonymously into a designated box at the end of the meetings.

Most items in the survey were based on information collected from ergonomic checklists and some questions were adapted from items validated by Viikari-Juntura et al. (1996). Other items were developed to establish incidence of self-reported pain, diagnosed MSDs, machine use, and machine preference.

The data were analyzed using SAS version 9.2. Crosstabs were used to identify associations between personal attributes, machine use, and/or posture and pain along with machine preference based on pain. Although pain was originally split into four categories (no pain, mild, moderate and severe), the categories were reduced to pain and no pain. The respondents were also categorized as part-time (identifying as having spent less than 4 hours per day either in the cab of a machine or in various postures) or full-time (identifying as having spent more than 4 hours per day either in the cab of a machine or in various postures) LMOs. The data was then fit to a logistic regression model in order to test for significant effects of the various postures on pain.

Results

Response rate is not known since some attendees were not logging firm workers or employers. Total attendance at the programs was about 250. Loggers who responded to the survey (N = 157) represented logging firms in four southern states (Alabama, Georgia, Mississippi and Tennessee). All respondents were male with an average age of 44 (range of 18-67), only slightly above the average age for all private industry (42). The average body mass index of this sample was 31.3, which is in the obese category and well above the average BMI for an average adult male in the United States (26.6) (CDC, 2003). The average years working in the logging industry was 22.9 and 152 out of 157 indicated they operate logging machines at least once a month. Most machines identified were manufactured within the past ten years (average machine age 6.7 years). For machine operators 10.5 percent (16) reported a diagnosis of an MSD, 74.3 percent (113) reported at least mild back pain, and 71.7 percent (109) reported at least mild neck pain over the past year.

Exposure measured in various ways seems to have some relationship to incidence of pain. Full-time machine operators had higher incidence of both neck and back pain than part-time operators (Table 1). Respondents who have been in the industry longer also seem to report greater incidence of neck and back pain (Table 2). Age relationships to pain are less distinct except for operators in the 61-70 age class (Table 3).

Table 1

Percentage of Part and Full-time Loggers Experiencing Neck and Back Pain Based on Risk Factor Exposure

	Neck Pain			**Back Pain**		
Risk Factor	**Part-time**	**Full-time**	**p-value**	**Part-time**	**Full-time**	**p-value**
In Cab (vibration)	26 (70%)	82 (75%)	0.55	26 (72%)	87 (78%)	0.45
Neck Twisted	74 (69%)	34 (87%)	0.03	80 (74%)	33 (85%)	0.18
Trunk Twisted	78 (68%)	30 (97%)	<0.01	85 (73%)	28 (90%)	0.05
Repetitive Hands	29 (73%)	79 (75%)	0.80	27 (69%)	86 (80%)	0.19
Repetitive Feet	29 (71%)	79 (75%)	0.58	27 (68%)	86 (80%)	0.10

Table 2

Neck and Back Pain by Years Spent in Logging Industry and 90% Confidence Interval (CI)

Years Logging	**Neck Pain (90% CI)**	**Back Pain (90% CI)**
1 - 10	15 58% (46-70%)	15 58% (46-70%)
11 - 20	30 70% (61-79%)	30 70% (61-79%)
21 +	57 81% (75-87%)	61 87% (82-92%)

Table 3

Logger Pain by Age

Age	**Neck Pain (90% CI)**	**Back Pain (90% CI)**
19-30	14 58% (45-71%)	16 67% (55-79%)
31-40	26 81% (72-90%)	23 72% (62-82%)
41-50	32 73% (64-82%)	32 74% (65-83%)
51-60	27 75% (66-84%)	31 84% (76-92%)
61-70	9 90% (78-100%)	11 100% (N/A)

Respondents were asked about machine preference based on pain (preferred, neutral, not preferred). There were only small differences among machines with the stationary machine (loader) being the most preferred (Table 4). Machine assignment or selection seems to be strongly related to age (Table 5). Machine bias with experience could be related to a combination of seniority and experience in addition to preference regarding discomfort. Typically loaders and feller bunchers are operated by workers with more experience or more responsibility (foreman or owners). Skidders are often the machines assigned to new operators. Whether operators move away from the skidder or towards other machines that require more experience is confounded in this sample. About half of survey respondents indicated that they knew someone who changed jobs within logging (51%) or someone who left logging (54%) because of pain or discomfort during work.

Table 4

Machine Preference

Machine	Prefer/Neutral	Do Not Prefer	Response Rate	Number
Feller Buncher	86%	14%	77%	119
Wheeled Skidder	82%	18%	73%	113
Dozer	92%	8%	66%	103
Loader	94%	6%	75%	117
Semi-Tractor	77%	23%	52%	81

Table 5

Machine Operation Based on Years in Logging Using Loggers that Only Have One Daily Machine Listed

	Years Logging		
Machine	1-10	11-20	21+
Feller Buncher	4 (31%)	9 (38%)	14 (52%)
Wheeled Skidder	4 (31%)	1 (4%)	1 (4%)
Dozer	0 (0%)	1 (4%)	2 (7%)
Loader	3 (23%)	12 (50%)	9 (33%)
Semi-Tractor	2 (15%)	1 (4%)	1 (4%)
Total	13	24	27

The risk factors involved in machine operation and their connection to pain was further investigated with a logistic regression using PROC LOGISTIC. The models used were of the form:

$$logit(\pi) = \beta_0 + \beta_1 * (RF) \quad (1)$$

Where logit (π) was the log odds of a logger experiencing the type of pain of interest for the specific model (either back or neck pain), RF was the risk factor of interest for the specific model (i.e. in cab, neck twisted, etc.), and β_0 and β_1 are the model parameters. RF took a value of one if the logger was exposed to the risk factor for more than 4 hours per day (full-time) and 0 otherwise (part-time).

The odds ratios and 95% confidence intervals (CI, in parentheses) for time spent in cab and in various postures are shown in Table 6.

Table 6

Odds Ratios and Confidence Intervals for Pain Based on Posture for Full-time Employees as Compared to Part-time Employees

Risk Factor/Posture	**Neck Pain**	**Back Pain**
In Cab	1.285 (0.561, 2.942)	1.394 (0.591, 3.288)
Neck Twist	3.032 (1.089,8.447)*	1.925 (0.729, 5.081)
Trunk Twist	14.231 (1.868, 108.399)**	3.403 (0.966, 11.991)
Repetitive Hands	1.110 (0.489, 2.520)	1.738 (0.761, 3.968)
Repetitive Feet	1.257 (0.562, 2.814)	1.972 (0.872, 4.458)

*indicates a p-value of 0.05 or less
**indicates a p-value of 0.01 or less

The odds ratio for the effect of neck twisting on neck pain was found to be significant. The odds ratio indicated that a logger who had his neck twisted for more than four hours a day is about 3 times more likely to report neck pain than a logger who had his neck twisted 4 hours or less. The relationship between neck pain and trunk twist is also significant, but the odds ratio is very high with a very wide confidence interval (CI). While the odds ratio estimates for the other risk factors for neck pain (in cab, repetitive hands, repetitive feet) and all risk factors for back pain were greater than 1, they were not significant.

These results most likely arise from the fact that very few people both reported being in the trunk twist position for less than 4 hours per day and reported experiencing pain (3 and 1 loggers for back and neck pain respectively). A sensitivity analysis was run by re-categorizing the trunk twist so that the part-time and full-time were redefined to 2 hours and less and more than 2 hours respectively. The significant result for neck pain was maintained although the odds ratio dropped. The back pain result became significant with the new categorization.

To investigate the impact of age on pain and the possible relationship to the amount of time in certain positions a categorical age variable was added into the model to see if it would change the effect. The updated model is of the form:

$$logit(\pi) = \beta_0 + \beta_1*(\text{RF}) + \beta_2*(age\text{19-30}) + \beta_3*(age\text{31-40}) + \beta_4*(age\text{41-50}) \qquad (2)$$

Where logit (π), RF, and the betas are the same as equation 1. Age variables are values of 1 for operators in each age group. Changes in model results were minor after including age. Including age in the model raised the odds ratio for neck twisting to 3.288 (1.146, 9.439). No other significant relationships between postures and pain were found.

Discussion

Statistical analysis was somewhat limited by sample size given number of categories for each question. There is a very high prevalence of both neck and back pain reported in this sample. Estimates for the incidence and prevalence of neck pain in the general population are between 10.4 and 21.3 percent (Hoy et al., 2010) compared to 70 percent in this sample. In several surveys in Sweden, 40-60 percent of LMOs reported experiencing pain or ache in the neck or shoulders over the previous year. Swedish loggers, who have highly mechanized logging processes much like the southern United States, also have very high rates of neck pain and MSDs (Lewark 2005, Synwoldt and Gellerstedt, 2003).

Age would be expected to contribute to the experience of pain in this sample, but actually the logistic regression model shows that at least with neck twist when age is considered the odds ratio increases. It is likely that loggers are less likely to operate certain machines as they age or as they gain seniority on the crew. They may self-select out of operating the more problematic machines that place them in the awkward postures.

Reports vary greatly on the prevalence and incidence of back pain, with ranges from 10-80 percent of the general population (Mortimer et al., 2006). Even with such varied reports, this sample is clearly on the high end of those estimates. The rate could be indicative of problems with the control of ergonomic hazards, ergonomic design of logging equipment and ergonomic considerations with regard to work hours and job tasks. Pain is one of the first indications of an MSD, so the high incidence of pain in this sample indicates high risk for the future development of MSDs. Intervention is needed for full-time LMOs, and focus should be at the machine design level. However, solutions should be implemented in the meantime including logger training in ergonomics and administrative controls to reduce exposures. Reports vary about the effectiveness of safety training and the prevention of injuries (Bell and Grushecky 2006, Robson et al. 2012, Kogi 2012), but training has been shown to raise awareness of the risks (Helmkamp et al. 2004), and operators may be able to recognize certain behaviors that are causing them pain and self-correct. However, increased safety knowledge and awareness of risks does not necessarily reduce injury rates (Daltroy et al. 1997).

There is an increase in pain in this sample as loggers stay in the industry, but age is also a factor, and BMI may also be playing a role. This may explain the reports of loss of productivity as loggers age (Synwoldt and Gellerstedt, 2003), as they are dealing with more pain, which could be chronic.

The physical work environment in logging is clearly taxing, and work needs to be done in this area. The time spent with the neck and trunk twisted is leading to an increase in the reporting of pain in this sample. Although not statistically significant the other odds ratios are all above one indicating a marked increase in pain with prolonged exposure to the other risk factors. Owners and operators should be able to describe and recognize better ergonomic designs in machines, so they can make machine selection decisions and communicate needs to dealers and manufacturers.

This investigation of pain incidence and machine preference may help determine where interventions may be most beneficial, although a limitation of this research is that risk factors related to machine use may be biased because most survey respondents had considerable choice or control in working conditions, as they were firm owners and/or supervisors. Although the semi-tractor and skidder both showed trends in preference and self-selection bias, only six percent of respondents indicated they use the semi-tractor daily. Future research should address variability of ergonomic risk factors among logging machines and machine operators.

Chapter 3: Noise and vibration exposure in full-tree logging systems in the southeastern United States

Abstract

LMOs were monitored at eight sites in the southeastern United States to better quantify the exposure to occupational noise and WBV. Twenty-seven LMOs were measured. Personal noise dosimeters were used to collect noise exposures while seat pad accelerometers were used to capture vibration exposures. Both datasets were collected during at least four hours of representative machine operation. The data were collected from eleven wheeled skidder operators, eight wheeled feller buncher operators, and eight loader operators from seven different logging crews. Wheeled skidders had the highest average WBV exposure at 1.58 m/s^2 Aeq(8), wheeled feller bunchers followed at 1.04 m/s^2 Aeq(8), and finally loaders at 0.64 m/s^2 Aeq(8), all of which exceed the ISO recommended action limit of 0.0.43 m/s^2. The value for skidders exceeded both the ISO 2631 exposure limit value of 0.87 m/s^2 and the EUD exposure limit value of 1.15 m/s^2 (EUD 2002 and ISO 1997). The majority of the noise exposures were below the OSHA Action Limit of 85 dBA, but due to the long hours, almost all operators received more than the ISO EU recommended daily noise dose of 100% (EUD 2003).

Keywords: Logging, vibration, noise

Introduction

In the southeastern United States research has shown that injury rates decreased with mechanized logging when compared to logging with manual tree felling operations (Roberts and Shaffer 2005). LMOs are, however, exposed to an array of risk factors for the development of musculoskeletal disorders while operating and have been found to report frequent musculoskeletal complaints (Axelsson 1995). The risk factors include WBV, static and awkward postures, and repetitive movements (Bovenzi and Betta 1994, Jack and Oliver 2008, Neitzel and Yost 2010, Shan et al. 2013, Tiemessen et al. 2008). Operators are also exposed to relatively high job stress, long hours, and are likely to be obese (Axelsson 1995, Lynch 2014, Smidt 2011).

LMOs account for the largest portion of the logging workforce (Smidt 2011). They are proportionally represented in workers' compensation claims (Roberts et al. 2005) even though there are effective engineering controls in the machines. The adverse effects of hazardous exposures to WBV, repetitive motion, and long work hours could be difficult to measure in workers' compensation claims or federal injury surveys due to the chronic nature of these injuries. Chronic injuries have been shown to be less likely to be reported with barriers to reporting being cited as a lack of understanding that the injuries are work-related or that they are serious enough to be reported (Ashby et al. 2001).

WBV levels associated with logging machine use have been shown to exceed ISO standards (Jack and Oliver 2008). WBV levels have been related to machine type (Neitzel and Yost 2002), age of the machine, or the manufacturer (Davis and Kotowski 2007, Gerasimov and Sokolov 2009). This exposure has also been linked to choices made by individual operators, with vibration levels in the vertical direction increasing by more than 50% when comparing the most aggressive driver to the least with a subjective rating (Wegscheid 1994).

Long-term exposure to WBV has been found to contribute to fatigue, central nervous system disturbances, lower back pain and injuries, vision problems, and adverse effects to the digestive and genital/urinary systems (Bovenzi and Hulshof 1999, Neitzel and Yost 2002, Dupuis and Zerlett 1987, Seidel 1993). Extended durations of WBV exposure has been found to significantly increase the potential for the development of low back pain (Tiemessen et al. 2008, Bovenzi and Betta 1994, Bovenzi 1996, NIOSH 1997, Bovenzi and Hulshof 1999). LMOs frequently work shifts in excess of 10 hours (Smidt 2011), and duration of exposure to WBV has been related to low back pain more consistently than the magnitude of the vibration (Bovenzi 1996). These negative health outcomes may explain the inability of LMOs to maintain a high productivity level (Synwoldt and Gellerstedt 2003).

Exposure to high levels of noise, those greater that 85 decibels, may contribute to NIHL. Logging machines in the United States have been shown to operate at noise levels that exceed the OSHA standard's time weighted average (TWA) of 90 dBA for full shift exposure (Neitzel and Yost 2002, Fonseca 2009, OSHA 1910.95). In fact, significant hearing loss may be prevalent among LMOs (Axelsson 1995, Fonseca 2009, Jack and Oliver 2008). Lewark (2005), however, stated based on his review of available research, that noise itself is only a minor problem for LMOs, but that noise levels greater than just 60 dBA could negatively impact operator concentration, mood, heart rate, and blood pressure (Lilley et al. 2001, Axelsson 1995). Other research suggests that WBV when combined with noise exposure may have a synergistic effect on NIHL (Jack and Oliver 2008, Seidel 1993). Considering a percentage of noise is conducted by our bones, and it involves the vibration of the basilar membrane, it may follow that vibration having a certain resonance in our bodies might be impacting how noise and vibration are impacting the mechanisms within the ear and thus NIHL (Seidel 1993, Boettcher et al. 1987, Dauman 2013).

There is evidence that exposure to noise and vibration may have adverse impacts on both worker health and productivity (Jack and Oliver, 2008; Stansfeld and Matheson, 2003). However, little research in the United States, quantifies LMOs exposure to WBV and noise, particularly with regards to any improvements in machine design and the reduction of these exposures. Low back pain and hearing loss are prevalent chronic injuries among LMOs (Axelsson, 1995; Hagen et al., 1998; Neitzel and Yost, 2002). Pain related to WBV and hearing loss both impact an individual's quality of life. With low back pain being consistently associated with WBV exposure (Tiemessen et al., 2008; Bovenzi and Betta, 1994; Bovenzi, 1996; NIOSH, 1997; Bovenzi and Hulshof, 1999) and noise known to cause NIHL, these risk factors became the focus of this study. The objective of this research was to describe the hazard exposure for LMOs to WBV and occupational noise. Documentation of exposure levels could lead to future work on injury and illness surveillance and appropriate interventions by machine manufacturers and firms.

Materials and Methods

Twenty-seven LMOs were measured for exposure to noise and WBV. Data were collected on 12 different days over an eight-week period in the summer of 2014 from seven different logging crews. The research involved recruiting LMOs for observation on the job for a duration of four or more hours. To be included in the study, a logging crew had to have at least one wheeled skidder, one trailer-mounted knuckleboom loader, and one wheeled feller-buncher in operation on any given day. Some crews had a fourth machine in operation, and in those cases, that operator was also observed. This fourth machine was typically a second wheeled skidder. One crew was in the process of purchasing a new loader, so one operator was observed in the old loader, and a second was observed in the new loader. Crews were chosen based on the logging system used (mechanized rather than manual) and their relative proximity to Auburn, Alabama. Participants included eleven wheeled skidder operators, seven wheeled feller-buncher operators, and nine loader operators.

Vibration exposure data was collected using an accelerometer (Larson Davis) placed on the seat of the machine. The device was placed under the ischial tuberosities of the operators in accordance with ISO 2631 guidelines. Accelerometer data recorded the vibration exposure of the operator with biodynamic root-mean square acceleration in three mutually perpendicular axes (x, y, and z) in accordance with ISO 2631 – 1 1997. The accelerometer was placed before the shift, and removed after at least four hours of self-reported representative work. To collect personal noise exposures, personal noise dosimeters (Cirrus doseBadge) were used. They were placed on the shoulder of an operator in the hearing zone. The dosimeters were data logging and measured the noise exposure on two channels. The first channel was set to the OSHA permissible exposure limit, which is based on a 90 dBA criterion level, 80 dBA threshold level, a 5 dBA exchange rate, 115 dBA ceiling, and a slow response. The second channel was set to the ISO European Union standards with an 80 dBA criterion level, a 3 dBA exchange rate, and fast response.

Field studies were conducted over multiple days when a minimum of four hours of a typical shift for each machine could not be monitored on the first day. Dosimeters and accelerometers were calibrated pre and post shift, and data was downloaded directly to a personal computer immediately after collection. Prior to the shift, participants had anthropometric measurements taken. At the end of the field study, participants were asked to complete a body part discomfort scale, and complete a survey.

Anthropometric data included measurements deemed necessary to provide appropriate descriptive data on the participants to account for any operator characteristics that might confound analysis of machine characteristics. This required no more than an hour. The lead investigator who was trained in the collection of anthropometric data took measurements. Anthropometric measurements collected are listed in Appendix G.

The body part discomfort scale lists parts/areas of the body (neck, upper back, lower back, and right and left shoulder, elbow/forearm, wrist/hand, hip/thigh/buttock, knee, ankle/foot), and has the participant indicate the amount of discomfort experienced in that body part/area. The scale went from zero indicating "no discomfort", to ten, indicating "worst discomfort ever". The Body Part Discomfort Scale is in Appendix H.

The survey was developed to assess individual demographics, frequency of machine use, machine preference, machine age, time spent in particular postures, and neck and back pain experienced over the past year. It included 10 sections with a total of 34 items, taking no more than 30 minutes to complete. Participants were allowed to either complete the survey on their own pre or post shift, or provide survey responses to the investigator orally.

A research proposal for this study was submitted and accepted by the Internal Review Board at Auburn University, Auburn, Alabama (Protocol 13-316 MR 1309) (Appendix B and C).

Results

Survey responses were collected for 26 participants (96% response rate), and of those, 96% (24) reported experiencing at least mild neck or back pain over the previous year, and 80% (20) believed that pain was at least in part related to their work in the logging industry. The average age of participants was 41 years old (20-64) with a standard deviation of 11.2. The average years in logging were 16 (1-40), and the average machine age was 2.5 years (0-10). Most machines were manufactured by John Deere (20). Only seven were not (4 Caterpillar and 3 Tigercat). Twenty (74%) of the machines had air suspension seats.

Dosimeter data was collected on all 27 participants. Total dosimeter run time was 251:26 (hours:minutes), with a mean dosimeter run time of 9:10. The average TWA was 77.17 dBA (53.9-88.8), but because so many exposures exceeded eight hours, it is more descriptive to look at the Equivalent Continuous Level of noise level recorded (LAeq). When a noise varies over time, the LAeq is the equivalent continuous sound that would contain the same sound energy as the time varying sound. It can be thought of as a type of average, where noisy events have a significant influence. The average LAeq was 82.90 dBA (73.7-88.8). The average dose based on the ISO EU standard with the more conservative and more widely accepted 3 dBA exchange rate was 120.59% (9%-371%). We found no notable differences in average exposure by machine: feller buncher 78.24 (58.5-86.5), loader 73.63 (53.9-85.3), and wheeled skidder 79.38 (64.0-88.8). Average noise levels by machine can be seen in Table 7. Almost all noise levels were below the OSHA mandated action level of 85 dBA, but due to the long hours, almost all operators received more than the ISO EU permissible daily dose.

Table 7

Average Noise Levels and Dose By Machine

Machine	**LAeq**	**Dose**	**Duration**
Feller	84.09	135.14	9:17:24
Loader	81.71	110.33	9:34:05
Skidder	83.13	130.66	9:07:07

Total accelerometer run time was 128:45, with an average accelerometer run time of 4:46 per machine (Total/Average, machine = 53:20/4:50, wheeled skidder; 36:05/5:09, feller-buncher; 39:20/4:22, loader). Total average vibration exposure for Aeq(8) across all vectors was 1.05 m/s^2. All of the average values were above the ISO recommended exposure action limit of 0.43 m/s^2 and above the EUD action limit of $0.5 m/s^2$ for Aeq(8). Aeq(8) by machine can be seen in Table 8. Figure 1 shows the Aeq(8) by the duration of sampling.

Table 8

Aeq(8) by machine

Machine	N	Aeq(8) m/s^2	Hours	Min m/s^2	Max m/s^2
		Mean (SD)	Mean (SD)		
Feller	7	1.04 (0.42)	5.15 (3.39)	0.54	1.75
Loader	9	0.64 (0.32)	4.37 (2.13)	0.17	1.15
Skidder	11	1.58 (0.34)	4.85 (2.42)	1.24	2.45
Skidder*	10	1.49 (0.19)	4.3 (1.68)	1.24	1.94

*extreme value removed

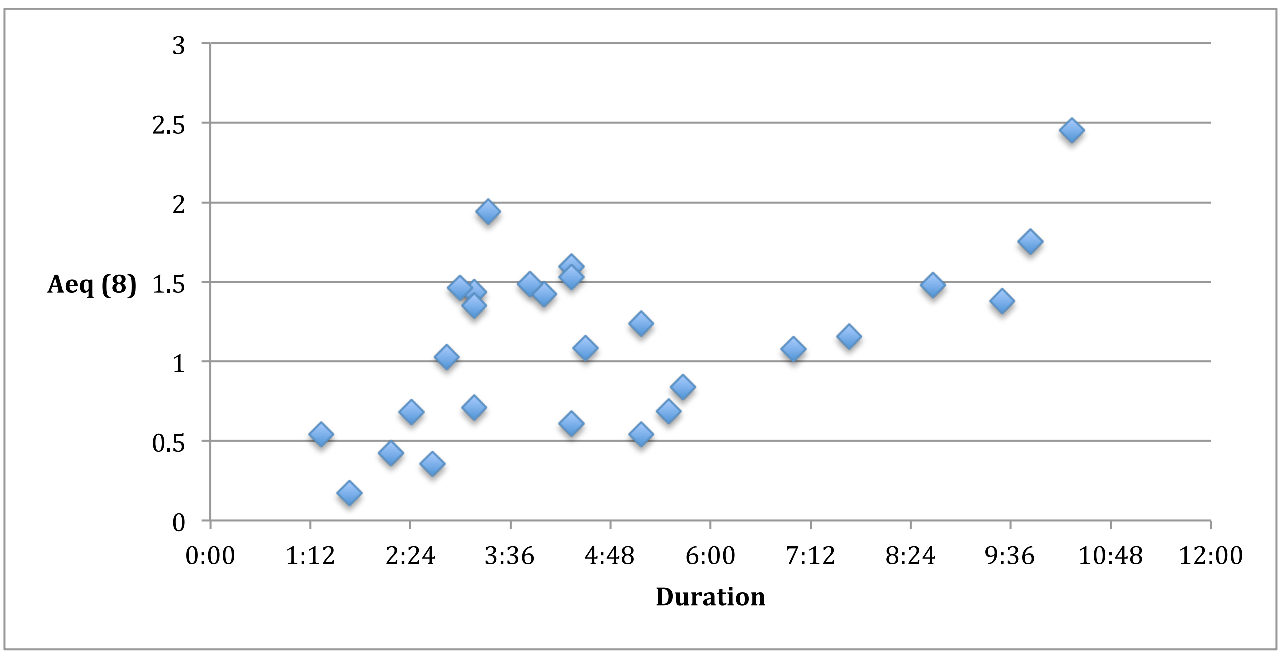


Figure 1. Scatterplot of Aeq(8) by duration of sampling

Average Aeq(8) for loaders was found to be 0.64 m/s^2. Two loaders were above the ISO exposure limit value of 0.86 m/s^2, and one was above the EUD exposure limit value of 1.15m/s^2. Wheeled feller-bunchers followed with an Aeq(8) at 1.04 m/s^2. Three fellers were above the ISO exposure limit, and one was above the EUD exposure limit. This value is above both the ISO and EUD exposure action limit. Wheeled skidders had the highest average WBV exposure at 1.58 m/s^2. This is above both the ISO exposure action limit and the exposure limit value; it is also the only average that was above the EUD exposure limit value for Aeq(8). All skidders measured were above both the ISO and EUD exposure limit values. Figure 2 shows the relationship of each measured Aeq(8) to the two exposure limit values.

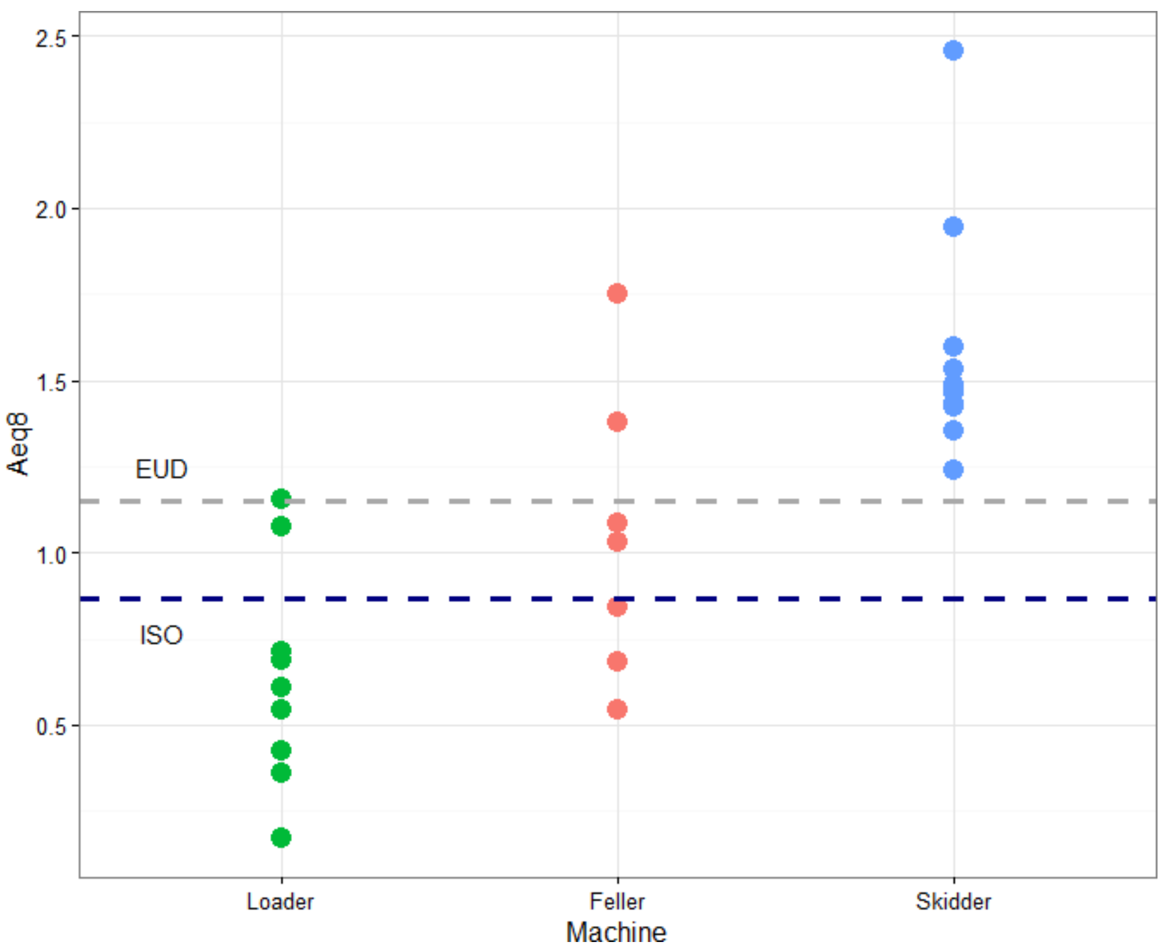


Figure 2. Relationship of measured Aeq(8) by machine to ISO and EUD exposure limit values

An ANOVA was performed to detect differences in the mean Aeq(8) per machine group. This test was significant ($p<0.001$). One of the Skidder measurements was noticeably higher than others (Aeq(8) = 2.455, over 10 hours measured), so another ANOVA was performed after removing this data point, and the test remained significant. Post-hoc tests using the Tukey correction for multiple comparisons indicate that the average skidder Aeq(8) level was statistically different from both the feller and loader, but there was no difference between feller and loader.

Table 9

Tukey's Test for Comparison of Aeq(8)by Machine

Machine Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Skidder - Feller	0.5375	0.1103	0.9648	***
Skidder - Loader	0.9445	0.5473	1.3417	***
Feller - Skidder	-0.5375	-0.9648	-0.1103	***
Feller - Loader	0.4070	-0.0384	0.8523	
Loader - Skidder	-0.9445	-1.3417	-0.5473	***
Loader - Feller	-0.4070	-0.8523	0.0384	

***Comparison is significant at the 0.05 level

Discussion

The reported experience of pain in this sample was consistent with previous research on pain experienced by LMOs; several surveys in Sweden showed 40-60% of LMOs reported experiencing pain or ache in the neck or shoulders over the previous year (Synwoldt and Gellerstedt, 2003).

There is clearly a strong relationship between long-term exposure to WBV and many negative health outcomes (fatigue, central nervous system disturbances, lower back pain and injuries, vision problems, and adverse effects to the digestive and genital/urinary systems) (Calvo, 2009; Tiemessen et al., 2008; Bovenzi and Betta, 1994; Bovenzi, 1996; NIOSH, 1997; Bovenzi and Hulshof, 1999; Neitzel and Yost, 2002; Seidel, 1993). Many of these negative health outcomes can impact productivity, and because of that, more importance should be placed on reducing lifetime exposure in LMOs. As this exposure takes place over several years, it can be difficult to assess at what point the damage is done without a long-term prospective study.

There have been several studies in North America that measured vibration from typical forest machines, mainly skidders (Cation et al., 2008; Golsse, 1990; Golsse, 1992; Hope and Golsse, 1987; Neitzel and Yost, 2002; Wegscheid, 1994), and there is a general sense that machines have improved over time both in terms of operator comfort and maintenance characteristics (Axelsson 1995). All of the machines in this study had average vibration levels recorded that were either comparable or less than the WBV levels delivered to operators in previous research (Table 10).

Table 10

Previously Reported Average Accelerations in Skidders/Logging Machines

				Average acceleration (m/s2)			
Author(s)	**Year**	**Location of measurement**	**Machine/driving conditions**	**Sum**	**x**	**y**	**z**
Golsse and Hope	1987	in seat	Skidder/Loaded	-	0.54	0.67	0.95
			Skidder/Unloaded	0.75	0.82	1.15	
Wegscheid	1994	in seat	Skidder	-	0.82*	1.09*	1.42*
Neitzel and Yost	2003	in seat	All logging machines/normal operation	3.53	1.46	1.4	1.83
Cation et al.	2008	in seat	Skidder/Loaded	0.72	0.96	0.72	
			Skidder/Unloaded	0.86	1.12	0.73	
Lynch et al.	2015	in seat	Skidder/Normal operation	1.58	0.83	1.09	0.87

*determined from ranges in figures

Most of the machines, including all skidders studied, were over the ISO recommended action limit for WBV exposure. However, all three types of the machines in this study had average vibration levels recorded that were less than the WBV levels delivered to operators in the research conducted by Neitzel and Yost (2002). Despite skidders delivering vibration exposures above recommended limits from both ISO and the EU, they had levels less than those studied by Wegscheid (1994). This supports the idea that advancements are being made, but further improvements are still needed.

There is not a lot of available data on loader vibration exposure, and the values in this sample were the lowest of the three machines. This may have been due to lull periods between loads and the availability of wood to delimb and load as opposed to strictly lower machine vibration. However, the measured value was still above the ISO recommended action limit and within the ISO health guidance caution zone.

The data indicates that exposures are below the OSHA action level of 85 dBA, but the long hours are exposing operators to a more than the EUD 100% recommended daily dose. The constant noise over a ten or more hour shift presents an exposure to workers that may contribute to operator fatigue (Axelsson 1995). The use of hearing protection could lower this dose, but no use of hearing protection was observed during this research. Neitzel and Yost (2010) reported high utilization of hearing protection (83.7%) in 2002 among workers in large forestry products companies. The lack of use observed here may be related to a lack of hazard recognition or knowledge, and may also have to do with a perception that the use of hearing protection indicates a personal weakness of some kind (Bordas et al., 2001). Neitzel and Yost (2002) also observed large forestry companies while this study observed small logging firms (fewer than 12 employees), which may have contributed to the limited compliance with hearing conservation practices. Larger companies are more likely to have an established safety program, a dedicated safety and health specialist, and are more likely to be visited by OSHA (Bordas et al., 2001; Egan, 1998). It appears that noise is still an issue in these machines, but only because of the long work hours.

One limitation with this data is that the duration of measurement varied by participant, and this was not adjusted for breaks taken during the sample period. Another limitation of this study is the relatively small sample size: however, there is no reason to suspect that these results are not typical for other full tree harvesting systems utilizing a wheeled skidder, wheeled feller-buncher, and trailer-mounted knuckleboom loader in the southeastern United States. Another weakness was the fact that the study took place during one season, so it does not account for any possible seasonal variations in work practices or workload.

The terrain on the study sites ranged from nearly level to gently rolling terrain. There is some chance the WBV levels could be higher on more difficult terrain in terms of either greater slope or amount of ground obstacles. The age range of machines was smaller than expected. Data suggest that there are many machines with more than 10 years service in fleet (WSRI 2013). It is possible that contractors with older machines would be less willing to volunteer for the study.

Conclusion

There is limited surveillance data to quantify musculoskeletal disorders among logging workers. To make any reasonable progress on reduction in hazard exposure, logging contractors and researchers will have to focus on chronic adverse health effects resulting from cumulative exposures. A long term or large population based surveillance is needed to understand whether WBV and noise are health risks in southeastern logging. The larger study should involve the collection of accelerometer and personal noise dosimeter data on many more participants across crews on a variety of machines, with observation over a variety of conditions and seasons.

Hazard control for WBV can be partially accomplished through owner and operator education into the health effects of vibration exposure. Manufacturer improvements to design may also reduce these exposures. Owners should train operators to balance productivity with slower speeds and avoidance of obstacles, steep rises, or sharp dips in terrain to reduce vibration and jolting and jarring. Owners should also allow and even encourage operators to take frequent short breaks and to change postures while operating as often as possible. The implementation of administrative controls like job rotation and instituted breaks are also options that should be explored. Those solutions would require more research and education of operators and owners on the costs and benefits of these measures.

Either a reduction in hours worked or the implementation of a hearing conservation program could help further lower worker noise dose. Reduced exposure to noise would likely be a benefit with any of the measures aimed at the reduction of WBV exposure. Future efforts should include further investigation into the inclusion of shocks into WBV standards and guidelines and work on a more thorough body of research examining whether or not there are any combined impacts of noise and vibration.

LMOs may not stay with one machine over the course of their career. New operators are usually assigned the skidder. With increasing skill and experience those operators may move to the loader or the feller-buncher. The career path away from the skidder could reduce the lifetime vibration exposure, but the health effects may have already taken their toll. Research should be done to see if job shifting during a career as a LMO could mitigate some of the health effects associated with that long-term exposure to WBV.

Reduction of WBV exposure could feasibly lead to higher productivity from LMOs. This would apply not only in the short term, reducing discomfort and allowing for more productive hours per day or week; but in the long term, allowing operators to have more pain or injury free years with higher productivity. It is also conceivable that a reduction in WBV exposure could lower costs resulting from days away from work due to pain or injury or the costs associated with training a new employee when one leaves due to pain or injury.

Chapter 4:

Impact of speed and terrain on vibration exposure in skidder operators in the southeastern United States

Abstract

In recent years, musculoskeletal disorders have accounted for about a third of injuries among all private industries (BLS 2015). Whole body vibration (WBV) has been shown to be a contributing factor, particularly in combination with awkward postures that include static seating and twisting of the trunk ((Bovenzi, 2005; Bovenzi and Hulshof ,1999; NIOSH, 1997; Bovenzi, 1996; Calvo, 2009; Tiemessen et al., 2008; Bovenzi and Betta, 1994; Neitzel and Yost, 2002; Seidel, 1993). Skidder operators in the southeastern United States are exposed to long hours of WBV combined with awkward postures. Eleven skidders were equipped with accelerometers and a global positioning system (GPS) to establish vibration exposure and speed. The terrain of the sites where these skidders were operating was then rated based on the number of obstacles of varying heights and depths. The data were analyzed to see if speed and/or the terrain rating were significantly impacting vibration exposure. There were trends suggesting lower speed and lower terrain rating resulted in lowered vibration exposure as would be expected. However, due to the limited number of data points, no statistically significant correlation was found. Time in the machine, however, was significantly correlated with vibration exposure.

Keywords: Whole body vibration, Noise, Logging, Skidders

Introduction

Many workers are exposed to whole body vibration (WBV) as a part of their job, with most of these exposures occurring while driving. The WBV delivered while operating a vehicle consists of two types, sinusoidal vibration delivered while traveling over relatively smooth terrain, and jarring vibration delivered via shocks that are typical during movement over uneven surfaces or obstacles. Exposure to WBV has been strongly associated with an increased risk of low back pain and disorders (Bovenzi, 2005; Bovenzi and Hulshof, 1999; NIOSH, 1997; Bovenzi, 1996; Calvo, 2009; Tiemessen et al., 2008; Bovenzi and Betta, 1994; Neitzel and Yost, 2002; Seidel, 1993).

More than a third of loggers in the southeastern United States are classified as equipment operators, and they are the most frequently injured employees in the logging industry (Smidt, 2011). While equipment operators are most protected from traumatic injury while in the cab of a machine, there is reason to believe that the WBV exposure experienced while driving along with other ergonomic risk factors within the cab may produce musculoskeletal disorders, especially of the back. The combination of awkward postures and WBV has been shown to increase the risk of injury (Raffler et al., 2010; Hoy et al., 2004). In logging these physical factors are combined with long hours, high productivity demands, and personal factors including age and body mass index that may further increase the risk of the development of pain and subsequent musculoskeletal disorders.

All of these exposures are particularly pronounced with the operation of the grapple skidder. Skidder operators must make repeated runs to and from the landing, subjecting themselves to the vibration of the cab, jarring when the terrain is rough, and constant twisting of their neck and trunk to turn forward and backward on those runs. Thomas and Smith found that skidder operators spent an average of 41% of their shift in a twisted posture (Thomas and Smith, 1991). Golsse and Hope believed that skidder operators might be exposed to higher levels of WBV as speed increased along rough terrain (Golsse and Hope, 1987).

These exposures and their health outcomes are not well characterized within the logging industry in the United States. However, research on similar industries in other countries has quantified several aspects of vibration exposures. Cation et al. found that skidder operators were exposed to acceleration exceeding ISO 2631 guidelines and that little had changed in seat attenuation over the previous 20 years (Cation et al., 2008; ISO, 1997). In another study, Malchaire et al. showed that vibration exposure for forklift drivers was influenced by both speed and the roughness of the track (Malchaire et al., 1995). It would follow that perhaps speed and terrain have a considerable impact on vibration exposures in skidder operators. Wegscheid concluded that the driving behavior of operators had a pronounced effect on the WBV exposure levels he observed based on the operator's aggressiveness (Wegscheid, 1994). It is possible that practical recommendations regarding speed and path selection based on the impacts of speed and terrain could help to reduce WBV exposure.

The purpose of this study was to collect data on WBV exposure experienced by skidder operators and compare those exposures to speed and terrain rating to examine the impacts of those factors on WBV. The long-term goal if for this research to inform the training of operators regarding optimum considerations about speed and path selection that could potentially lower their exposures to WBV.

Materials and Methods

Eleven skidders were equipped with Larson Davis HVM 100 seat pad accelerometers and Trackstick global positioning systems (GPS). The devices were placed in the cabs of the machines before the shift, and operators were measured and tracked for at least four hours of self-reported typical operation at seven sites in Alabama and Georgia. Data were collected on 12 different days over an eight-week period in the summer of 2014. Observations were conducted over multiple days when at least four hours of typical operation did not take place on the first day. An accelerometer was placed under the ischial tuberosities of the operators in accordance with guidelines presented in the ISO 2631-1 1997. The accelerometer recorded the WBV exposure with biodynamic root-mean square acceleration in three mutually perpendicular axes (x, y, and z) also in accordance with ISO 2631 guidelines. The Tracksticks were placed either on the dash or roof near the front windshield. Accelerometers were calibrated pre- and post- shift, and data from both the accelerometers and Tracksticks were downloaded directly to a personal computer immediately after collection.

The terrain at these sites was then evaluated by using a random number generator to select the starting point from the landing, pacing half a chain (33ft) from that point, and counting the obstacles across the width of the path one meter in front and one meter behind each point on the path travelled by the skidder operator. The obstacles were defined, measured, and classified using a variation of methods in the Terrain Classification System for Forestry Work (Berg, 1992). Obstacles were any rocks, boulders, soil mounds, or stumps greater than ten centimeters and any cavity deeper than 20 centimeters. The more obstacles that were present along the skidder path equated to a higher terrain rating. A single terrain rater was used, and two other investigators simultaneously assessed the first site to ensure similar results were attained.

Speed was calculated by converting the latitudinal and longitudinal coordinates recorded by the GPS Tracksticks to Universal Transverse Mercator (UTM) coordinates. This allowed the distances to be converted to meters. The time provided by the Tracksticks was converted to a decimal format to then calculate kilometers per hour.

The skidder operators also completed a survey with questions about demographics, frequency of machine use, machine preference, machine age, time spent in particular postures, musculoskeletal disorder diagnosis, and neck and back pain experienced over the past year. The survey included 34 items and took no longer than 30 minutes to complete. Participants had the option of taking the survey on their own or having the survey given orally by the investigator.

Results and Discussion

The average age of skidder operators was 38 (20-62) with one response left blank and a standard deviation of 12.8. Most operators (8) indicated they had experienced pain over the previous year and attributed at least part of that pain to their job in logging. The average accelerometer run time was 4.8 hours, and average Aeq(8) was 1.6 m/s^2 with a standard deviation of 0.34. Table 11 shows the terrain rating, speed (including distance and elapsed time used in speed calculations), and Aeq(8) for each skidder studied.

Table 11

Terrain Rating, Speed, and Average Acceleration by Machine

Machine	Operator	Terrain Rating	Distance (m)	Time (h)	Speed (km/h)	Aeq(8) (m/s^2)
1	a	65	21,380	6.4	3.3	1.4
2	a	204	21,893	12.1	1.8	2.5
3	a	21	17,246	3.1	5.6	1.5
	b	21	16,741	4.4	3.8	2.0
4	a	90	18,692	4.2	4.5	1.5
	b	90	8,650	3.6	2.4	1.4
5	a	103	19,405	4.5	4.3	1.5
	b	103	14,301	4.8	3.0	1.5
6	a	236	17,137	4.7	3.7	1.6
	b	236	18,261	5.1	3.6	1.2
7	a	163	18,155	4.0	4.6	1.4

Aeq(8) for all subjects was above the ISO exposure action limit (0.43m/s^2) and exposure limit value (0.87m/s^2), and also above the EUD exposure limit value (1.15m/s^2). Vibration exposure is clearly an issue within these machines. Regression analysis was performed for time, speed, terrain and Aeq(8). Time was the only factor with a statistically significant correlation to Aeq(8) with a correlation coefficient of 0.032 and a p-value of 0.007. More specifically, for every additional hour spent in the machine, Aeq(8) would be expected to rise by 0.11m/s^2.

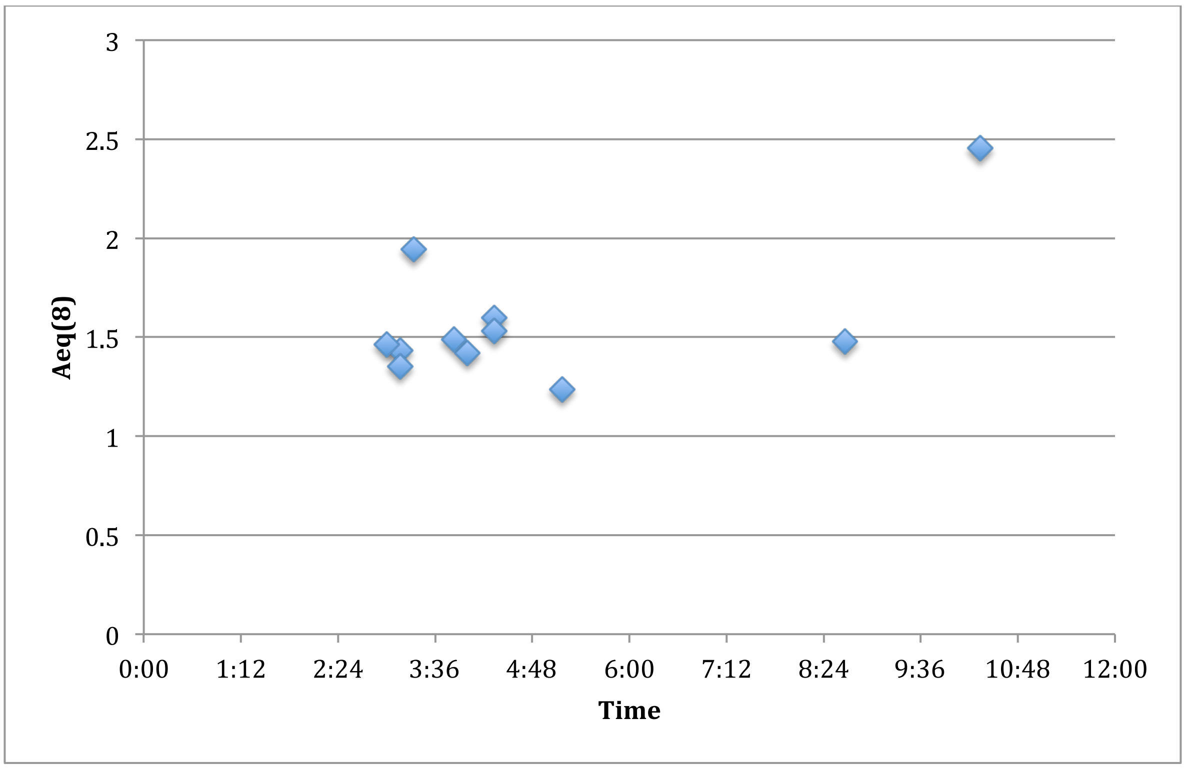


Figure 3. Time and Aeq(8)

Terrain and speed had a correlation coefficient of -0.3612, with a p-value of 0.275, therefore the null of a zero correlation cannot be rejected. With both terrain and speed, when holding the other steady, there will be an increase in Aeq(8) as the variable increases up until a pivot point at which it will begin to reduce. For speed the pivot point is about 3.5 km/h, and for terrain rating the pivot is about 54.5. From the saddle point of 54.5,3.5 if the variables go in opposite directions, the predicted Aeq(8) will increase. If they go in the same direction, the predicted Aeq(8) will decrease.

To summarize, there are basically four different types of results seen: 1) if terrain and speed are low, low Aeq(8) is expected, 2) if terrain and speed are high, low Aeq(8) is expected, 3) if terrain is low and speed is high, high Aeq(8) is expected, 4) if terrain is high and speed is low, high Aeq(8) is expected. None of these, however, were statistically significant. In the case of number 2, this result is unexpected, but it could be that scenario 2 is not something that would actually happen. It may not even be physically possible to drive fast on paths with a lot of obstacles. Scatter plots of speed and Aeq(8), terrain and Aeq(8), and the interaction of speed and terrain are shown in Figures 4, 5, and 6 respectively.

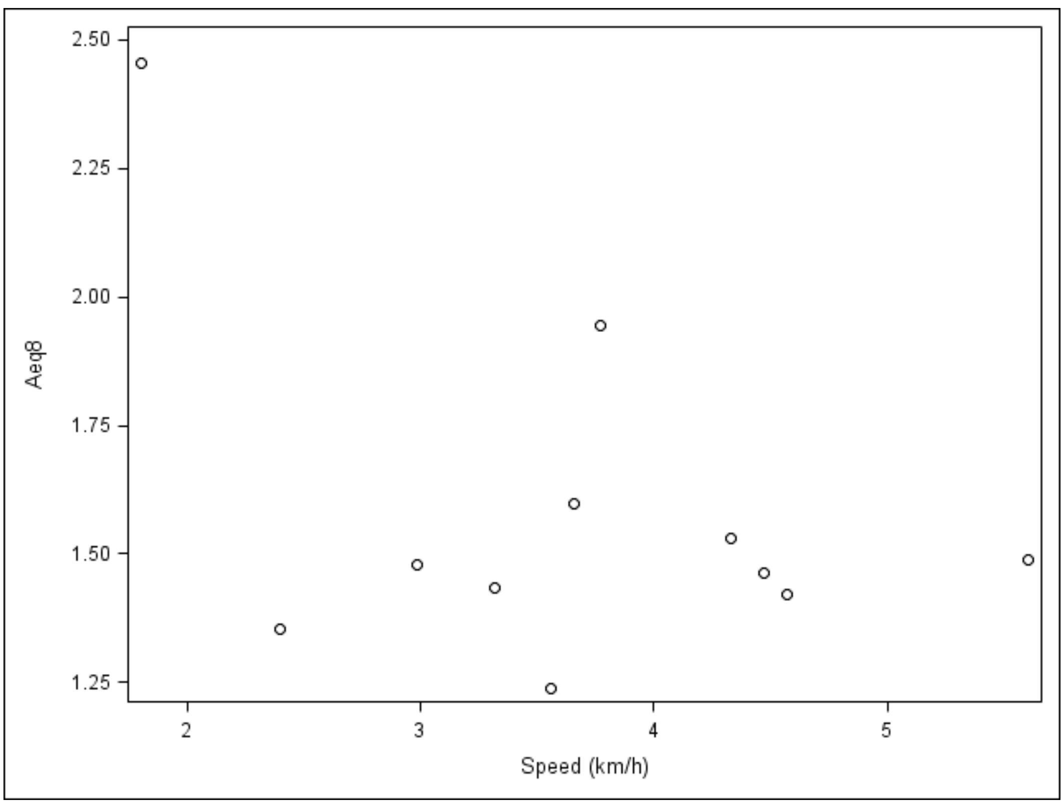


Figure 4. Speed and Aeq(8)

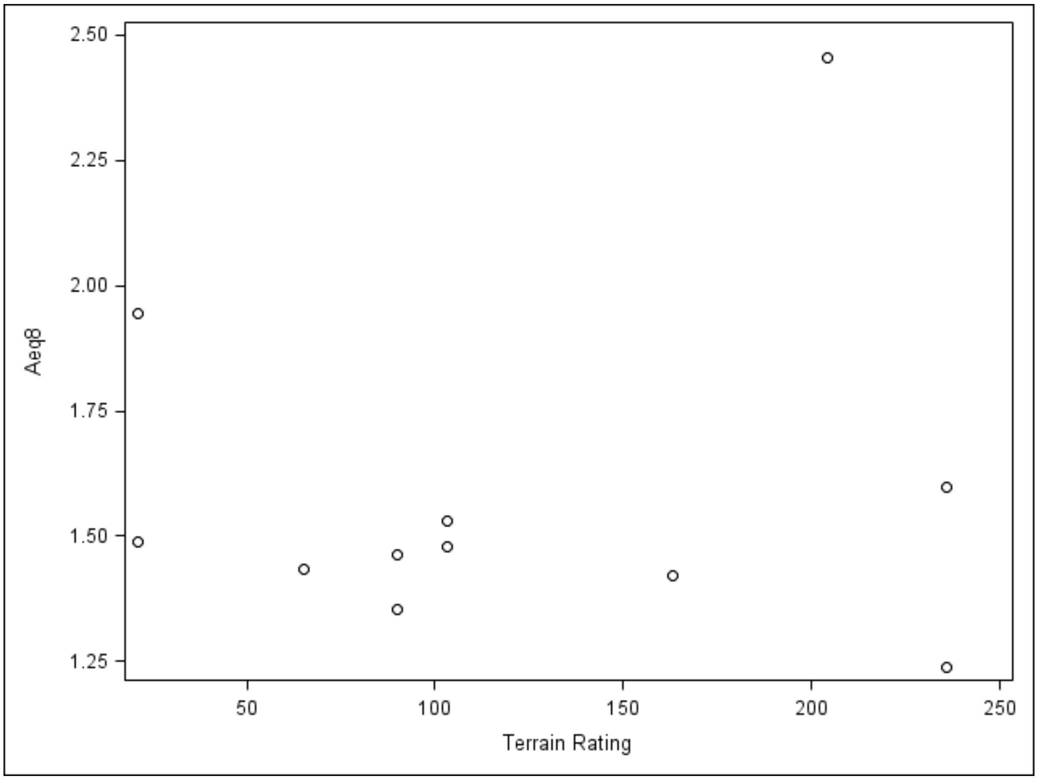


Figure 5. Terrain rating and Aeq(8)

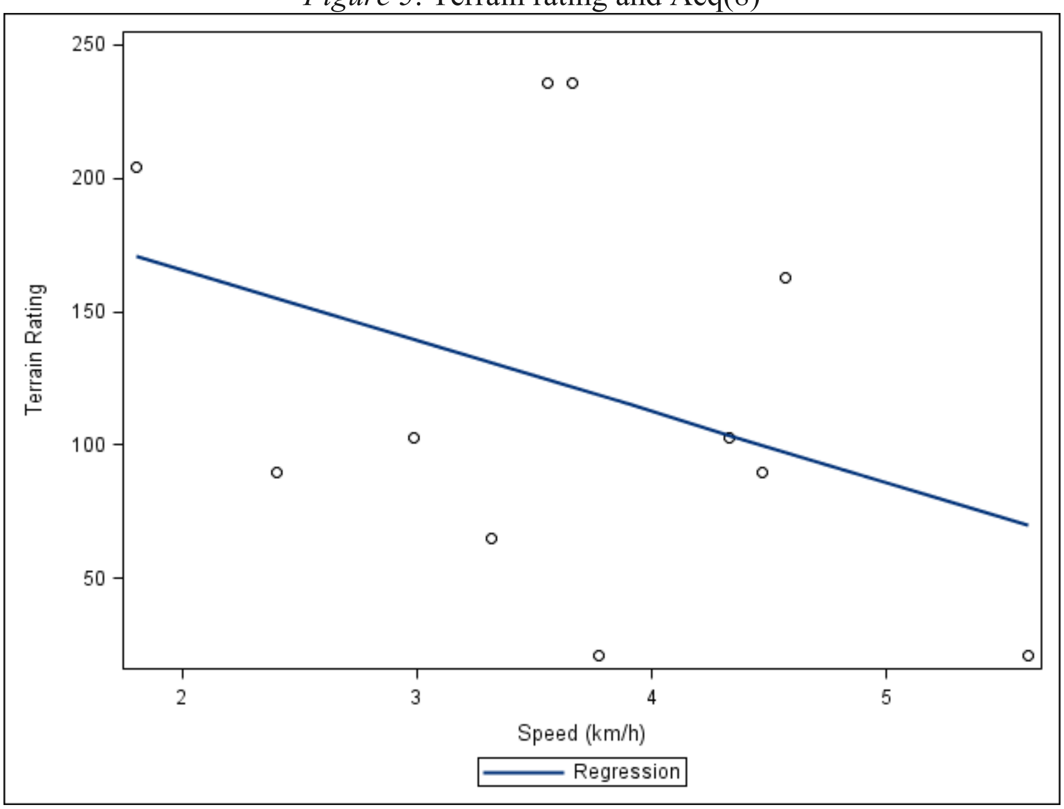


Figure 6. Interaction of Speed and Terrain rating

In an attempt to better understand the relationship seen above, speed was broken down into four quartiles to then examine the interactions. For the lowest quartile of speed, the data point with rougher terrain had higher vibration. This could indicate a possible relationship between terrain rating and vibration at these speeds, however, it may be the result of random variation. Within the other quartiles of speed, the data do not appear to indicate a relationship between the terrain rating and Aeq(8).

The major limitation to this study was small sample size. All measurements were also taken during the same season under similar conditions over a relatively short amount of time, and each operator was only measured on a single day at a single site.

Conclusion

Time did show a significant relationship with Aeq(8). The hourly increase in Aeq(8) of $0.11 m/s^2$ is not only statistically significant, but significant in the real world due to the relatively low recommended limit values WBV exposure, including the aforementioned ISO action limit of $0.43 m/s^2$ and threshold limit value of $0.87 m/s^2$. This means that placing a time limit on operation per day could significantly reduce WBV exposure and the risks associated with it. This was not one of the metrics initially considered for this experiment, and it may not be possible to limit the time of operation due to production demands.

The data indicate that lower speeds and a less rough terrain may be associated with a lower WBV exposure. This would fit with previous research, but research involving a larger pool of subjects needs to be conducted to draw statistically significant conclusions and propose practical solutions. The benefits of the application of ergonomic principles to the logging industry are far reaching. Further research aimed at reducing exposure to WBV and other ergonomic risk factors could lead to benefits such as cost savings from reduced days away from work due to injury and lower insurance premiums. Increased productivity from a healthier workforce could also result.

Chapter 5:

Conclusion and Recommendations

Conclusion

Even with the inclusion of this dissertation, little research has been performed quantifying the impact of ergonomic risk factors and MSDs in logging operations especially when compared to the amount of attention paid to traumatic injuries. Ergonomic risk factors are present during logging machine operation, and their health outcomes are not well characterized within the logging industry. Even within OSHA's logging standard (OSHA, 1995), there are no requirements or recommendations addressing logger safety with regards chronic injuries, such as an MSD. This is in spite of the fact that MSDs are responsible for 32% of nonfatal injuries reported in all private industry and for 17% of nonfatal injuries reported within the logging industry (BLS, 2015).

There is still a need to do more research focusing on the exposure to ergonomic risk factors that may contribute to the knowledge of the development of MSDs among LMOs. The costs of MSDs are also not well defined with in this industry. It seems unlikely that explaining the cost benefit analysis and projected production benefits of an ergonomic intervention at the crew level could outweigh the pressing production demands. Intervention would be most effective at the machine design level.

Summary of Findings

Three experiments were performed for this dissertation. The first involved the development, distribution, and collection of a survey as well as analysis of the data. The survey found that of the 157 machine operators surveyed

1. 10.5% (16) reported an MSD diagnosis

2. 74.3% (113) reported at least mild back pain over the past year

3. 71.7% (109) reported at least mild neck pain over the past year

It also found that the odds ratio for the effect of neck twisting on neck pain was significant. The odds ratio indicated that a logger who had his neck twisted for more than four hours a day was about 3 times more likely to report neck pain than a logger who had his neck twisted 4 hours or less.

There were two experiments both based on data collected in the study titled, "Survey of Ergonomic Risk Factors Among Logging Machines". The first looked at 27 LMOs and found:

1. Wheeled skidders had the highest average WBV exposure at 1.58 m/s^2 Aeq(8), wheeled feller bunchers followed at 1.04 m/s^2 Aeq(8), and finally loaders at 0.64 m/s^2 Aeq(8)

2. All Aeq(8) averages by machine exceeded the ISO recommended action limit

3. The value for skidders exceeded both the ISO 2631 exposure limit value of 0.87 m/s^2 and the EUD exposure limit value of 1.15 m/s^2

4. Due to working long hours, almost all operators received more than the ISO EU recommended daily noise dose of 100%

The second was a deeper look into the data for the 11 grapple skidder operators focusing on speed and terrain's impact on Aeq(8). It found:

1. No significant correlations between speed or terrain with Aeq(8), but a possible pattern suggests that further research is warranted to investigate potential relationships

2. Time did show a significant relationship with Aeq(8) with an hourly increase in Aeq(8) of 0.11m/s^2

This means that placing a time limit on operation per day could significantly reduce WBV exposure and the risks associated with it, however, it may not be possible to limit the time of operation due to production demands.

Limitations

Limitations associated with the study titled, "What is the Self-Reported Incidence of Risk Factors with MSDs in Loggers across the United States" include:

1. All surveys were collected in only four states, with the majority collected in Alabama.
2. All surveys were collected at training and continuing education classes which may have biased results since most survey respondents had considerable choice or control in working conditions, as they were likely firm owners and/or supervisors.

Limitations associated with the first part of the study titled, "Survey of Ergonomic Risk Factors Among Logging Machines" included:

1. The duration of measurement varied by participant, and this was not adjusted for breaks taken during the sample period.
2. Relatively small sample size.
3. The study took place during one season, so it does not account for any possible seasonal variations in work practices or workload.
4. All participants were recruited based on their proximity to Auburn University.
5. Each operator was measured over a single day of operation at a single site.

Limitations associated the second part of the study titled, "Survey of Ergonomic Risk Factors Among Logging Machines" include all of those associated with the first part, as well as:

1. Smaller sample size.
2. Speeds were determined with shift total distances traveled and time. This is not as

descriptive as point to point analysis. Point to point analysis may better reveal relationships among speed, terrain, and WBV.

Recommendations for Future Research

There are several sources of untapped data collected during the course of this study. Some possible future analyses include:

- Analysis of videos to possibly establish a metric for productivity (trees felled/skidded/loaded).
- Use of video to compare loaded and unloaded skidder WBV data.
- Posture analysis of operators in videos.
- Point to point speeds to run a more descriptive analysis of speed to Aeq(8).

Future research should include a larger population over a larger area and a longer period of observation ranging through different seasons/weather conditions and over more varied terrain.

References

AFPA. (2015). Retrieved November 21, 2015, from www.afandpa.org

Ashby, L., Bentley, T., and Parker, R. (2001). Musculoskeletal disorders in silvaculture and logging 1995-1999. Centre for Human Factors and Ergonomics Report. 2(3): ISSN 1174-1234.

Axelsson, S. (1995). Occupational safety and health in forestry: an international study. Research notes number 280. ISSN 0282-2377.

Azaroff, L. S., Levenstein, C., and Wegman, D. H. (2002). Occupational injury and illness surveillance: conceptual filters explain underreporting. American J. Public Health. 92(9): 1421-1429.

Barynin, P., Taylor, D., Ghouri, W., and Warth, C. (2013). Wood Supply Research Institute Wood Supply Chain Analysis. Online report. http://wrsi.org/resources/media/WoodSupplyChainAnalysisFinalRpt.pdf. Accessed on 25 January 2016.

Bell, J.L. and Grushecky, S.T. (2006). Evaluating the effectiveness of a logger safety training program. J. Safety Res. 37:53-61.

Boettcher, F. A., Henderson, D., Gratton, M. A., Danielson, R. W., and Byrne, C. D. (1987). Synergistic interactions of noise and other ototraumatic agents. Ear and Hearing. 8(4): 192-212.

Bordas, R. M., Davis, G. A., Hopkins, B. L., Thomas, R. E., and Rummer, R. B. (2001). Documentation of hazards and safety perceptions for mechanized logging operations in east central Alabama. J. of Agricultural Safety and Health. 7(2):113-123.

Bovenzi, M. (1996). Low back pain disorders and exposure to whole-body vibration in the workplace. Seminars in Perinatology. 20(1):38-53.

Bovenzi, M. and Betta, A. (1994). Low back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. Appl. Ergonomics. 25(4):231-41.

Bovenzi, M. and Hulshof, C. T. (1999). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low-back pain (1986-1997). Int. Arch. Occup. Environ. Health. 72:351-365.

BLS. (1997). Census of Fatal Occupational Injuries, 1997. http://stats.gov.

BLS. (2012). Nonfatal occupational injuries and illnesses requiring days away from work, 2011. http://stats.bls.gov.

BLS. (2013). Nonfatal occupational injuries and illnesses requiring days away from work, 2011. http://stats.bls.gov.

BLS. (2015). Nonfatal occupational injuries and illnesses requiring days away from work, Private Industry and Forestry and Logging, 2015. https://data.bls.gov/ggt/Profiledata.

Calvo, A. (2009). Musculoskeletal disorders (MSD) risks in forestry: a case study to propose an analysis method. CIGR ejournal 11.

Cation S, Jack R, Oliver M, Dickey J. P. , Lee-Shee N. K. (2008). Six degree of freedom whole-body vibration during forestry skidder operations. Intl. J. of Ind. Ergonomics 38:739-757.

Centers for Disease Control and Prevention. (1995). National Institute for Occupational Safety and Health. NIOSH Alert: Preventing Injuries and Deaths of Loggers. May 1995. Publication No. 95-101.

Daltroy, L. H., Iverson, M. D., Larson, M. G., Lew, R., Wright, E., Ryan, J., Zwerling, C., Fossel, A. H., and Liang, M. H. (1997). A controlled trial of an educational program to prevent low back injuries. New England J. Med. 337(5):322-328.

Dauman, R. (2013). Bone conduction: An explanation for this phenomenon comprising complex mechanisms. European Ann. of Otorhinolaryngology, Head and Neck Diseases. 103(4):209-213.

Davis, K. G. and Kotowski, S. E. (2007). Understanding the ergonomic risk for musculoskeletal disorders in the United States agriculture sector. Am. J. Ind. Med. 50:501-511.

Deyo, R. A., Mirza, S. K., and Marting, B. I. (2006). Back rate prevalence and visit rates: estimates from U.S. national surveys, 2002. Spine 31.23:2724-727.

Dupuis, H. and Zerlett, G. Whole-body vibration and disorders of the spine. Int. Arch. Occup. Environ. Health. 59:323-336.

EUD. (2002). Directive 2002/44/EC – vibration. Sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). ELI:

EUD. (2003). Directive 2003/10/EC – noise. Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC.

Egan, A. F. (1998). The introduction of a comprehensive logging safety standard in the USA: The first eighteen months. J. Forest Eng. 9(1):17-23.

Freemont, A. J. and Hoyland, J. A. (2007). Morphology, mechanisms and pathology of musculoskeletal ageing. J. Pathology. 211(2):252-259.

Fonseca, A. A. (2009). Hearing assessment of forest loggers. Department of Construction Management and Industrial Engineering. Louisiana State University, Baton Rouge. P. 105.

Gellerstedt, S. (1998). A self-leveling and swiveling forestry machine cab. J. Forest Eng. 9(1):7-16.

Gerasimov, Y. and Sokolov, A. (2009). Ergonomic characterization of harvesting work in Karelia. Croatian J. of Forest Eng. 30:159-170.

Golsse JM. (1990). Evaluation of skidder seats for reducing whole-body vibration. In: Technical Report: FERIC. 8.

Golsse JM. (1992). Ergonomic evaluation of feller-buncher cabs and controls. In: Technical Note: FERIC. 8.

Hagen, K. B. and Vetlesen, K. (1998). Neck/shoulder and low-back disorders in the forest industry: relationship to work tasks and perceived psychosocial job stress. Ergonomics. 41(10):1510-1518.

Helmkamp, J. C., Bell, J. L., Lundstrom, W. J., Ramprasad, J., Haque, A., (2004). Assessing safety awareness and knowledge and behavioral change among West Virginia loggers. Injury Prevention. 10:233-238.

Holmstrom, E. and Engholm, G. (2003). Musculoskeletal disorders in relation to age and occupation in Swedish construction workers. American J. Ind. Med. 44(4): 377-384.

Hope P. A., and Golsse J. M. (1987). Analysis of whole-body vibration levels during skidding. In: Technical Report : FERIC. 22.

Hoy, D. G., Protani, M., De, R., and Buchbinder, R. (2010). The epidemiology of neck pain. Best Practice Res. Clinical Rheumatology. 24(6):783-792.

Hoy, J., Mubarak, N. Nelson, S., Sweerts de Landas, M., Magnusson, M., Okunribido, O., and Pope, M. (2004). Whole body vibration and posture as risk factors for low back pain among forklift truck drivers. J. of Sound and Vibration. 248:933-946.

ISO 2631-1: 1997. Mechanical vibration and shock – evaluation of human exposure to whole-body vibration.

Jack, R. J. and Oliver, M. (2008). A review of factors influencing whole-body vibration injuries in forestry mobile machine operators. Intl. J. Forest Eng. 19(1):51-65.

Kogi, K. (2012). Practical ways to facilitate ergonomics improvements in occupational health practice. Human Factors. 54(6):890-900.

Lewark, S. (2005). Scientific reviews of ergonomic situation in mechanized forest operations. Swedish Agricultural University. Uppsala. ISSN 1651-114X Number 2. Institutionen för skogens produkter och marknader.

Latko, W. A., Armstrong, T. J., Franzblau, A., Ulin, S. S., Werner, R. A., and Albers, J. W. (1999). Cross-sectional study of the relationship between repetitive work and the prevalence of upper limb musculoskeletal disorders. American J. Ind. Med. 36:248-259.

Lynch, S. M., Smidt, M. F., Merrill, P. D., and Sesek, R. F. (2014). Incidence of MSDs and neck and back pain among logging machine operators in the Southern U.S. Journal of Ag Safety and Health 20(3):211-218.

Lyons, J. (2002). Factors contributing to low back pain among professional drivers: A review of current literature and possible ergonomic controls. Work. 19:95-102.

Malchaire, J., Piette, A., and Mullier, I. (1995). Vibration exposure on fork-lift trucks. Ann. Occup. Hyg. 40(1):79-91.

Morse, T., Dillon, C., Kenta-Bibi, E., Weber, J., Diva, U., Warren, N., and Grey, M. (2005). Trends in work-related musculoskeletal disorder reports by year, type, and industrial sector: a capture-recapture analysis. American J. of Ind. Med. 48:40-49.

Mortimer M, Pernold G, Wiktorin C. (2006). Low back pain in a general population Natural course and influence of physical exercise--a 5-year follow-up of the Musculoskeletal Intervention Center-Norrtalje Study. Spine. 31(26):3045-3051.

NIOSH. (1997). Musculoskeletal disorders and workplace factors: a critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back. NIOSH, DHHS Publication number 97-141.

Neitzel R, Yost M. (2002). Task-based assessment of occupational vibration and noise exposures in forestry workers. AIHA J (Fairfax, VA). 63:617-627.

Nordander, C., Ohlsson, K., Akesson, I., Arvidsson, I., Balogh, I., Hansson, G., Stromberg, U., Rittner, R., and Skerfving, S. (2009). Risk of musculoskeletal disorders among females and males in repetitive/constrained work. Ergonomics. 52(10):1226-1239.

OSHA. (1995). Logging Operations. 29 CFR 1910.266

Palmer, K. T. and Smedley, J. (2007). Work relatedness of chronic neck pain with physical findings – a systematic review. Scand, J. Work Environ. Health. 33(3):165-191.

Pegula, S. and Janocha, J. (2013). Death on the job: fatal work injuries in 2011. Beyond the numbers. Workplace injuries. Bureau of Labor Statistics. 2(2).

Raffler, N., Hermanns, I., Sayn, D., Gores, B., Ellegast, R., and Rissler, J. (2010). Assessing combined exposures of whole-body vibration and awkward posture – further results from application of a simultaneous field measurement methodology. Ind. Health. 48:638-644.

Roberts, T., Shaffer, R. M. (2005). 2003 Injury rate for mechanized logging operations in the south. Forest Resources Association Inc. Technical Release 05-R-5.

Roberts, T., Shaffer, R. M., and Bush, R. J. (2005). Injuries on mechanized logging operations in the southeastern United States in 2001. Forest Prod. J. ISSN:0015-7473.

Seidel, H. (1993). Selected health risks caused by long-term, whole-body vibration. Am. J. Ind. Med. 23:589-604.

Shan, X., Ning, X., Chen, Z., Ding, M., Shi, W., and Yang, S. (2013). Low back pain development response to sustained trunk axial twisting. European Spine J. DOI 10.1007/s00586-013-2784-7. www.springerlink.com.

Smidt, M. F. (2011). A description of forest industries and forest occupations with focus on forestry workers' jobs and injury and illness surveillance. 34th Council on Forest Engineering Annual Meeting. Session 1. June 13.

Stansfeld, S. A. and Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. British Medical Bulletin. 68:243-257.

Synwoldt, U. and Gellerstedt. S. (2003). Ergonomics initiatives for machine operators by the Swedish logging industry. Applied Ergonomics. 34:149-156.

Tiemessen, I. J. H., Hulshof, C. T. J., and Frings-Dresen, M. H. W. (2008). Low back pain in driver exposed to whole body vibration: an analysis of a dose-response pattern. Occup. Environ. Med. 65:667-675.

Viester, L., Verhagen, E., Hengel, K., Koppes, L., van der Beek, A. J., and Bongers, P. M. (2013). The relation between body mass index and musculoskeletal symptoms in the working population. BMC Musculoskeletal Disorders. 14:238.

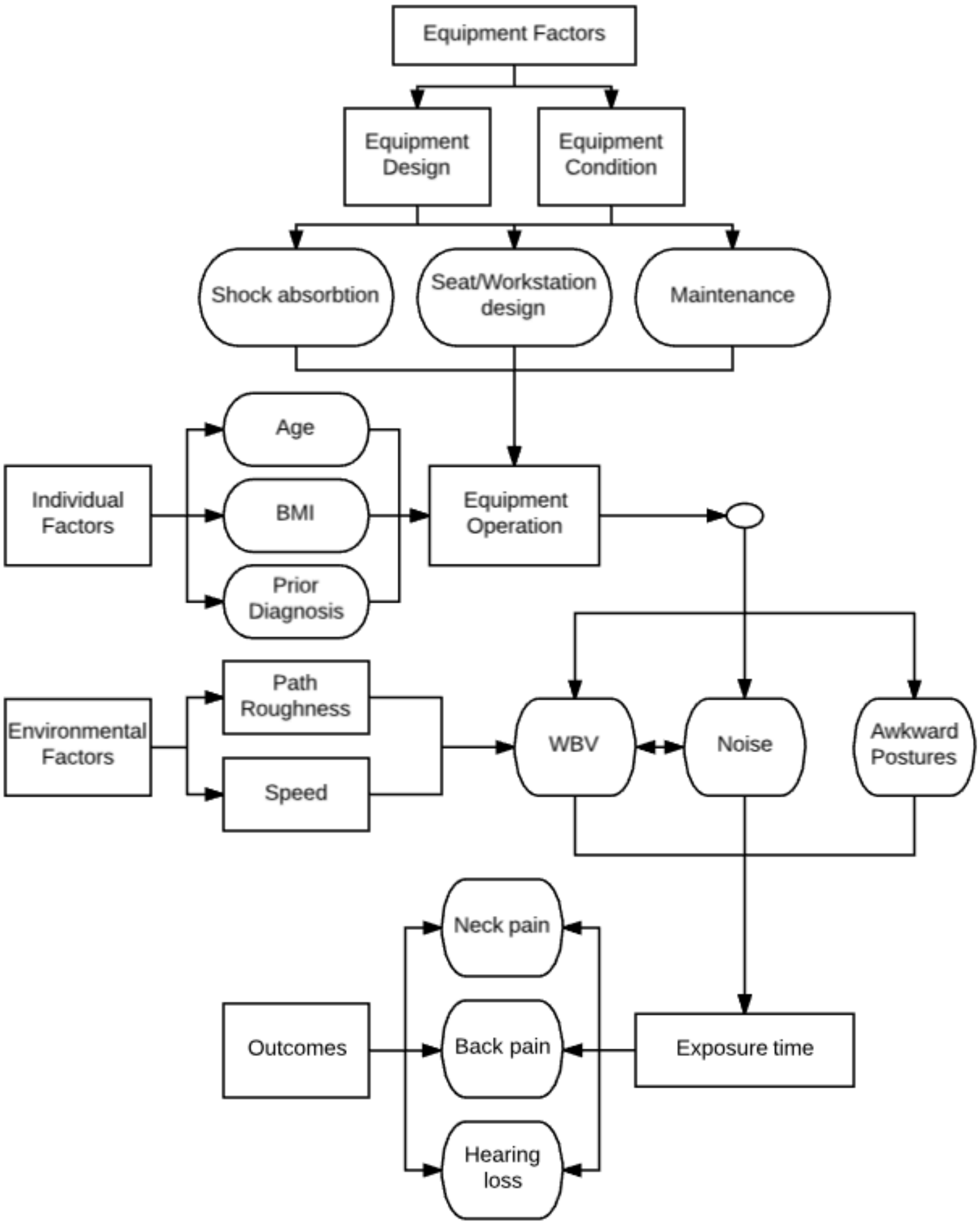
Viikari-Juntura, E., Rauas, S., Martikainen, R., Kuosma, E., Riihimaki, H., Takala, E-P., and Saarenmaa, K. (1996). Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. Scandinavian J. Work Environ. Health. 22(4):251-259.

Wearing, S. C., Hennig, E. M., Byrne, N. M., Steele, J. R., and Hills, A. P. (2006). Musculoskeletal disorders associated with obesity: a biomechanical perspective. Obesity Review. 7(3):239-250.

Wegscheid E. (1994). Another look at skidder ride vibration. J. of Forest Eng. 5:21-32.

Appendix A:

Research Conceptual Model



Appendix B:

Internal Review Board Approval Emails

Stephanie Lynch <stephmlynch@gmail.com>

Protocol approved , #11-343 EX 1111

2 messages

Human Subjects <HSUBJEC@auburn.edu> Tue, Feb 14, 2012 at 10:08 PM
To: Stephanie Lynch <szl0040@tigermail.auburn.edu>
Cc: Mathew Smidt <smidtmf@auburn.edu>, Jorge Valenzuela <valenjo@auburn.edu>

Dear Ms. Lynch,

Your revisions to your protocol entitled " What is the Self-Reported Incidence of Risk Factors Associated with the Development of MSDs in Loggers Across the United States? " have been reviewed. Your protocol has now received final approval as "Exempt" under federal regulation 45 CFR 46.101(b)(2).

Official notice:

This e-mail serves as official notice that your protocol has been approved. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also accept your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Consent document:

Your approved, stamped information letter will soon be sent through campus mail.

Please note that *you may not begin your research that involves human subjects until you receive the consent* with an IRB approval stamp applied. You must use copies of that document when you consent participants, and provide a copy (signed or unsigned) for them to keep.

Expiration:

Your protocol **will expire on November 17, 2012**. Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request. (You might send yourself a delayed e-mail reminder for early next November.)

If you have any questions, please let us know.

Best wishes for success with your research!

Susan

Susan Anderson, IRB Administrator

IRB / Office of Research Compliance

115 Ramsay Hall (basement) ** **NOTE ADDRESS** ***

Auburn University, AL 36849

(334) 844-5966

hsubjec@auburn.edu

Stephanie Lynch <stephmlynch@gmail.com>

Renewal request - approved, Exempt Protocol #11-343 EX 1111

4 messages

IRB Administration <irbadmin@auburn.edu> Thu, Nov 15, 2012 at 10:40 PM
To: Stephanie Lynch <szl0040@tigermail.auburn.edu>
Cc: Richard Sesek <rfs0006@auburn.edu>, Jorge Valenzuela <valenjo@auburn.edu>

Dear Ms. Lynch,

Your request for renewal of your protocol entitled " What is the Self-Reported Incidence of Risk Factors Associated with the development of MSDs in Loggers across the United States " has been approved by the IRB, continuing as "Exempt " under federal regulation 45 CFR 46.101(b)(2).

Official notice:

This e-mail serves as official notice that your protocol has been renewed. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also acknowledge your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Consent:

Your stamped consent will soon be sent by campus mail. You may not continue your research that involves human subjects after *the current expiration date* unless you have received your new consent document with an IRB approval stamp applied. You must provide a copy for each participant to keep.

Expiration:

*****Note that the new policy for Exempt approvals is a *three year approval*.** Therefore, your protocol **will expire on November 17, 2015** . Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request. (*You might consider sending yourself a delayed e-mail reminder.)*

If you have any questions or concerns, please let us know.

Best wishes for success with your research!

Susan

Susan Anderson, M.S., CIM

IRB Administrator

Office of Research Compliance

115 Ramsay Hall, basement

Auburn University, AL 36849

(334) 844-5966

hsubjec@auburn.edu

fax 334-844-4391

Stephanie Lynch <stephmlynch@gmail.com>

Approval, Protocol #13-316 MR 1309

8 messages

IRB Administration <irbadmin@auburn.edu> Tue, Oct 29, 2013 at 3:49 PM
To: Stephanie Lynch <szl0040@tigermail.auburn.edu>
Cc: Richard Sesek <rfs0006@auburn.edu>, Jorge Valenzuela <valenjo@auburn.edu>

Please note: Use IRBadmin@auburn.edu for questions and information; use IRBsubmit@auburn.edu for protocol/forms submissions.

Dear Ms. Lynch,

Your protocol entitled " Survey of Ergonomic Risk Factors among Logging Machines " has received approval as "Minimum Risk" under federal regulation 45 CFR 46.

Official notice:

This e-mail serves as official notice that your protocol has been approved. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also accept your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Consent document:

Your approved, stamped consent document/s will soon be sent. Please make copies as needed.

Please note that you must use copies of that/those document/s when you consent participants, and provide a copy (signed or unsigned) for them to keep.

Expiration:

Your protocol **will expire on September 17, 2014.** Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request.

If you have any questions, please let us know.

Best wishes for success with your research!

IRB / Office of Research Compliance

115 Ramsay Hall (basement)

Auburn University, AL 36849

(334) 844-5966

irbadmin@auburn.edu *(for general queries)*

irbsubmit@auburn.edu *(for protocol submissions)*

Stephanie Lynch <stephmlynch@gmail.com>

Modification request - approved, Protocol# 13-316 MR 1309

1 message

IRB Administration <irbadmin@auburn.edu> Mon, Feb 17, 2014 at 5:35 PM
To: Stephanie Lynch <szl0040@tigermail.auburn.edu>
Cc: Richard Sesek <rfs0006@auburn.edu>, Jorge Valenzuela <valenjo@auburn.edu>

Please note: Use IRBadmin@auburn.edu for questions and information; use IRBsubmit@auburn.edu for protocol/forms submissions.

Dear Ms. Lynch,

Your request for modification of your protocol entitled " Survey of Ergonomic Risk Factors Among Logging Machines " has been approved. The review category continues as "Minimum risk " under federal regulation 45 CFR 46.

Official notice:

This e-mail serves as official notice that your protocol has been modified. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also acknowledge your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Consent document:

Your new stamped consent document will soon be sent. Please make copies as needed.

Please note that you may not initiate the modifications to your protocol that involve human subjects unless you use the new document. You must provide a copy for the participant to keep.

Expiration:

Your protocol **will still expire on September 17, 2014**. Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request.

If you have any questions or concerns, please let us know.

Best wishes for success with your research!

Susan

IRB / Office of Research Compliance

115 Ramsay Hall, basement

Auburn University, AL 36849

(334) 844-5966

IRBadmin@auburn.edu *(for general queries)*

IRBsubmit@auburn.edu *(for protocol submissions)*

Appendix C:

Survey Information Letter

AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING

INDUSTRIAL AND SYSTEMS ENGINEERING

INFORMATION LETTER for Logger Survey

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

You are invited to participate in a research study to assess the self-reported incidence of risk factors associated with the development of musculoskeletal disorders in logging machine operators in the southeastern United States. The study is being conducted by Stephanie Lynch, MPH, under the direction of Mathew Smidt, PhD, in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you are a logging machine operator and are age 19 or older.

If you decide to participate in this research study, you will be asked to complete a survey. Your total time commitment will be approximately one hour. There are no risks associated with participating in this study, and there is no compensation or costs.

If you participate in this study, you can expect to provide valuable information that may aid in efforts to improve comfort in logging operations. We cannot promise you that you will receive any or all of the benefits described.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University.

Your privacy will be protected. Any information obtained in connection with this study will remain anonymous. Information obtained through your participation may be used to fulfill an educational requirement, published in a professional journal, or presented at a professional meeting.

If you have questions about this study, *please ask us now or* contact Stephanie Lynch at (205) 613-5276.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

The Auburn University Institutional Review Board has approved this document for use from 11/18/11 to 11/17/12 Protocol # 11-343 EX 1111

Investigator's signature Date	Co-Investigator Date
Print Name	Print Name

Shelby Center for Engineering Technology
Suite 3301
Auburn, AL 36849-5346
Telephone
334-844-4340
Fax:
334-844-1381

Appendix D:

Study Informed Consent

SAMUEL GINN COLLEGE OF ENGINEERING
INDUSTRIAL AND SYSTEMS ENGINEERING

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
for a Research Study entitled
"Survey of Ergonomic Risk Factors among Logging Machines"

You are invited to participate in a research study to *explore the ergonomic risk factors present in feller bunchers, skidders and loaders.* The study is being conducted by Stephanie Lynch under the direction of Dr. Mathew Smidt in the Auburn University Department of Forestry and Wildlife Sciences. You were selected as a possible participant because you are a logging machine operator and are age 19 or older.

What will be involved if you participate? If you decide to participate in this research study, you will be asked meet at some point before the day of observation for no more than an hour to do informed consent, video consent, get instruction on registering on the AU vendor center site, complete a survey, and for the collection of anthropometric measurements.
On the day of observation, participants will need to meet one hour before the start of the shift so the machine can be equipped with GPS, a point of view camera, and accelerometers (one on the seat and one on the floor of the cab), and an ergonomic checklist will be performed on the machine. Thirty minutes before the shift, the operator will be hooked up with 10 surface electromyography (EMG) sensors that will be placed on the left and right side of the subject's lower back the upper back/shoulder, and the lower abdomen for no more than 2.5 hour, a 17 sensor motion capture system for no more than 2.5 hours, and personal noise dosimeters.
The operator will perform the regular duties of his job for his normal shift as the principle investigator observes from the landing and is available for any questions or concerns or if equipment malfunctions. At the end of the shift the operator will answer a few questions about his machine and shift, and will fill out a body part discomfort sheet. Your total time commitment will be approximately 9 hours.

Are there any risks or discomforts? The risks associated with participating in this study are the risks that are already associated with your job along with possible discomfort or irritation where the surface EMG patches are placed. In the unlikely event you are injured during participation in this study, you will assume all financial responsibility for your own medical care.

Are there any benefits to yourself or others? If you participate in this study, you can expect to contribute to better training practices for the prevention of exposure to risk factors for the development of pain. We/I cannot promise you that you will receive any or all of the benefits described.

Will you receive compensation for participating? To thank you for your time you will be offered $300.00.

Are there any costs? If you decide to participate, you may be asked to run your machine under artificial circumstances if normal tasks are not being performed.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering or the Department of Forestry and Wildlife Sciences.

Participant's initials ______

AUBURN
UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING
INDUSTRIAL AND SYSTEMS ENGINEERING

Your privacy will be protected. Any information obtained in connection with this study will remain confidential. Information obtained through your participation may be used to fulfill an educational requirement, published in a professional journal, or presented at a professional meeting.

If you have questions about this study, *please ask them now or* contact Stephanie Lynch at (205) 613-5276 or Mathew Smidt at (334) 844-1038. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

The Auburn University Institutional Review Board has approved this document for use from 2/11/14 to 9/17/14
Protocol # 13-316 MR 1309

____
Participant's signature Date

____
Printed Name

____
Investigator obtaining consent Date

____
Printed Name

____
Co-Investigator Date

____
Printed Name

Page 2 of 2

SHELBY CENTER FOR
ENGINEERING TECHNOLOGY
SUITE 3301
AUBURN, AL 36849-5346

TELEPHONE
334-844-4340

FAX:
334-844-1381

Appendix E:

Video Release Form

Note: No video data was used for this dissertation, but video was collected.

VIDEO RELEASE

During your participation in this research study, “Survey of Ergonomic Risk Factors among Logging Machines”, you will be videotaped. Your signature on the Informed Consent gives us permission to do so.

Your signature on this document gives us permission to use the videotape(s) for the additional purposes of training or publication beyond the immediate needs of this study. These videotapes will not be destroyed at the end of this research but will be retained indefinitely.

In addition, the following persons or groups will have access to the tapes:
Stephanie Lynch
Dr. Mathew Smidt
Dr. Richard Sesek

Your permission:

I give my permission for videotapes produced in the study , “Survey of Ergonomic Risk Factors among Logging Machines” to be used for the purposes listed above, and to also be retained indefinitely.

______________________________	______________________________
Participant’s Signature Date	Investigator’s Signature Date
______________________________	______________________________
Participant’s Printed Name	Investigator’s Printed Name

Appendix F:

Logging Mobile Machine Operator Survey

Age _____ Height: _____ Weight: _____ Gender: Male or Female

How many years have you worked in the logging industry? _____ years

About how old is the piece of machinery you operate most frequently? ________years

1.Please indicate how often you operate each of the following equipment

*** Wheeled feller-buncher**	Never	Monthly	Weekly	Daily
*** Wheeled skidder**	Never	Monthly	Weekly	Daily
*** Dozer**	Never	Monthly	Weekly	Daily
*** Knuckle boom loader**	Never	Monthly	Weekly	Daily
*** Over-the-road tractor**	Never	Monthly	Weekly	Daily
***Other1(write name)**	Never	Monthly	Weekly	Daily
***Other2(write name)**	Never	Monthly	Weekly	Daily

2. Please indicate whether or not pain, discomfort, or fatigue affects your preference for using this equipment.

	I prefer *NOT* to use this equipment because of pain, discomfort, or fatigue	Neutral	I *prefer* to use this machine over others
*** Wheeled feller-buncher**	Do not prefer	Neutral	Prefer
*** Wheeled skidder**	Do not prefer	Neutral	Prefer
*** Dozer**	Do not prefer	Neutral	Prefer
*** Knuckle boom loader**	Do not prefer	Neutral	Prefer
*** Over-the-road tractor**	Do not prefer	Neutral	Prefer
***Other1**	Do not prefer	Neutral	Prefer
***Other2**	Do not prefer	Neutral	Prefer

3. Please check the most appropriate response				
*** How would you categorize the back pain you've experienced in the past year?**	I have not experienced any pain	Mild	Moderate	Severe
*** How would you categorize the neck pain you've experienced in the past year?**	I have not experienced any pain	Mild	Moderate	Severe

4. Please check the box with the most appropriate response from a normal day

How many hours per work day:	Never	Less than ½	½ to 1	More than 1 to 2	More than 2 to 4	More than 4
***Are you in the cab of a machine/truck?**	◻	◻	◻	◻	◻	◻
***Is your trunk in a twisted position while operating the machine?**	◻	◻	◻	◻	◻	◻
***Is your neck in a twisted position while operating your machine?**	◻	◻	◻	◻	◻	◻
***Do you perform tasks involving repetitive movements of the hands?**	◻	◻	◻	◻	◻	◻
***Do you perform tasks involving repetitive movements of the feet?**	◻	◻	◻	◻	◻	◻
***Are you exposed to vibration from handtools (chainsaws, polesaws, etc.)**	◻	◻	◻	◻	◻	◻

5. When considering the pain you have experienced over the past year, is the source your job(s) in logging or other jobs/activities?

oI have not experienced any pain
oDon't know/Uncertain
oCertainly logging
oA mix of logging and other jobs/activities
oCertainly other jobs/activities

6. Please circle the appropriate response

Have you known loggers that have changed jobs in a logging crew due to pain or discomfort during work?	Yes	No
Have you known loggers that have left logging due to pain or discomfort during work?	Yes	No
When seated in the cab of a machine, are your knees at 90° or slightly more?	Yes	No
When seated in the cab of a machine, are your forearms supported?	Yes	No
Are the controls you use most frequently in the cab of a machine/truck within easy reach?	Yes	No
Have you been diagnosed with any type of musculoskeletal disorder?	Yes	No
Do you use the Internet, at least occasionally?	Yes	No
Do you send or receive email, at least occasionally?	Yes	No
Do you own a computer?	Yes	No
Do you own a cell phone?	Yes	No

7. If you use the Internet, about how often do access it?

oDaily oWeekly oMonthly oNever

8. If you own a computer and/or cell phone, do you use either to do any of the following things? Please place a check next to the activities you DO perform.

oAccess the internet
oLook up health or medical information
oLook up workplace safety information
oHave software applications or "apps" that help you track or manage your health
oSend or receive email
oSend or receive text messages
oSend or receive Instant Messages
oParticipate in a video call, video
oChat or teleconference

9. Thinking now just about your cell phone… Please tell me if you ever use your cell phone to do any of the following things. Please place a check next to the activities you DO perform.

oSend or receive text messages
oSend or receive email
oSend or receive Instant Messages
oAccess the internet
oParticipate in a video call, video
oChat or teleconference

Appendix G:

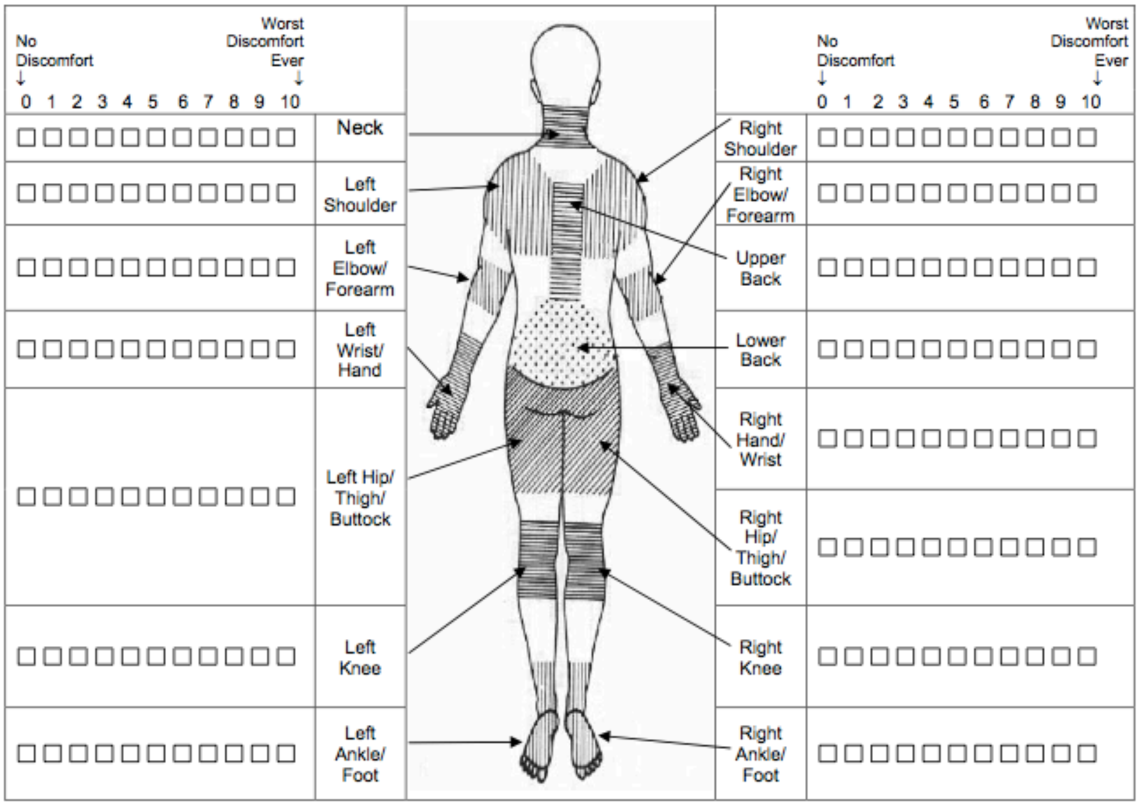
Anthropometric Measurements Collected

Anthropometric measurements

Weight	
Stature (Height)	
Functional Reach	
Functional Reach Extended	
Elbow-Fingertip Length	
Elbow-Grip Length	
Functional Leg Length	
Thumbtip Reach	
Seated Eye Height	
Forearm-Hand Length	
Shoulder Breath	
Seated Height Relaxed	
Seated Height Erect	
Hip Breath	
Buttock-Popliteal Length	
Buttock-Knee Length	
Seated Knee Height	
Popliteal Height	
Foot Width	
Foot Length	
Hand Width	
Hand Length	
Chest Depth	
Elbow Rest Height	
Forearm Grip Distance	

Appendix H:

Body Part Discomfort Scale



Appendix I:

Statistical Analysis

Chapter 2:

Logistics Regression

- 23 observations were deleted due to missing values for the response or explanatory variables.

- Variable list: Name in paper – Name in dataset
  - In Cab - CAB
  - Neck Twist - NECKV
  - Trunk Twist - TRUNK
  - Repetitive Hands - HAND
  - Repetitive Feet – FEET
  - Age – AGE

Dependent variable: back pain, or neck pain (Categorical)
Independent variable: CAB, NECKV, TRUNK, HAD, FEET, AGE

For back pain:

Model Fit Statistics		
Criterion	**Intercept Only**	**Intercept and Covariates**
AIC	363.950	334.324
SC	372.644	360.404
-2 Log L	357.950	316.324

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	0	1	1.6488	1.0244	2.5908	0.1075
Intercept	1	1	3.4756	1.0600	10.7512	0.0010
Intercept	2	1	5.3974	1.1134	23.5015	<.0001
CAB		1	0.2748	0.2163	1.6145	0.2039
TRUNK		1	-0.5327	0.1338	15.8434	<.0001
NECKV		1	0.0607	0.1349	0.2026	0.6526
HAND		1	-0.0137	0.2415	0.0032	0.9547
FEET		1	-0.4419	0.2469	3.2023	0.0735
AGE		1	-0.0314	0.0144	4.7381	0.0295

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
CAB	1.316	0.862	2.011
TRUNK	0.587	0.452	0.763
NECKV	1.063	0.816	1.384
HAND	0.986	0.614	1.583
FEET	0.643	0.396	1.043
AGE	0.969	0.942	0.997

For neck pain:

Model Fit Statistics		
Criterion	Intercept Only	Intercept and Covariates
AIC	341.611	317.844
SC	350.282	343.857
-2 Log L	335.611	299.844

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	0	1	1.2493	1.0048	1.5458	0.2138
Intercept	1	1	3.2395	1.0401	9.7017	0.0018
Intercept	2	1	5.5338	1.1240	24.2405	<.0001
CAB		1	0.0483	0.2110	0.0524	0.8190
TRUNK		1	-0.4160	0.1322	9.8997	0.0017
NECKV		1	-0.1015	0.1363	0.5545	0.4565
HAND		1	0.0971	0.2404	0.1630	0.6864
FEET		1	-0.1313	0.2429	0.2924	0.5887
AGE		1	-0.0309	0.0145	4.5079	0.0337

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
CAB	1.049	0.694	1.587
TRUNK	0.660	0.509	0.855
NECKV	0.903	0.692	1.180
HAND	1.102	0.688	1.765
FEET	0.877	0.545	1.412
AGE	0.970	0.942	0.998

Age as categorical data type:

Age1: 19-30
Age2: 31-40
Age3: 41-50
Age4: 51-60
Age5: 61-70

For back pain:

Model Fit Statistics		
Criterion	**Intercept Only**	**Intercept and Covariates**
AIC	363.383	339.549
SC	372.077	377.221
-2 Log L	357.383	313.549

Analysis of Maximum Likelihood Estimates						
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
Intercept	**0**	1	2.6422	1.6240	2.6471	0.1037
Intercept	**1**	1	4.4957	1.6551	7.3779	0.0066
Intercept	**2**	1	6.4845	1.7054	14.4574	0.0001
CAB		1	0.2738	0.2172	1.5897	0.2074
TRUNK		1	-0.5398	0.1355	15.8775	<.0001
NECKV		1	0.0514	0.1358	0.1436	0.7047
HAND		1	-0.0233	0.2446	0.0090	0.9242
FEET		1	-0.4532	0.2514	3.2489	0.0715
AGE1		1	-1.5920	1.3932	1.3056	0.2532
AGE2		1	-2.1399	1.3860	2.3837	0.1226
AGE3		1	-2.4820	1.3759	3.2538	0.0713
AGE4		1	-2.5505	1.3921	3.3566	0.0669
AGE5		1	-2.8898	1.4675	3.8779	0.0489

Odds Ratio Estimates			
Effect	**Point Estimate**	**95% Wald Confidence Limits**	
CAB	1.315	0.859	2.013
TRUNK	0.583	0.447	0.760
NECKV	1.053	0.807	1.374
HAND	0.977	0.605	1.578

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
FEET	0.636	0.388	1.040
AGE1	0.204	0.013	3.123
AGE2	0.118	0.008	1.780
AGE3	0.084	0.006	1.240
AGE4	0.078	0.005	1.195
AGE5	0.056	0.003	0.986

For neck pain:

Model Fit Statistics		
Criterion	Intercept Only	Intercept and Covariates
AIC	344.098	321.868
SC	352.791	359.539
-2 Log L	338.098	295.868

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > Chi Sq
Intercept	0	1	1.7218	1.6247	1.1232	0.2892
Intercept	1	1	3.7774	1.6535	5.2188	0.0223
Intercept	2	1	6.1528	1.7192	12.8082	0.0003
CAB		1	0.0291	0.2125	0.0188	0.8909
TRUNK		1	-0.4491	0.1352	11.0403	0.0009
NECKV		1	-0.1070	0.1385	0.5966	0.4399
HAND		1	0.1429	0.2448	0.3408	0.5593
FEET		1	-0.1503	0.2495	0.3629	0.5469
AGE1		1	-0.8162	1.4037	0.3381	0.5609
AGE2		1	-2.0776	1.4005	2.2006	0.1380

Analysis of Maximum Likelihood Estimates						
Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > Chi Sq
AGE3		1	-2.0902	1.3862	2.2737	0.1316
AGE4		1	-1.7419	1.3993	1.5496	0.2132
AGE5		1	-2.5478	1.4795	2.9658	0.0850

Odds Ratio Estimates			
Effect	Point Estimate	95% Wald Confidence Limits	
CAB	1.030	0.679	1.561
TRUNK	0.638	0.490	0.832
NECKV	0.899	0.685	1.179
HAND	1.154	0.714	1.864
FEET	0.860	0.528	1.403
AGE1	0.442	0.028	6.924
AGE2	0.125	0.008	1.949
AGE3	0.124	0.008	1.871
AGE4	0.175	0.011	2.720
AGE5	0.078	0.004	1.422

Table 2. Pain vs. Years on Logging
YL1: Years on Logging
1-10: 1 to 10 years.

Table of YL1 by BACK					
YL1	**BACK(BACK)**				
Frequency Percent Row Pct Col Pct	**0**	**1**	**2**	**3**	**Total**
1-10	11 7.80 40.74 33.33	12 8.51 44.44 24.00	3 2.13 11.11 7.89	1 0.71 3.70 5.00	27 19.15
11-20	13 9.22 30.23 39.39	13 9.22 30.23 26.00	11 7.80 25.58 28.95	6 4.26 13.95 30.00	43 30.50
21+	9 6.38 12.68 27.27	25 17.73 35.21 50.00	24 17.02 33.80 63.16	13 9.22 18.31 65.00	71 50.35
Total	33 23.40	50 35.46	38 26.95	20 14.18	141 100.00
Frequency Missing = 16					

Table of YL1 by NECK					
YL1	**NECK(NECK)**				
Frequency Percent Row Pct Col Pct	**0**	**1**	**2**	**3**	**Total**
1-10	11 7.80 40.74 29.73	12 8.51 44.44 21.05	3 2.13 11.11 7.89	1 0.71 3.70 11.11	27 19.15
11-20	13 9.22 30.23 35.14	16 11.35 37.21 28.07	9 6.38 20.93 23.68	5 3.55 11.63 55.56	43 30.50
21+	13 9.22 18.31 35.14	29 20.57 40.85 50.88	26 18.44 36.62 68.42	3 2.13 4.23 33.33	71 50.35
Total	37 26.24	57 40.43	38 26.95	9 6.38	141 100.00
Frequency Missing = 16					

Table 3. Pain vs. Age
AGE1: Age
19-30: age is from 19 to 30.

Table of AGE1 by BACK					
AGE1	**BACK(BACK)**				
Frequency Percent Row Pct Col Pct	**0**	**1**	**2**	**3**	**Total**
19-30	7 4.76 31.82 21.21	8 5.44 36.36 15.69	5 3.40 22.73 11.90	2 1.36 9.09 9.52	22 14.97
31-40	9 6.12 27.27 27.27	13 8.84 39.39 25.49	7 4.76 21.21 16.67	4 2.72 12.12 19.05	33 22.45
41-50	11 7.48 25.58 33.33	11 7.48 25.58 21.57	14 9.52 32.56 33.33	7 4.76 16.28 33.33	43 29.25
51-60	6 4.08 16.22 18.18	12 8.16 32.43 23.53	13 8.84 35.14 30.95	6 4.08 16.22 28.57	37 25.17
61-70	0 0.00 0.00 0.00	7 4.76 58.33 13.73	3 2.04 25.00 7.14	2 1.36 16.67 9.52	12 8.16
Total	33 22.45	51 34.69	42 28.57	21 14.29	147 100.00
Frequency Missing = 10					

Table of AGE1 by NECK					
AGE1	NECK(NECK)				
Frequency Percent Row Pct Col Pct	0	1	2	3	Total
19-30	9 6.16 40.91 24.32	9 6.16 40.91 15.52	3 2.05 13.64 7.32	1 0.68 4.55 10.00	22 15.07
31-40	6 4.11 18.18 16.22	18 12.33 54.55 31.03	7 4.79 21.21 17.07	2 1.37 6.06 20.00	33 22.60
41-50	12 8.22 27.27 32.43	14 9.59 31.82 24.14	14 9.59 31.82 34.15	4 2.74 9.09 40.00	44 30.14
51-60	9 6.16 25.00 24.32	13 8.90 36.11 22.41	11 7.53 30.56 26.83	3 2.05 8.33 30.00	36 24.66
61-70	1 0.68 9.09 2.70	4 2.74 36.36 6.90	6 4.11 54.55 14.63	0 0.00 0.00 0.00	11 7.53
Total	37 25.34	58 39.73	41 28.08	10 6.85	146 100.00
Frequency Missing = 11					

Chapter 3

ANOVA test:
Dependent variable is the Aeq8

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4.48155074	2.24077537	17.89	<.0001
Error	24	3.00558390	0.12523266		
Corrected Total	26	7.48713464			

R-Square	Coeff Var	Root MSE	Aeq8 Mean
0.598567	31.37916	0.353882	1.127762

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Machine	2	4.48155074	2.24077537	17.89	<.0001

Tukey's Test for Aeq8:

Alpha	0.05
Error Degrees of Freedom	24
Error Mean Square	0.125233
Critical Value of Studentized Range	3.53170

Comparisons significant at the 0.05 level are indicated by ***.				
Machine Comparison	**Difference Between Means**	**Simultaneous 95% Confidence Limits**		
Skidder - Feller	0.5375	0.1103	0.9648	***
Skidder - Loader	0.9445	0.5473	1.3417	***
Feller - Skidder	-0.5375	-0.9648	-0.1103	***
Feller - Loader	0.4070	-0.0384	0.8523	
Loader - Skidder	-0.9445	-1.3417	-0.5473	***
Loader - Feller	-0.4070	-0.8523	0.0384	

Chapter 4

Summarize:

Simple Statistics							
Variable	**N**	**Mean**	**Std Dev**	**Median**	**Minimum**	**Maximum**	**Label**
Terrain	11	121.09091	77.98007	103.00000	21.00000	236.00000	Terrain
Time	11	5.17672	2.46459	4.48334	3.07778	12.13333	Time
Speed	11	3.67872	1.06390	3.65930	1.80438	5.60342	Speed

Correlation Matrix:

Spearman Correlation Coefficients, N = 11 Prob > |r| under H0: Rho=0			
	Terrain	**Time**	**Speed**
Terrain Terrain	1.00000	0.47708 0.1379	-0.28900 0.3887
Time Time	0.47708 0.1379	1.00000	-0.63636 0.0353
Speed Speed	-0.28900 0.3887	-0.63636 0.0353	1.00000

Regression Analysis:

Dependent variable: Aeq8
Independent variable: Terrain, Time, and Speed

Root MSE	0.22522	**R-Square**	0.6906
Dependent Mean	1.58196	**Adj R-Sq**	0.5580
Coeff Var	14.2365 6		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	1	0.89568	0.50996	1.76	0.1224
Terrain	Terrain	1	-0.00115	0.00101	-1.14	0.2925
Time	Time	1	0.13344	0.04012	3.33	0.0127
Speed	Speed	1	0.03652	0.09118	0.40	0.7007

Regression Analysis with interaction term:

Dependent variable: Aeq8
Independent variable: Terrain, Time, Speed, Speed*Terrain

Root MSE	0.23561	R-Square	0.7097
Dependent Mean	1.58196	Adj R-Sq	0.5162
Coeff Var	14.89331		

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.76562	0.57210	1.34	0.2293
Terrain	Terrain	1	0.00234	0.00565	0.42	0.6924
Time	Time	1	0.10639	0.06006	1.77	0.1269
Speed	Speed	1	0.09709	0.13548	0.72	0.5005
SpeedTerrain		1	-0.00089786	0.00143	-0.63	0.5522