HETA 99–0025–2756
Oakes and Parkhurst Glass
Winslow, Maine

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Dan Habes, Randy L. Tubbs, and Richard J. Driscoll, of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Desktop publishing was performed by Ellen Blythe. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Ergonomics Evaluation of Windshield Installers at Oakes & Parkhurst Glass

NIOSH was asked to measure how much the power tools vibrate and to identify any other risks to workers' hands, arms, and backs from removing and installing windshields.

What NIOSH Did

Looked at the movements made by workers who replace windshields.

Measured how much effort is needed to cut through windshield adhesives with a cold knife.

Measured how much three powered tools (Equalizer, FEIN, and BTB) vibrate.

Asked the glass installers to tell us where they hurt.

What NIOSH Found

The powered tools vibrate to the point where they should not be used all day.

Using the powered tools causes the workers to bend their arms and wrists more than if they used the hand tools.

Most workers have the strength to cut the glass out with a cold knife.

The windshield glass is too heavy to be set in place by one worker.

Workers reported shoulder, back, and wrist problems that could be related to their job.

What Oakes & Parkhurst Glass Managers Can Do

Train workers in the safe and efficient use of hand tools, particularly the cold knife.

Consider buying hand tools for the workers so they will have them and get used to using them.

Get an air compressor that works efficiently with the pneumatic tools.

Add a handle to the sheath of the Equalizer tool to avoid pinching of the blade.

What Oakes & Parkhurst Employees Can Do

Learn how to use the hand tools to remove glass.

Make sure powered tools are not used all day.

Use the cold knife to cut as much adhesive as possible before using a powered tool.

Get help from another worker when lifting and setting the glass.

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NIOSH National Institute for Occupational Safety and Health

Health Hazard Evaluation Report 99–0025–2756

Oakes and Parkhurst Glass
Winslow, Maine
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SUMMARY

On November 10, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a management request from Oakes & Parkhurst Glass in Winslow, Maine, to evaluate tasks and tools involved in the aftermarket installation of automotive windshields. There was concern that vibration exposure from some of the new power tools available to remove the glass might lead to long–term musculoskeletal disorders and hand–arm vibration syndrome (HAVS) among the workers. The company also was seeking help in developing an accident and injury prevention program.

Use of the vibrating tools to cut through the windshield adhesive was associated with awkward postures of the arm, shoulder, and wrist, and with acceleration levels restricting the amount of time the vibrating tools could be used daily. The hand tools, particularly the cold knife, posed fewer postural demands and could cut through the adhesive with effort levels within the capabilities of most workers. Lifting and setting windshield glass in place without the assistance of another worker was determined to be beyond the capabilities of all but the strongest workers.

The pneumatic BTB tool had the lowest acceleration values, but like the Equalizer Magnum and the FEIN orbital tool, the evaluation criteria suggested that it be used fewer than 8 hours per day. Measured acceleration levels for all three tools were affected by worker practices, type of cutting blade used, and in which of the two glass installation facilities the measurements were taken.

Review of Occupational Safety and Health Administration (OSHA) Log and Summary of Occupational Injuries and Illnesses (the OSHA 200 log) for the year 1998 revealed no entries related to HAVS or musculoskeletal disorders. Four workers were interviewed. They reported a range of conditions that included sore shoulders, low back pain, strained wrists, generalized muscle aches, cuts, and bruises.

NIOSH investigators conclude that use of the cold knife and other hand tools to remove windshields from motor vehicles is within the physical capabilities of most workers and poses less risk of injury or musculoskeletal disorders than vibrating tools. All of the vibrating tools evaluated were found to be in a restricted–use category according to the evaluation criteria, and should be used only for necessary tasks when removing glass. The unassisted setting of windshield glass into place by one worker is beyond the capabilities of most individuals and should be avoided. Recommendations on page 23 are aimed at reducing the risk of injury and musculoskeletal disorders, including HAVS while using the hand tools and vibrating tools.

Keywords: SIC 7536, auto glass installation and removal; ergonomics, vibrating tools, awkward postures, hand tools, pulling forces, hand–arm vibration syndrome.

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INTRODUCTION

On November 10, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a management request from Oakes & Parkhurst Glass in Winslow, Maine, to evaluate tasks and tools involved in the aftermarket installation of automotive windshields. There was concern that vibration exposure from some of the new power tools available to perform the task might lead to long term musculoskeletal and hand–arm vibration syndrome (HAVS) problems among the workers. The company also was seeking help in developing an accident and injury prevention program.

NIOSH representatives visited the site January 11–14, 1999. The visit included an opening conference and visits to two of the company's windshield replacement shops. During these two site visits, workers were interviewed, workers performing the various job tasks involved in windshield removal and installation were videotaped, and vibration acceleration measurements were made on the power tools used by the workers. The closing conference was held on the afternoon of January 14, 1999.

BACKGROUND

Oakes & Parkhurst Glass employs 35 people in five shops, 27 of whom are installers. In addition to windshields, workers install garage doors, vinyl siding, replacement windows, and commercial store–front glass. Replacing windshields is a small part of the company's business. Over the years, the methods and materials used to replace automotive glass have changed while the primary tools used have not. Prior to the mid 1980s, windshields were secured using a butyl–based compound as an adhesive. The main function of the butyl compound was to hold the windshield in place and prevent water leaks. As vehicles became lighter and frame and pillar components were made with less substantial materials, the windshield emerged as a significant component in a vehicle's structure, particularly for maintaining the integrity of the roof in rollover accidents. This necessitated the use of a stronger adhesive to ensure that the windshield would stay in place during a vehicle rollover. Adhesives used now are polyurethane–based, and are much stiffer and more difficult to cut than the butyl–based compounds.

The traditional tools used to remove windshields include a variety of knives, blades, and chisels to cut through the adhesive. These are still used, but the arrival of the polyurethane adhesives brought with them a selection of power tools designed to cut through the stronger adhesives. These tools are either electric or air–powered (pneumatic) and cut the seal with a reciprocating or orbital vibrating action.

Job Description

The following are the general elements comprising the task of replacing a damaged windshield:

1. Clean debris (dirt, leaves, snow, salt) from the vehicle and allow it to reach the shop's ambient temperature.

2. Remove any exterior moldings around the perimeter of the windshield.

3. Remove exterior cowling, windshield wipers, and radio antenna, if necessary.

4. Select the appropriate tool and method of glass extraction. The adhesive securing the windshield can be cut from inside the vehicle, outside, or with a combination of the two methods.

5. Lift the windshield from the car. This task is generally performed by two workers because nearly all installations at Oakes & Parkhurst Glass are performed in one of their shops where help is available. Most windshields weigh between 50 and 60 pounds.

6. Remove excess adhesive from the pinch weld of the car. The pinch weld is a groove around the

perimeter of the windshield opening on which the glass is placed. This task is accomplished with specialized chisels that fit in the shape of the pinch weld.

7. Clean and prime the pinch weld groove and the new windshield, as necessary.

8. Apply the polyurethane adhesive to the windshield or to the pinch weld. This step is a matter of installer preference. When the adhesive is applied to the glass, the windshield is placed horizontally on a stand. This technique relieves the worker from having to reach across the vehicle while holding a caulk dispenser, but care must be taken to ensure that the polyurethane will line up properly with the pinch weld. Using this method, the weight of the caulk gun is supported by the glass, but the installer abducts (raises) the shoulders as the dispensing tool is moved along the curved edges of the glass.

9. Set the glass. When the polyurethane is applied to the glass, the windshield is usually lifted into place by two workers to avoid disturbing the bead of adhesive. Suction cups with handles are affixed to the underside of the glass to facilitate the lifting and maneuvering of the glass. When the polyurethane is applied to the vehicle's pinch weld, the glass can be lifted and gripped in any manner chosen by the installer.

10. Reinstall molding and other components that were removed from the vehicle.

11. Allow polyurethane to cure for at least one hour in the garage before releasing the vehicle to the customer.

These steps can usually be accomplished in 2.5 hours or less.

Tool Descriptions

Cold Knife

The cold knife is a versatile, non–powered tool used to cut the adhesive between the glass and the pinch weld. The typical cold knife has a metal handle five inches long which is held by either hand, depending on which side of the vehicle the cut is being made. There is a sharp, narrow blade at the bottom perpendicular to the handle. A pull handle three inches long is attached to the main handle with a metal cable forming a "T." This handle is held with the other hand as the cold knife is pulled through the adhesive. There are other blades and main handle sizes available for the cold knife.

Long Knife

The long knife has a metal handle and a long shank with a razor blade tip. It is used primarily to finish breaking the seal from inside a vehicle in instances when the cold knife did not completely cut through the seal from the outside. Incomplete cuts occur most commonly at the bottom edge and corners of the windshield glass.

Other Non–powered Tools

There are a variety of chisels, scrapers, and cut–out knives that the installers use to loosen the glass at hard–to–reach places like the corners and bottom of the windshield. The availability of these specialty tools depends on each worker at Oakes & Parkhurst Glass because the hand tools are the property of the glass installers. The company only buys power tools for the workers to use.

Equalizer® Magnum

The Equalizer is a powered tool with a reciprocating blade used to cut through the polyurethane adhesive. The blade is contained in a long sheath with only the tip exposed, but otherwise the Equalizer resembles a pistol–type scroll or jig saw. Usually a worker will cut the glass out with the Equalizer from inside the car. Workers who usually use the cold knife standing outside the vehicle will often use the Equalizer to free a corner of the glass or any other point along the perimeter of the glass that did not cut easily with the cold knife.

FEIN Window Cutter (Model AstIxe 638)

The FEIN tool is a straight–handle powered tool that somewhat resembles the cold knife. It can be used with either straight or hook–shaped blades and has an optional pull "T" handle like the cold knife. The blade cuts through the windshield adhesive with a vibrating, orbital action.

BTB Air Power Tool

The BTB is a straight–handle, air–driven tool with a reciprocating blade. The tool can be equipped with blades of various lengths and shapes. The BTB power tool can be used inside or outside the vehicle, depending on the type of blade in use. The tool was powered by a 110 volt air compressor in the garages visited during this evaluation.

METHODS

Ergonomics

The ergonomics evaluation took place at two of the company's glass shops. At each of these sites, workers were videotaped while performing the various tasks needed to replace a windshield. Powered tools were weighed with a Wagner Model FDV–50 push–pull force meter, and the amount of force needed to cut through the polyurethane adhesive with a cold knife was measured with the same device. Reach distances and other workplace dimensions were measured with a standard tape measure. The purpose of the video tapes was to allow for subsequent analysis, in either real time or slow motion, to categorize and evaluate body postures and to provide inputs into biomechanical models. It also gave a real–time depiction of the activities performed by the installer while the powered tools were being evaluated for their vibration output.

Hand–Arm Vibration (HAV)

The NIOSH investigators spent two days measuring HAV on three hand–held powered tools used at two of the company's windshield replacement facilities. The measurement procedures described here were developed from the evaluation criteria described in the next section of this report. The investigators collected vibration data using the equipment listed in Table 1.

Before and after each day of data collection, the investigators calibrated the three channels for all the necessary power unit gain settings using a hand–held calibrator. The calibration procedure recorded the channel's system sensitivity, including the accelerometers, cables, power units, and the digital audio tape (DAT) recorder. The NIOSH investigators monitored the calibration signals with an oscilloscope as they were recorded on DAT tape for 30–60 seconds. The channel information, i.e., channel number, accelerometer serial number, axis, and power unit gain setting, was documented on a separate voice channel of the recorder. Figure 1 shows a schematic of the equipment set–up during calibration.

The investigators attached accelerometers to the handle of the tool ensuring that the three accelerometers were fixed as close to the worker's hand as possible without interfering with the normal operation of the tool. The accelerometers were screwed into a 3–axis mounting block welded to a hose clamp. The investigators identified and recorded the x, y, and z axes for the appropriate accelerometer using the basicentric coordinate system described in the Evaluation Criteria section. The clocks on the DAT tape recorder and 8 millimeter (mm) video camera were synchronized, enabling a complete documentation of the worker's and tool's activity during data collection. The worker was instructed to work normally as raw unweighted vibration data and video were recorded. To avoid overloading the DAT tape recorder, the investigators monitored the signal levels on the oscilloscope and DAT level indicator and adjusted the power unit gains accordingly. Figure 2 shows the equipment set–up during data collection and the single hose clamp mounting technique.

The analysis and reporting techniques were developed from the four referenced standards discussed in the Evaluation Criteria section. The NIOSH investigators used the equipment and software listed in Table 2 to analyze the collected data and generate acceleration versus frequency graphs.

In the laboratory, a NIOSH investigator analyzed over 100 acceleration measurements in meters per second squared (m/s^2) on three brands of powered tools from the x, y, and z axes. Before any analysis, a log sheet of the DAT data tape was created. By watching the video in synch with the vibration data, the investigator was able to record measurement locations on the DAT tape. The tape counter (start/finish), event number, measurement number, approximate actual time and date of the data collection, tool and attachment description, power unit gain setting, and the averaging time of the measurement were all contained in the log sheet.

Next, the investigator set up the unit conversions (mV [millivolts] to m/s^2) on the analyzer for each channel and power unit gain setting. This was accomplished by running the calibration signals on the DAT tape through the real–time analyzer. The sensitivities were measured and stored on the analyzer. Referring to the log sheet, the investigator played HAV data through the analyzer using the 1/3 octave band filters, converting the real time data into the frequency domain. Each measurement maximized the available averaging time to ensure credible data. A majority of the measurements had averaging times lasting over 30 seconds. Figure 3 shows the equipment set–up used during data analysis. Notice that the 8 mm camera and DAT recorders are now players. This set–up allows the investigator to totally recreate the test recorded in the field.

Each of the measurements graphed acceleration versus frequency across the 1/3 octave center frequency bands of 6.3 Hertz (Hz) to 1,250 Hz. The American National Standards Institute's (ANSI) suggested time–of–exposure zones were overlaid on the tool data to identify excessive acceleration levels. In addition, the overall weighted acceleration for each measurement was calculated using Equation 1 (Evaluation Criteria section).

Medical

To determine whether auto glass installers were experiencing musculoskeletal disorders as a result of their work, installers were asked to describe any work–related musculoskeletal symptoms (such as joint pain, muscle strain, or numbness) that they had. The four workers interviewed were the glass installation staff at the two glass shops the company asked the NIOSH investigators to evaluate. Each facility had an experienced installer (greater than 10 years on the job) and a novice installer (less than 2 years experience). As a general policy, workers are interviewed individually and privately away from the work station; however, because of the nature of the work at this glass shop, and the demands of the workload during our visit, workers were interviewed at their respective work stations. In addition to personal interviews, the Occupational Safety and Health Administration (OSHA) 200 log of injuries and illnesses was examined for any notation of recordable injury.

EVALUATION CRITERIA

Ergonomics

Overexertion injuries, such as low back pain, tendinitis, and carpal tunnel syndrome, are often associated with job tasks that include: (1) repetitive, stereotyped movement about the joints; (2) forceful manual exertions; (3) lifting; (4) awkward and/or static work postures; (5) direct pressure on nerves and soft tissues; (6) work in cold environments; or (7) exposure to whole–body or segmental vibration.[1,2,3] The risk of injury appears to increase as the intensity and duration of exposures to these factors increases and recovery time is reduced.[4] Although personal factors (e.g., age, gender, weight, fitness) may affect an individual's susceptibility to overexertion injuries/disorders, studies conducted in high–risk industries show that the risk associated with personal factors is small compared to that associated with occupational exposures.[5]

In all cases, the preferred method for preventing/controlling work–related musculoskeletal disorders (WMSDs) is to design jobs, work stations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker. Under these conditions, exposures to task factors considered potentially hazardous will be reduced or eliminated.

The criteria used to evaluate the glass replacement job at Oakes & Parkhurst Glass were workplace and job design criteria found in the ergonomics literature and recommendations for acceptable lifting weights as determined by the NIOSH Revised Lifting Equation.[6] The biomechanical forces associated with the unassisted lifting and setting in place of a windshield on a vehicle was evaluated with the Michigan 3–Dimensional Static Prediction Program.[7]

The NIOSH lifting equation (NLE) is a tool for assessing the physical demands of two–handed lifting tasks. A full description of the components of the NLE is provided in Appendix A. In brief, the equation provides a recommended weight limit (RWL) and a lifting index (LI) for a lifting task, given certain lifting conditions. The RWL is the weight that can be handled safely by almost all healthy workers in similar circumstances. The LI is the ratio of the actual load lifted to the RWL. Lifting tasks with a LI $\leq$ 1.0 pose little risk of low back injury for the majority of workers. Tasks with a LI > 1.0 may place an increasing number of individuals at risk of low back injury. The consensus opinion of experts described in the NLE report is that tasks with a LI > 3.0 pose a risk of back injury for most workers.

Hand–Arm Vibration (HAV)

In general, vibration is the study of mechanical oscillations of a dynamic system. Frequency, displacement, velocity, and acceleration are four parameters that characterize vibration. Usually, frequency and acceleration are the two quantities that draw the most concern. The vibration data in this report are graphed as acceleration versus frequency in a log–log plot. The motion of a vibrating system is periodic. This means the motion is repetitive, creating a definite cycle or period. Frequency is the inverse of the period (1/T, where T is the period) and has units of Hz or cycles per second. Acceleration levels have dimension, in the International System of Units (SI), of m/s^2 or units of gravity (g's) and are vector quantities that characterize the amplitude and direction of vibration.

Vibration is an ergonomic stressor seen in a number of industries. For example, forestry, electronics, automobile, aerospace, shipbuilding, mining, transportation, road construction, trucking, and even dentistry all are industries that involve vibrating hand–held tools and/or vehicles. Occupational vibration exposure is classified as either whole–body vibration (WBV) or HAV, the latter sometimes referred to as segmental vibration. Occupational WBV usually involves industrial vehicles, public transportation, or vibrating platforms. The vibration enters through the worker's feet and/or seat. In comparison, HAV is produced by power tools that are either electric, pneumatic, or hydraulic. Drills, impact hammers, polishers, buffers, rivet guns, sanders, grinders, routers, and nut runners are all examples of common power tools found in industry that expose workers to HAV.

Hand–Arm Vibration Syndrome

The health effects from over–exposure to HAV is hand–arm vibration syndrome (HAVS). Basically, HAVS involves circulatory, neurological, and musculoskeletal disturbances. Victims experience vasospasms which reduce the blood flow in the fingertips and cause the fingers to turn white or blanch. These attacks are triggered by cold temperatures. Sufferers may also experience numbness, tingling, and sensitivity threshold shifts after years of HAV exposure. These disturbances are caused by damage to the sensory nerves in the hand and arm and are more permanent than circulatory disturbances.[8] Finally, some musculoskeletal problems can be attributed to HAV. Muscle fatigue is the most common outcome, and is probably linked to the neurological sensitivity threshold shift which may cause workers to unintentionally and unnecessarily over–grip the tool.

Scientists and physicians are continuously improving screening and monitoring techniques for HAVS. The most widely used scales for classifying the circulatory and neurological symptoms are the Stockholm Workshop Scales.[9,10] Currently, no such scale exists for rating the musculoskeletal symptoms caused by HAV.

Standards and Criteria

The four recommended standards and criteria for assessing HAV exposure are the following: (1) ANSI S3.34–1986, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand;[11] (2) International Standards Organization (ISO) 5349–1986, Mechanical vibration – Guidelines for the measurement and the assessment of human exposure to hand–transmitted vibration;[12] (3) Threshold Limit Values (TLVs®) and Biological Exposure Indices by the American Conference of Governmental Industrial Hygienists (ACGIH®);[13] and (4) NIOSH Criteria for a Recommended Standard: Occupational Exposure to Hand–Arm Vibration.[14]

The ANSI and ISO standards provide similar accepted measurement and reporting techniques. Both documents define the biodynamic and basicentric coordinate systems for positioning the accelerometers used to measure the vibration in the three orthogonal axes of direction; up and down, side to side, and back and forth. The basicentric coordinate system was chosen for this survey. This system seems to be easier to apply since the Y direction is based on the tool geometry rather than the hand position. The Y axis parallels the handle of the tool. The X axis runs perpendicular to plane containing the top of the hand. The Z axis follows and should be aligned with the forearm. Figure 4 shows a typical basicentric coordinate assignment.

In addition, the ANSI and ISO standard both provide a plot to predict the latent periods before the first stage of HAVS. The plots are not in the body of the standards but are found in an appendix. The accuracy of this approach has been questioned[15] and has therefore been left out of this report.

The ANSI, ISO, and ACGIH require weighting the 1/3 octave band acceleration data (af) to find an overall acceleration value for the 1/3 octave center band frequencies 6.3 through 1,250 Hz. The weighting factors (Wf) for each center band frequency are given in both the ANSI and ISO standards. These factors gradually reduce the significance of acceleration beyond 20 Hz and are used to calculate the overall weighted acceleration (OWA). Equation 1 calculates the OWA.

$$OWA = \left(\Sigma \left[Wf\ af \right] 2 \right)^{½} \qquad \text{Equation (1)}$$

ANSI incorporates the weighting filter into suggested HAV exposure zones. These zones demonstrate that acceleration levels at higher frequencies are considered to be less dangerous. In the analysis for this report, the exposure zones were over–laid on the unweighted data to reveal the suggested daily use of the hand–held power tool. Figure 5 shows the suggested ANSI exposure zones.

The ACGIH TLVs determine a time–weighted average of the OWA for the dominant axis of each exposure, defined as the axis with the highest overall acceleration. This analysis method provides the investigator with a single number for the HAV assessment of multiple tools and/or tasks.

Table 3 shows the suggested overall daily exposure limits found in the ACGIH TLVs.

Unlike the ANSI and ACGIH criteria, NIOSH does not provide a recommended exposure limit for HAV. The NIOSH criteria document emphasizes reporting unweighted data since the weighting factors used in the other criteria are based on limited research.[16] This criteria document also recommends conducting HAV measurements from 5 to 5,000 Hz. Although no current standard exists that links unweighted acceleration levels to health risks, some studies have suggested that high frequency vibration may cause more damage than once believed.[17]

RESULTS

Ergonomic

Posture

Video analysis indicated that reaching across the windshield to cut the polyurethane with the cold knife resulted in trunk and shoulder flexion. Hand postures while using the cold knife were mainly neutral with both hands in a power grip (fingers wrapped around the handle). The fender of the vehicle provides good leverage for pulling the knife towards the body.

Use of the powered tools while inside the car resulted in cramped and awkward postures of the trunk and shoulder. The most common awkward posture was shoulder and elbow flexion (hands above the shoulder) when cutting the top and sides of the glass. During these cuts the worker must support the weight of the tool, which ranged from 2.2 pounds for the BTB air–powered tool to 5.7 pounds for the Equalizer Magnum. For cuts along the bottom edge, the postures are more neutral and the tool weight is supported by the vehicle dashboard. Wrist postures were generally neutral while using the powered tools, mainly because of the need for precision positioning of the cutting blade. The dominant hand was mostly neutral, but the other hand was often in a pinch grip, particularly when the worker held the sheath of the Equalizer as it was guided through the polyurethane. Pinch grips are not recommended when using tools because strength capability while pinching is only 15–25 % of that while using a power grip.[18]

The main postures associated with use of the Beta gun (20.5 pounds) for dispensing the polyurethane were trunk flexion and shoulder abduction. The shoulder abduction peaks as the worker reaches the edges of the glass, which are curved upwards.

Force

Two measures of the force needed to pull a cold knife through a polyurethane bead were taken from a worker experienced with the tool. The first was with the blade inserted as close to the glass as possible, a technique which minimizes the force needed to cut the polyurethane. The force measurement was 35.5 pounds. The second measurement was made using the same cold knife with the blade inserted in the middle of the polyurethane. The resulting force was 60 pounds.

Lifting

Application of the NLE to the unassisted lifting of a windshield and placing it in the opening results in a lifting index of between 2.5 and 3.1. The assumptions made were that lifting took place occasionally (less than once per five minutes), the weight of the windshield was between 50 and 60 pounds, there was no twisting of the body at the moment of setting the glass, that the hand–to–load coupling was fair (hands could not be wrapped around the glass), and that significant control was needed at the destination of the lift. Comparison of these results to the NLE criteria indicates that one–person lifting can be safely accomplished by only the strongest workers (50–pound glass) or should not be attempted at all (60–pound glass).

Hand Arm Vibration

Oakes & Parkhurst Glass provided NIOSH investigators three different powered tools to evaluate in their Belfast and Farmington, Maine, installation facilities. One experienced installer in each of the two garages used the tools in the removal of auto windshields. The installers were asked to use the tools as they normally would in the removal of the glass while the tool was instrumented with the vibration–measurement transducers. All three powered tools were evaluated at the Belfast shop; however, because of difficulties with the shop's air compressors, the pneumatic tool was not used in the Farmington location. Also, the installer at the Belfast location used both a hooked and straight blade with the FEIN tool. Each of these conditions were analyzed separately. The Farmington employee only used the FEIN tool with a hooked blade. Vibration acceleration data were recorded for the entire time that the tool was used during windshield removal.

The initial analysis of the vibration data involved timing the periods when the tool was in actual use. For the Equalizer Magnum and FEIN tools, the periods were generally 10 to 60 seconds in duration. Because of the small air compressor at the Belfast facility, which did not allow the BTB tool to run as long as was necessary to perform the tasks needed in the removal of the windshield, the time periods for this tool were only 10– 20 seconds. Each individual data run was analyzed with the real–time analyzer to calculate the acceleration energy in the one–third octave bands from 6.3 to 1,250 Hz. The median acceleration levels were then calculated for the measurements made on each installer using a particular tool.

The one–third octave band acceleration data for each tool/installer condition were graphed onto the ANSI recommended exposure zones for the three orthogonal directions and are presented in Figures 6–11.[11] Also included in each figure is the median overall weighted acceleration value calculated according to Equation 1 for the axis having the highest energy. The ANSI, ISO, and ACGIH evaluation criteria all state that the axis with the most energy is to be used when comparing the vibration levels of a tool to the criteria.[11,12,13] Inspection of the figures shows that all three tools used in the two installation locations fall into some restricted–use time zone regardless of who was using the tool.

The pneumatic BTB tool had the lowest acceleration values. The one–third octave values indicate that the tool can be used 4–8 hours per day. The OWA value of 4.9 m/s^2 places the tool in the 2–4 hour zone. The other reciprocating tool, the Equalizer Magnum, was found to have vibration levels that either placed the tool at the upper extreme of the 1–2 hour zone (less than 1 hour when comparing the OWA value, see Figure 6) or in the not to be used for any amount of time (Figure 7), depending on who was using the tool during the measurement period. The orbital tool (FEIN) was measured three different times, with either a hooked or straight blade and at each of the two locations. For the hooked blade, the FEIN tool fell into the 1–2 or 2–4 hours per day range. The one installer who also used the FEIN tool with a straight blade had acceleration levels that placed the tool into the 2–4 hour range. Both electric–powered tools had maximum vibrational energy in the Z–axis which travels along the worker's forearm. The BTB tool was measured with maximum energy in the Y–axis which runs parallel to the handle of the tool.

Medical

There were no recordable injuries noted in the OSHA 200 log for the previous year. Workers described conditions that could be considered work related musculoskeletal injuries, however, because the number of workers interviewed was less than or equal to five workers, the Centers for Disease Control and Prevention (CDC) privacy regulations prohibit us from enumerating conditions or symptoms that could identify individual workers. Therefore, results of the personal interviews are presented without specific symptom counts or tabulation.

Workers reported a range of conditions that included sore shoulders and low back, strained wrists, generalized muscle aches, cuts, and bruises. In general, the more experienced workers reported less injury and greater efficiency when working with the cold knife than when working with the powered window extracting tools. Experienced workers stated that they preferred using the cold knife but added that under certain conditions they had to use a powered tool to complete the removal of the windshield glass.

DISCUSSION

Ergonomics

Available data for force capability from a standing position indicate that the upper limit for a male pulling a lever towards the body is about 120 pounds.[19] This assumes that the point of application of force on the lever is optimized between waist and shoulder height. This type of body posture and motion closely resembles that used with the cold knife and indicates that the force needed to cut through the polyurethane with the cold knife is well within the capabilities of most workers. There is also sufficient recovery time for the exertions needed to cut though the polyurethane by hand. Video analysis indicated that the time the cold knife was used to remove the glass during a one hour installation was between three and five minutes. Within the five minute period, the glass is separated from the pinch weld by a series of cuts lasting 10 or 15 seconds. Recovery time criteria indicate that for moderate static muscle exertions, the exertion can be repeated when about twice the exertion time has elapsed.[18] The installer gets enough recovery time between exertions as the knife is repositioned for successive cuts or by walking around the vehicle to cut the other side of the windshield. It is important to note, however, that the observations of the cold knife in use, and the force measurements taken while using it, were from an experienced worker. Even though one of the NIOSH investigators tried the cold knife and found it to be fairly easy to use, inexperienced workers may consider the cold knife to be awkward and difficult to use, presenting a risk of injury if the blade were to slip out of the polyurethane as it was being pulled towards the body. Such an occurrence would be most likely when the tool was being used in a cold or wet environment or while the installer was in an unstable posture such as when standing on a step or on the running board or rocker panel of a large vehicle.

Of the four workers observed during the evaluation, only one lifted glass without assistance from other workers. The lifting analyses indicated that at the minimum, there would be an elevated risk of injury to the low back of a worker who lifted the glass alone. No video or relevant body posture measurements were taken during this study that would provide inputs into the Michigan biomechanical model, but results of a NIOSH evaluation of lifting automobile glass in a previous Health Hazard Evaluation (HHE) indicated that only 3% of the male population has the shoulder strength to lift a 50–pound windshield and set it in place.[20] This finding confirms the results of the NLE application indicating that only the strongest workers should be lifting windshield glass without assistance. In general, the risk of injury due to lifting is not a concern at Oakes & Parkhurst owing to the few number of installers who choose the solo method of setting the glass.

Vibration

Powered–tool usage during this evaluation was somewhat contrived to allow the NIOSH investigators to obtain sufficient acceleration measurements on the tools for meaningful analyses. The experienced installers at the two locations most likely used the powered tools longer than they normally would because during typical installations their preferred tool is the cold knife. Despite this alteration of their normal routine, the installers only used the powered tools from 1 to 4 minutes per windshield. Even with the restrictions in usage recommended by the evaluation criteria, 4 minutes per job would allow these two installers to replace up to 15 windshields per day. The vibration levels measured in Farmington with the Equalizer tool would preclude its use for any amount of time. Further analysis of the video record showed that the manner in which the two installers held this tool seemed to affect the acceleration measurements. The Farmington employee placed one hand on the handle of the tool and his second hand on top of the tool's case, leaving the sheathed blade untouched. The Belfast employee placed his second hand on the blade's sheath, much closer to the tip of the blade.

The latter work practice appears to reduce the amount of vibration measured on the handle. However, as was pointed out earlier in the report, the second hand used a pinch grip on the sheath that may lead to musculoskeletal problems.

The measurements on the BTB tool were restricted because of the size of the air compressor at the Belfast garage. The available compressed air was insufficient to allow the pneumatic tool to operate for more than 15–20 seconds at a time before the tool would bog down and fail to cut the adhesive. A new air compressor would be needed that delivered sufficient air pressure for longer time periods to adequately measure the vibration levels emitted by this powered tool.

A question that arises from this evaluation is how would an inexperienced installer use the powered tools. It is probable that an inexperienced employee not trained in the use of the cold knife may want to use powered tools to complete a majority of the glass removal. This would obviously increase the amount of time that the tool was used on each job, thus decreasing the number of windshields able to be replaced per day. In the case of the experienced installers, the powered tools sometimes appeared to place the employee in positions that may be less desirable from an ergonomic perspective, i.e., the use of powered tools may necessarily put workers in postures that are not recommended because of their larger size and power cords or hoses.

Hand Tools versus Powered Tools

The results of this evaluation suggest that the cold knife should be used as much as possible during a windshield removal and that the powered tools should be used as a back–up to the cold knife in corners and other hard–to–reach areas on the windshield. The powered tools result in more awkward postures than the cold knife, and the vibration levels are such that each falls into some type of restricted use category. The powered tools are more expensive and require maintenance. Powered tools must also be used carefully, as they can cause damage to a vehicle's dashboard or headliner if the worker deviates from the cut line. Use of the powered tools, particularly the Equalizer Magnum, creates a conflict between work practices that reduce vibration and those that add to the risk of injury to the upper extremity (holding the tip of the sheath with a thumb opposing index finger pinch grip).

The hand tools require more skill to use than the powered tools, but once the skill is acquired, they can be used with effort levels within the capabilities of most workers. The hand tools are not expensive, but a variety of blades and chisels are needed for the many applications that are encountered. The hand tools are paid for by the worker, not the company. There is a danger of acute injury using the hand tools, particularly the cold knife, because the tool is pulled toward the worker and could result in a serious cut if the blade slips out of the polyurethane bead. Padding on the handles of the cold knife and other hand tools would make them more comfortable and easier to hold onto, decreasing the risk of acute injury.

CONCLUSIONS

1. The amount of pull force needed to cut through the polyurethane adhesive with the cold knife is within the strength capabilities of most workers.

2. The postural load on the trunk and upper extremities is greater while using any of the powered tools observed than that while using the cold knife.

3. All of the powered tools measured in the evaluation fell into a restricted use category. Depending on the tool and the employee, the restrictions ranged from 4 to 8 hours per day of accumulated use to not to be used at all because of excessive acceleration levels.

4. The unassisted lifting of windshield glass exceeds the capabilities of most workers and presents an elevated risk of low back and shoulder injury.

RECOMMENDATIONS

Based on the measurements and observations made during the evaluation at Oakes & Parkhurst Glass, the NIOSH investigators offer the following recommendations to improve the work conditions for the employees.

1. Train workers in the safe and efficient use of the cold knife to remove windshield glass. There may be training materials available from tool manufacturers, but based on the observations made during this evaluation, sufficient training in the use of the cold knife can be obtained from experienced workers already employed by the company.

2. When removing windshield glass, use the cold knife as the first option for cutting the polyurethane. There should be a variety of blades and cold knife sizes available to the workers so that the cold knife can be used in all but the most difficult windshield removal tasks. Powered tools should also be made available to workers to finish the windshield removal task, if necessary. The results of this evaluation indicate that any of the powered tools measured during the evaluation may be used, but for less than 8 hours per day.

3. Consider purchasing hand tools for the workers, in addition to the power tools, which are already provided by the company. As noted in the Results and Discussion sections, many workers, particularly new ones, do not have a selection of hand tools from which to choose because, under the current system, they are the personal property of the installer. The more experienced workers should be consulted in compiling the selection of tools to be provided by the company to all windshield installers. The newer hand tools have cushioned handles for improved support and comfort for the hands.

4. Add a removable T–shaped handle that can be attached to the blade sheath of the Equalizer Magnum tool. This modification would allow the worker the option to grasp the sheath at the tip to reduce vibration, while using a power grip to minimize hand fatigue and/or injury. An ideal size and shape for the grip would be 1.5 inches in diameter and 4–6 inches in length to span the width of the hand.[21]

5. Obtain an air compressor that is compatible with existing or new pneumatic tools that may be purchased. The compressor should allow the tools to operate at optimum air pressures for extended time periods.

6. Avoid the unassisted lifting of windshield glass. As noted in this report, solo lifting is not common at Oakes & Parkhurst Glass, but the hazards associated with lifting the glass without assistance should be communicated to the work force.

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Table 1: Data Collection Equipment

Item	Description	Make	Model
1.	hand–held calibrator (1g rms, 79.6 Hz)	PCB	394B06
2.	accelerometers (500g, 10 kHz)	PCB	353B16
3.	5–44 coaxial to BNC cable – 25 ft	PCB	018C25
4.	3–axis mounting block	PCB	080A16
5.	ICP sensor power unit (1,10,100)	PCB	480E09
6.	digital audio tape (DAT) recorder	TEAC	RD–111TN
7.	oscilloscope (2 channel)	Leader	LS1020
8.	8 mm video camera recorder/player	Sony	DCR–TRV7
9.	force gage (0–50 lbs)	Wagner	FDV–50
10.	hose clamp	Tridon	ϕ33/57 mm

Table 2: Data Analysis Equipment

Item	Description	Make	Model
1.	digital audio tape (DAT) recorder	TEAC	RD–111TN
2.	oscilloscope (2 channel)	Leader	LS1020
3.	8 mm video camera recorder/player	Sony	DCR–TRV7
4.	real time signal analyzer	Larson|Davis	2800
5.	spreadsheet/graphics	Microsoft	Excel 4.0
		Harvard Graphics	98

Table 3: Threshold Limit Values for HAV Exposure

Total Daily Exposure Duration	Values of Acceleration Not to be Exceeded (m/s^2)
4 to 8 hrs	4
2 to 4 hrs	6
1 to 2 hrs	8
less than 1 hr	12

Table 4
Frequency Multiplier (FM) for NIOSH Lifting Equation

Frequency Lifts/min	Work Duration					
	≤ 1 Hour		≤ 2 Hours		≤ 8 Hours	
	V < 75	V ≥ 75	V < 75	V ≥ 75	V < 75	V ≥ 75
0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

† Values of V are in cm; 75 cm = 30 in.

Table 5
Coupling Multiplier (CM) for NIOSH Lifting Equation

Couplings	V< 75 cm (30 in)	V ≥ 75 cm (30 in)
	Coupling Multipliers	
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Figure 1: Calibration Set-up

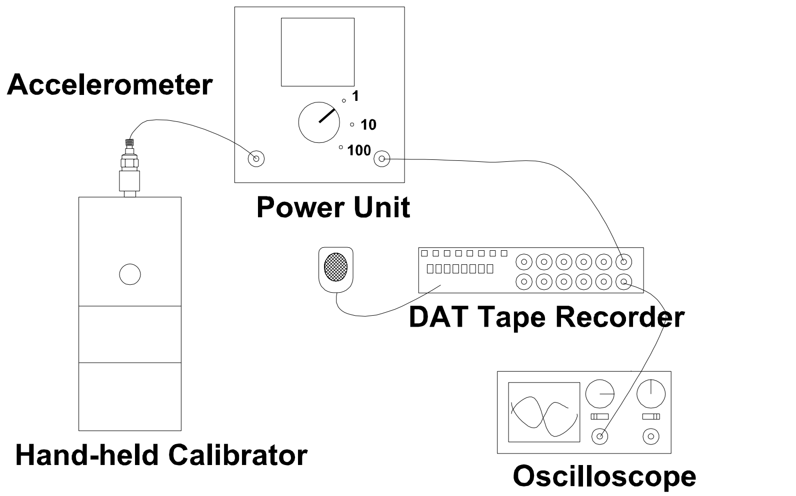


Figure 2: Data Collection Equipment Set-up

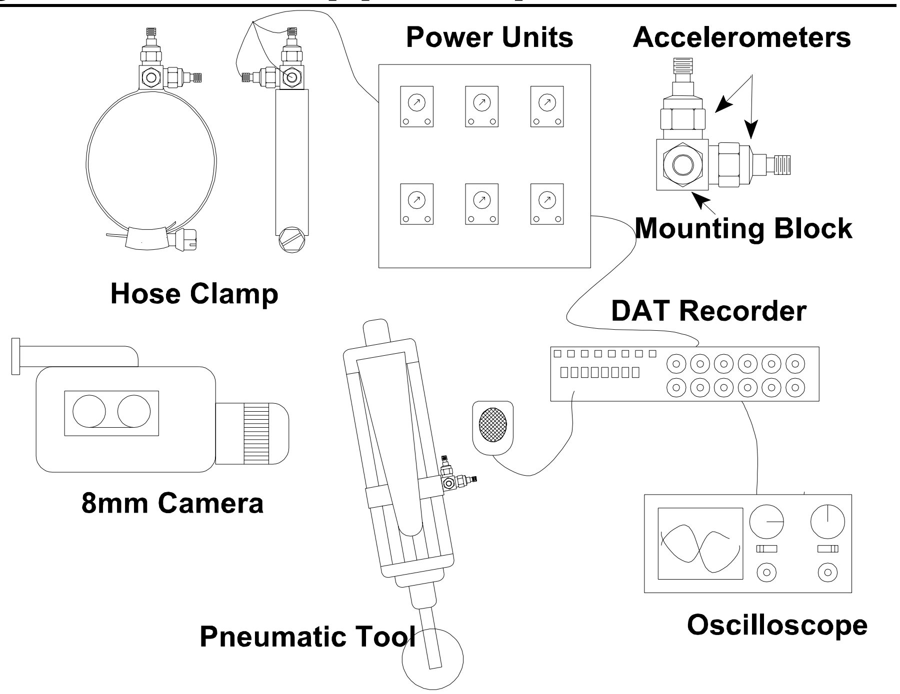


Figure 3: Data Analysis Equipment Set-up

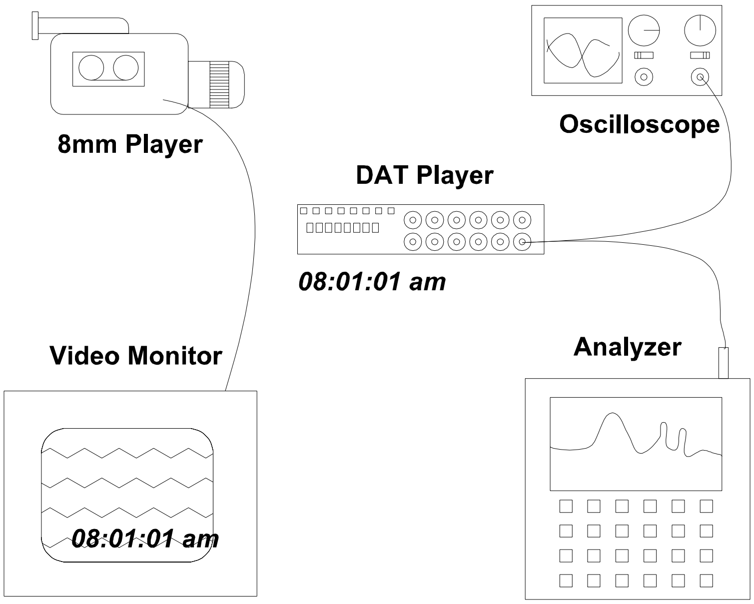


Figure 4: Basicentric Coordinate System

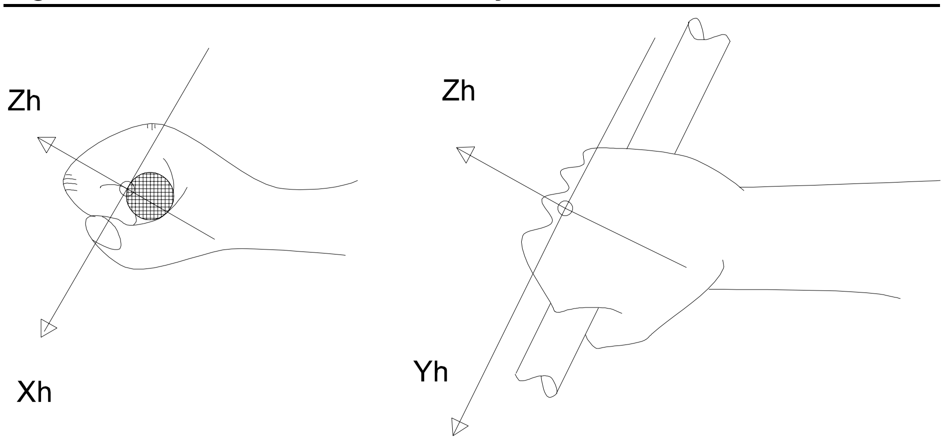


Figure 5: ANSI Recommended HAV Exposure Zones

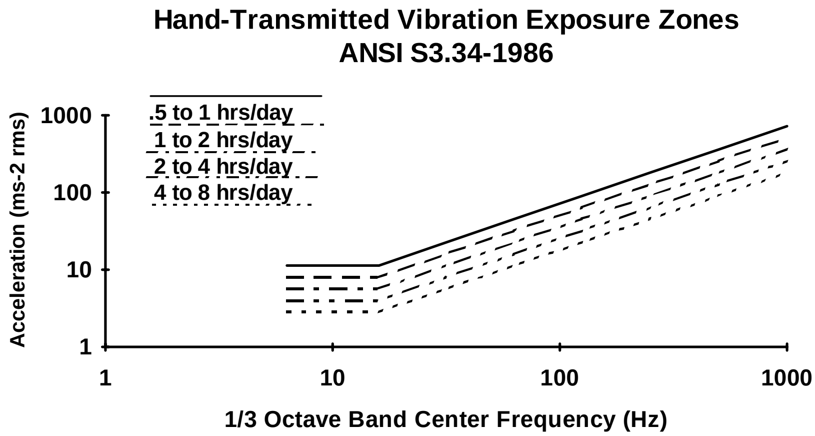
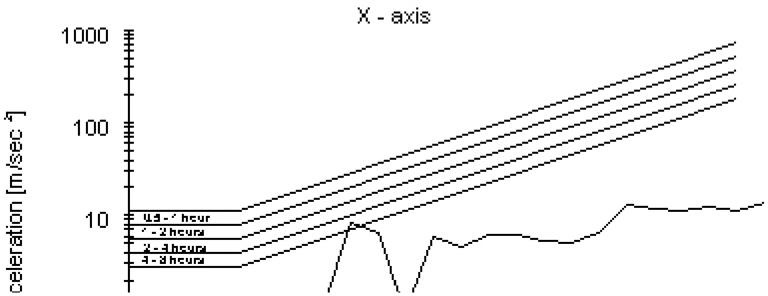


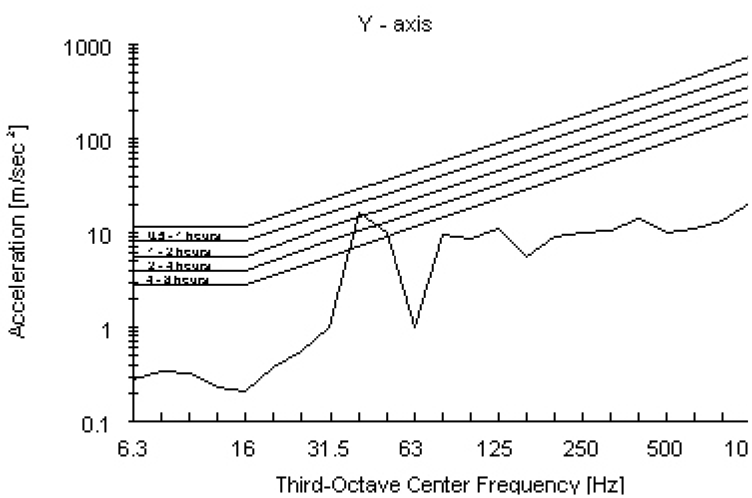
Figure 6

Equalizer Magnum

Oakes & Parkhurst Glass
Belfast, Maine
HETA 99-0025

Number of Samples - 5
Average Sample Time - 28.4 sec
Median Overall Weighted Acceleration (Z-axis) - 10.2 m/s^2





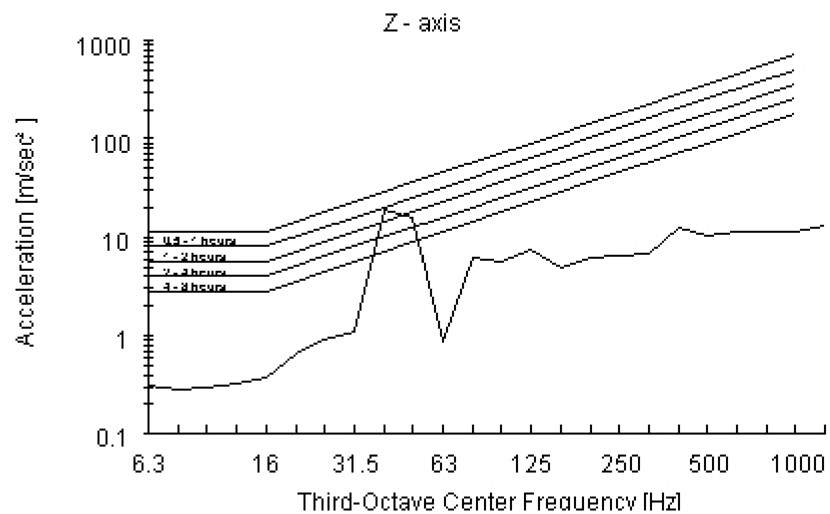
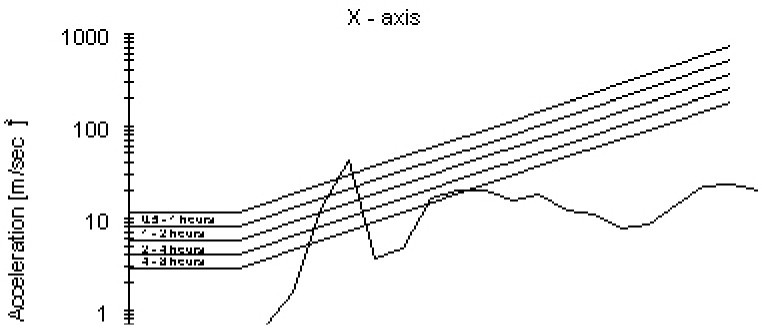


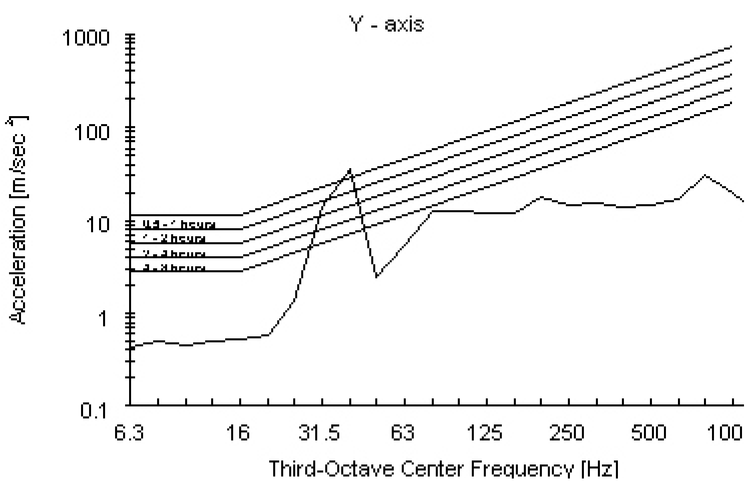
Figure 7

Equalizer Magnum

Oakes & Parkhurst Glass
Farmington, Maine
HETA 99-0025

Number of Samples - 3
Average Sample Time - 36.7 sec
Median Overall Weighted Acceleration (Z-axis) - 20.8 m/s^2





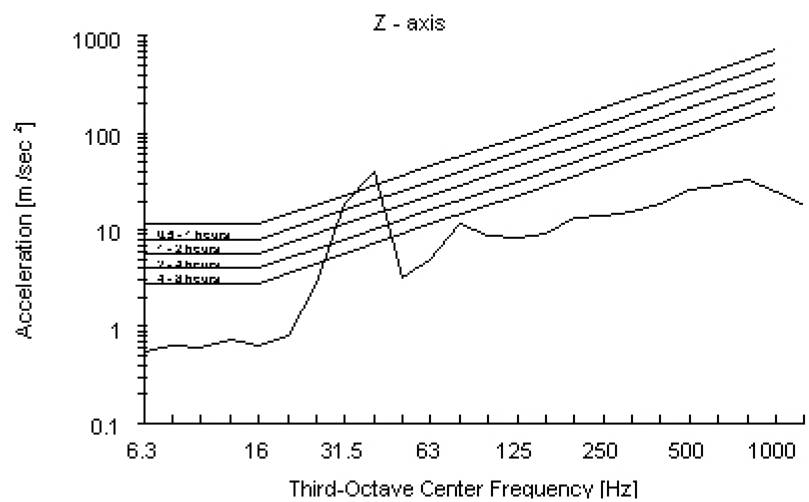
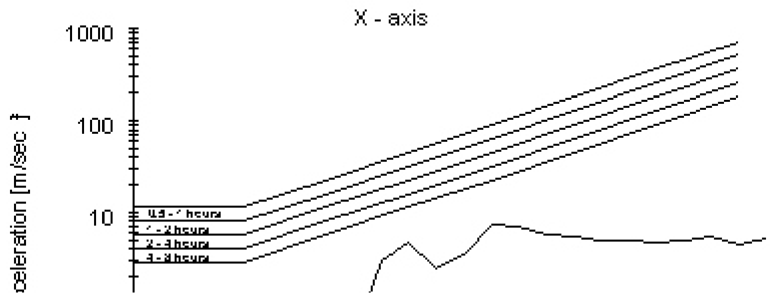


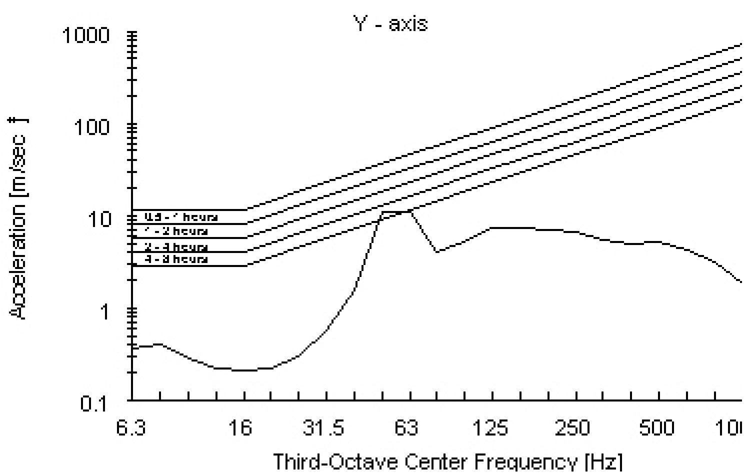
Figure 8

BTB Power Operated Air Tool

Oakes & Parkhurst Glass
Belfast, Maine
HETA 99-0025

Number of Samples - 4
Average Sample Time - 15.0 sec
Median Overall Weighted Acceleration (Y-axis) - 4.9 m/s^2





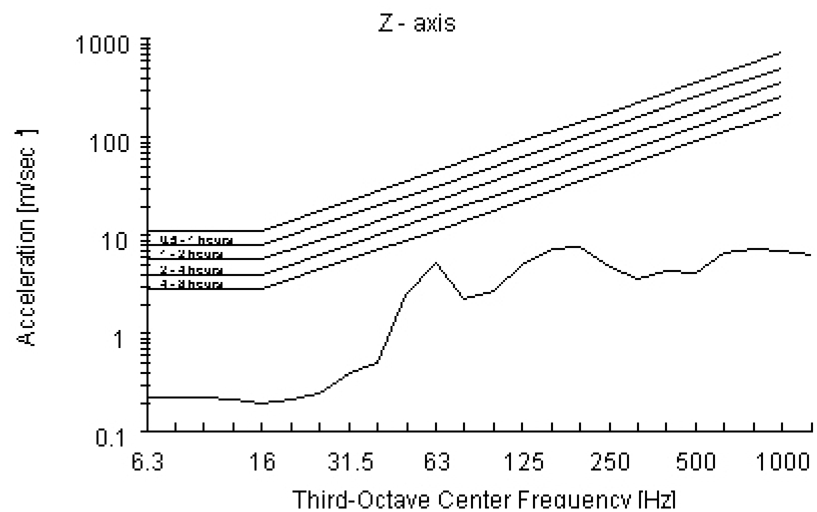
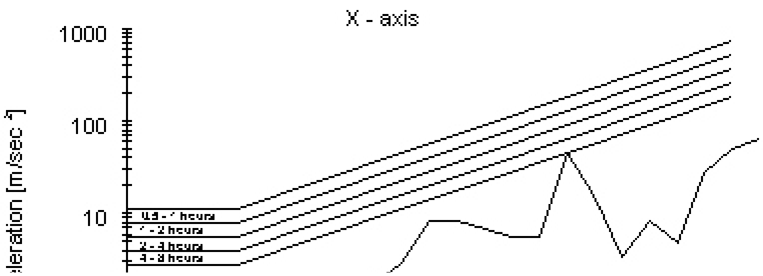


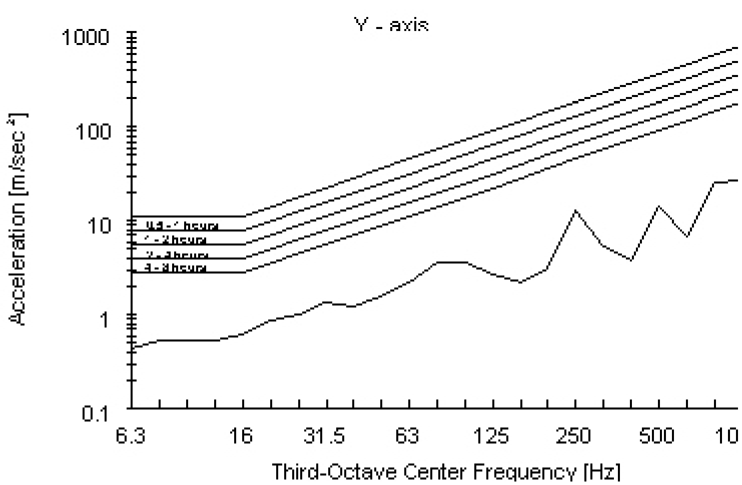
Figure 9

FEIN Window Cutter Astlxe 638
Hooked Blade #63903 156 017

Oakes & Parkhurst Glass
Belfast, Maine
HETA 99-0025

Number of Samples - 3
Average Sample Time - 44.0 sec
Median Overall Weighted Acceleration (Z-axis) - 9.6 m/s^2





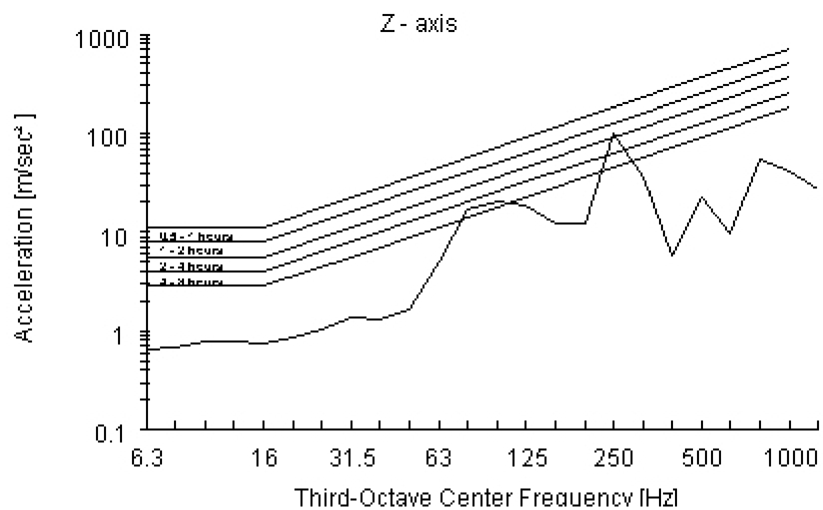
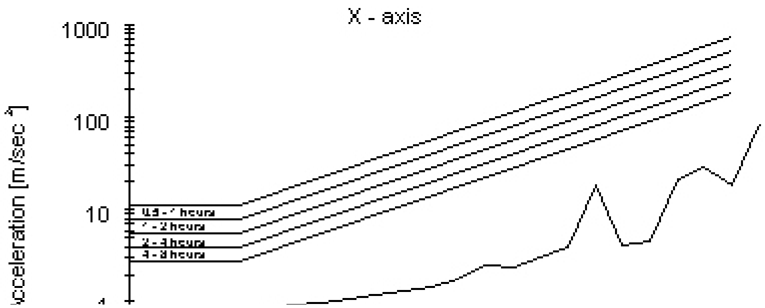


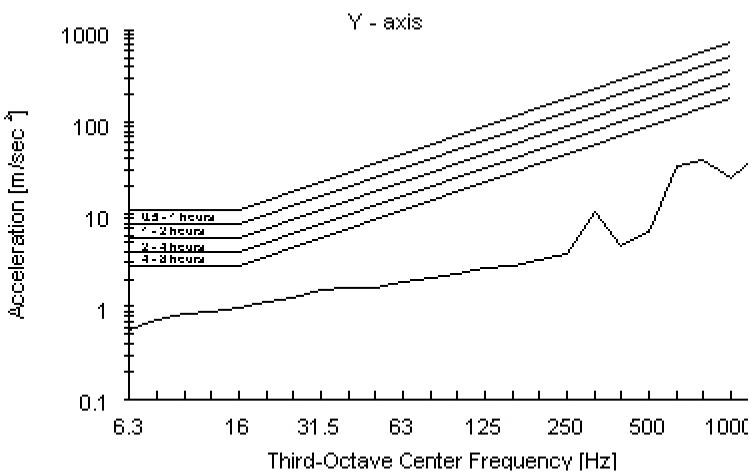
Figure 10

FEIN Window Cutter Astlxe 638
Straight Blade #63903 170 014

Oakes & Parkhurst Glass
Belfast, Maine
HETA 99-0025

Number of Samples - 6
Average Sample Time - 30.0 sec
Median Overall Weighted Acceleration (Z-axis) - 6.1 m/s^2





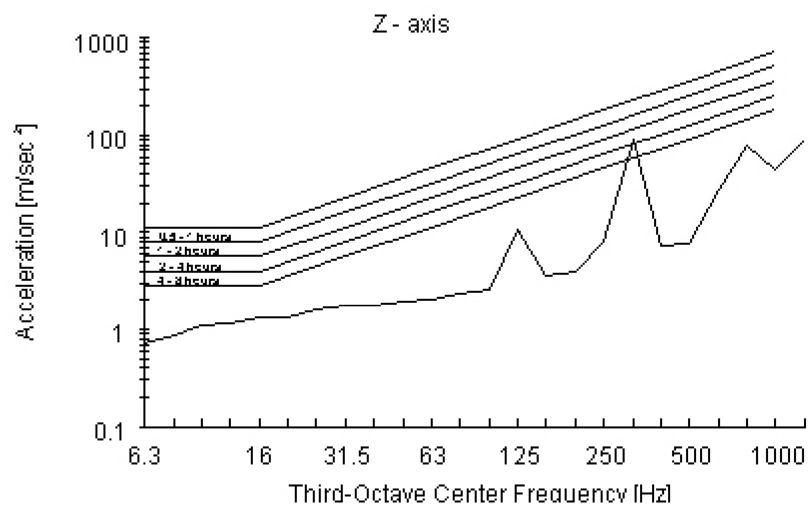
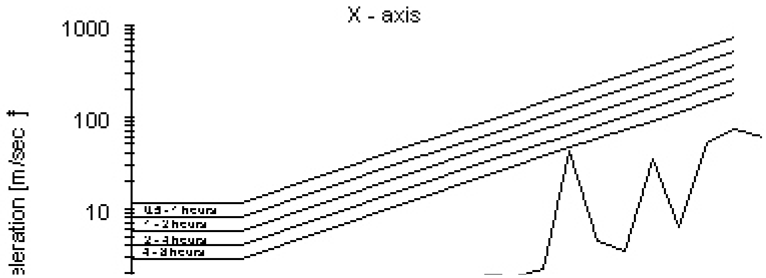


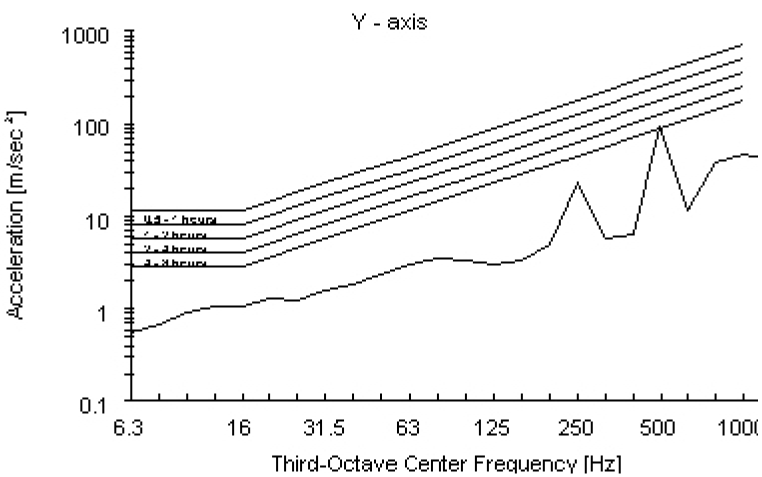
Figure 11

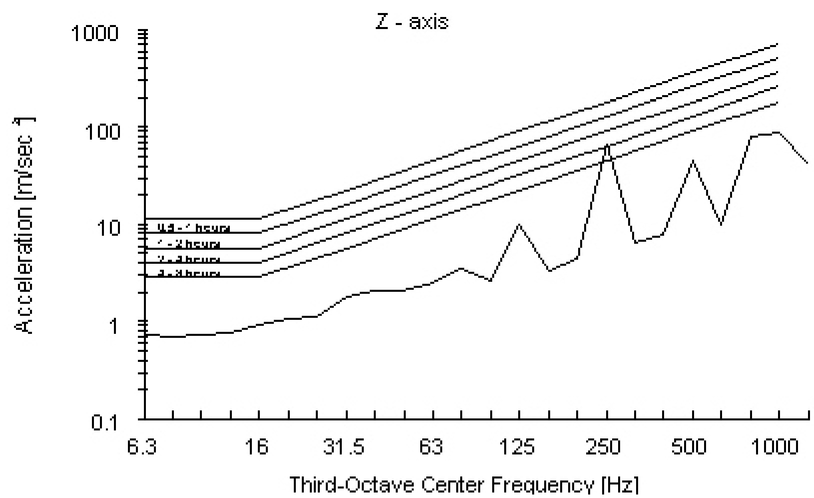
FEIN Window Cutter Astlxe 638
Hooked Blade #63903 156 017

Oakes & Parkhurst Glass
Farmington, Maine
HETA 99-0025

Number of Samples - 7
Average Sample Time - 31.7 sec
Median Overall Weighted Acceleration (Z-axis) - 5.6 m/s^2







APPENDIX A

The Factors Comprising the NIOSH Revised Lifting Equation

Calculation for Recommended Weight Limit

RWL = LC * HM * VM * DM * AM * FM * CM
(* indicates multiplication.)

Recommended Weight Limit

Component			Metric	U.S. Customary
LC	=	Load Constant	23 kg	51 lbs
HM	=	Horizontal Multiplier	(25/H)	(10/H)
VM	=	Vertical Multiplier	(1–(.003|V–75|))	(1–(.0075|V–30|))
DM	=	Distance Multiplier	(.82+(4.5/D))	(.82+(1.8/D))
AM	=	Asymmetric Multiplier	(1–(.0032A))	(1–(.0032A))
FM	=	Frequency Multiplier	(From Table 4)	
CM	=	Coupling Multiplier	(From Table 5)	

Where:

H = Horizontal location of hands from midpoint between the ankles.
Measure at the origin and the destination of the lift (cm or in).

V = Vertical location of the hands from the floor.
Measure at the origin and destination of the lift (cm or in).

D = Vertical travel distance between the origin and the destination of the lift (cm or in).

A = Angle of asymmetry – angular displacement of the load from the sagittal plane.
Measure at the origin and destination of the lift (degrees).

F = Average frequency rate of lifting measured in lifts/min.
Duration is defined to be: < 1 hour; < 2 hours; or < 8 hours assuming appropriate recovery allowances.

For Information on Other
Occupational Safety and Health Concerns

Call NIOSH at:
1–800–35–NIOSH (356–4674)
or visit the NIOSH Web site at:
www.cdc.gov/niosh