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A Pilot Study to Develop Guidelines for Reducing Tree Planter Injuries

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A Pilot Study to Develop Guidelines for Reducing Tree Planter Injuries

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"Guidelines for Preventing Tree-planting Injuries"

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Main research findings

Part 1- Tree Planting Task Analysis

- In Part 1 of this pilot project the average subject can be described as follows: height 183 cm; weight 79 kg; age 28; planting experience 5.9 seasons.
- The average work cycle was 10.2 seconds. Work cycles were faster for planters with 5 or more years experience but age did not affect work cycle times.
- Forty-three percent (43%) of shoulder abduction and 27% of shoulder flexion observations for the shovel shoulder were awkward ($>60^o$).
- Forty-four percent (44%) of seedling shoulder abductions were awkward.
- Almost one-third of seedling-hand wrist postures were awkward.
- When penetrating the soil, trunk flexion in the range of $0\text{-}45^o$ was observed 59% of the time and trunk flexion in the range $>45^o$ was observed 39% of the time
- When inserting the seedlings, trunk flexion in the range $45\text{-}90^o$ was observed 16% of the time and trunk flexion in the range $>90^o$ was observed 84% of the time.
- Forty-four percent (44%) of the shovels had lengths within the recommended range.
- Shovel lengths ‘below-fingertips’ and ‘above-wrist-to-elbow’ resulted in significantly less shovel shoulder abduction compared to shovel lengths that were ‘fingertip-to-wrist’.
- Full bag weights ranged from 13-24 kg which is greater than the recommended 10-15 kg.

Part 2- Biomechanical Methods Research

- Muscle effort in the forearms are at low to moderate intensity level most of the time during planting activity but for the seedling hand wrist extensor the intensity level is high for 24% of the total planting time.
- During the early part of the planting session, the thumb and finger flexor muscles for the shovel hand are rarely used at high intensity, but by the end of the 45-minute planting session both muscles are used at the high intensity level for nearly 20% of the planting time.
- The wrist flexor muscle shows a similar trend and is used at high intensity for over 20% of the time in the late phase of the planting session. The wrist extensor was consistently used at high intensity for over 20% of the planting time.

Part 3 – Shock and vibration in planting tools

- In Part 3 methods were developed and tested for measurement and analysis of accelerations at the hand of tree planters. Instrument specifications, methods of measurement and data analysis techniques are defined.
- Measurements of acceleration should be referenced to the anatomical co-ordinate system described in ISO 8727. The triaxial accelerometer should be mounted on a bar accelerometer adapter as described in ISO 5349-2
- RMS and RMD accelerations should be calculated in the x, y and z axes.
- An acceleration dose should be calculated similar to that defined in ISO 2631-5. Daily acceleration dose should be reported together with sample period, number of acceleration peaks, mean peak acceleration, and 1-minute acceleration dose.

- A 3rd octave band analysis of the acceleration frequency spectrum should be included to determine the attenuation afforded by absorbent materials or devices.
- Subjective data of perceived comfort, perceived force at the hand, and perceived muscular exertion of planting should be collected during testing of different tools and anti-vibration materials
- Pilot results suggest that an anti-vibration glove is not effective in reducing peak acceleration at the hand.

Executive Summary

Tree planters in British Columbia suffer high rates of musculoskeletal injuries (MSI). Repetitive motion and overexertion claims accounted for 15% of the $5.2 million in claims costs incurred by silvicultural contractors and 22% of the days lost over a 5-year period.

Exposure to factors such as repetitive movements, back stress, high physical workload, and inappropriate tool and equipment design create the risk of injury but few studies have been devoted to assessing the MSI risk factors for this occupation.

The study reported on here was devised to analyze how planters use their bodies during planting and how they interact with their tools and equipment.

While the ultimate goal of the project is to develop guidelines that will help reduce work related injuries in tree planters, the complexity of the subject matter is such that this study was designed as a pilot project with a limited dataset to test the methodologies for data collection and analysis before carrying out the main study.

The study was designed in three parts to look at different aspects of tree planting. The first part involves a task analysis which details the body movements in relation to the tree planting activity. The second part assesses the muscle effort during planting using electromyography while the third part analyzes the shock and vibrations transmitted through the planting tool into the hand and arm of the planter.

Part One data collection took place in southern Interior of BC. Sixteen volunteers were recruited from a crew of tree planters working for a silvicultural contractor. Volunteers signed informed consent forms and answered questions from a prepared questionnaire during an interview at roadside when anthropometric data was also collected. This was followed by an hour of video recording of the tree planter at work. Task analysis of thirty video-taped work cycles were then done for each planter and results tabulated.

Part Two was carried out on Vancouver Island where five volunteer in a planting crew participated. Each participant signed an informed consent form prior to the study. Four muscles in each arm were wired for electromyography (EMG) and the muscular effort was recorded and analyzed.

Part Three developed methods for measurement and evaluation of tree-planting tool designs and shock absorbent materials. A series of pilot studies were conducted to develop and test instrumentation, measurement methods and analysis techniques. A set of guidelines are provided for measurement and analysis of hand-arm accelerations in tree planting.

Research Problem

Tree planters suffer high rates of musculoskeletal injuries (MSIs)[1] according to statistics from the Worker's Compensation Board of British Columbia.

The tree planter occupation is associated with an injury rate of 16 lost time claims per 100 estimated person-years of work (1999-2003 average, WCB of BC). This is high compared to the calculated forest industry sub-sector injury rate of 9.6 (Forestry web page, WCB of BC).

Analysis of the accident types shows 29% of WCB claims from tree planters were classified as overexertion or repetitive motion accidents (1999-2003, WCB Statistical Department). Repetitive motion and overexertion claims accounted for 15% of the $5.2 million in claims costs incurred by silviculture contractors and 22% of the days lost over the 5-year period. Likewise claims for tendonitis accounted for 24% of claims costs, and along with back and other strains accounted for 50% of claims costs. Wrist and fingers were indicated as the body part injured 20% of the time. Eighty-nine percent (89%) of shovel related claims are coded as repetitive motion and overexertion accident types costing the industry $83,306 per year (WCB Statistical Department, 1996-2000).

Risk of injury has been identified for this occupation through exposure to factors such as repetitive movements, back stress, high physical workload, and inappropriate tool and equipment design (Smith, Gilbert & Henshaw, 1986) but few studies have been devoted to assessing MSI risk factors for this occupation. Various planting techniques and equipment selection

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[1] [1] "Musculoskeletal injury, or MSI, describes injuries to the following body structures: muscles, tendons, ligaments, nerves, joints, cartilage, spinal discs, bones and blood vessels. These are also known as Musculoskeletal Disorders (MSD), Repetitive Strain Injury (RSI), Cumulative Trauma Disorders (CTD), "strains and sprains", tendonitis, epicondylitis, carpal tunnel syndrome, sciatica, herniated discs, low back pain, and other such related injuries. MSI can affect the neck, back, trunk and limbs, and it may develop suddenly (acute injury) or over time (chronic injury). Workers risk MSI whenever their abilities do not match the demands of their jobs." (Health Care Health & Safety Association of Ontario, 2001)

recommendations exist for MSI prevention, but there is little supporting research. How different techniques and equipment fit affect MSI risk exposure is not well studied. Modified shovel handles to reduce stress to the hand/wrist and arm area are available but the purported benefits of the design changes have not been scientifically validated.

The study reported on here was devised to analyze how the planters use their bodies and the interaction between planters and their tools and equipment. There are many variables in this type of work. The terrain varies across the landscape where planting takes place. Planters vary in age, sex and size, and the tools and equipment used vary in shape and size.

While the ultimate goal is to come up with guidelines that will help reduce work related injuries in tree planters, the complexity of the subject matter is such that this study was designed as a pilot project with the following objectives:

1. To test methodologies before carrying out the main study,
2. To analyze tree planting work methods for specific stressful exertions using posture analysis techniques,
3. To compare the fit of tree planting equipment with ergonomics guidelines,
4. To provide baseline data for future research.

Methodology

The study was divided into three parts with each part assigned to a specialist in that subject matter:

1. Tree planting task analysis - Suzanne Kinney, Human Factors West.
2. Biomechanical methods research - Dr. Douglas Weber, University of Alberta.
3. Shock and vibration in planting tools - Dr. James Morrison, Simon Fraser University.

1. Tree Planting Task Analysis

Subjects. Subjects were recruited by their employer, a silviculture contractor working in the Princeton area. He informed his tree planting crew about the study and asked for volunteers. Fourteen males and two females were recruited from the crew. Researchers then visited the work camp and explained the purpose and methods of the study. Interested participants were provided with informed consent forms to sign. Data was collected from subjects in the 6th week of a 7½ week tree planting work contract.

Terrain conditions. The tree planting sites had disc-trenched and excavator mounded ground as well as non-site prepared (raw) ground. Slopes where planting took place ranged from 0 to 38%. A mixture of one-year pine, spruce and fir seedlings was planted.

Equipment. An ergonomics questionnaire was developed in consultation with a steering committee of industry stakeholders. A semi-structured interview guided by a questionnaire containing close-ended and open-ended questions was used to gather planter history information. Measuring tape, verniers, weigh scales, and tracings on grid paper were utilized to gather anthropometric measurements, planting tool measurements, and bag and harness fit. Observation and subject opinions were also recorded in the questionnaire. Data was later input into a statistical processing software package for analysis.

Digital video recorders were used to collect posture and movement information. Posture and movement analysis was carried out by reviewing video recordings in slow motion. A scheme for describing the position of each joint was developed. Postures were determined by their locations about three axes of rotation in the shoulder, two axes in the trunk (lower back), and one axis in the wrist. The hand position on the tool was also recorded. Variables corresponding to each axis of rotation were assigned one of three to four values corresponding to the joint position.

Procedure. During two days of planting work, subjects were interviewed and their equipment measured at the roadside when re-filling of their bags with seedlings (called bag-up). One researcher then followed the subject onto the planting block for observation and video recording during planting work.

Researchers took approximately one hour of video per subject to gather a minimum of 10 work cycles from the front and 20 work cycles from each side where picture quality could show joint positions during critical elements of the task.

Data Reduction. Thirty video-taped work cycles were reviewed for each subject. Cycles were selected based on picture quality. Work cycle times and posture categories for the maximum joint angles observed in the motion were recorded on the form described above. One researcher performed all the coding to minimize inter-researcher differences.

Questionnaire data was coded into a statistical processing software package so that means and frequencies could be calculated. Effect on postures from shovel style and shovel length was also determined using one-way analysis of variance.

Six work cycles were randomly selected from video recordings for each subject and reviewed to determine posture timing and duration information. Timing and duration of sub-tasks was normalized to work cycle length to provide a typical sequence of postures for a planting work cycle (Appendix 1). Joint posture and duration information were compared to ergonomic criteria to determine critical factors in the work cycle that are contributing to the risk of musculoskeletal injury.

2. Biomechanical Methods Research

This part of the project was designed to measure the forearm muscle activities produced during typical tree planting activities. Electromyography, simply defined as ‘the recording and study of intrinsic electrical properties of skeletal muscle’, can be used to study fatigue, since the EMG activity of the muscle changes with the onset of fatigue. Electromyography (EMG) was used to record muscle activity in 4 major muscle groups in both arms throughout the course of one “bag-up”, a period spanning approximately 45 minutes. The EMG was recorded with a Noraxon Telemyo 2400T system which telemeters the signals to a data acquisition computer operated by Dr. Doug Weber (University of Alberta). The transmitter was worn in a small backpack and did not impede the planter’s motion. Figure 1 shows pictures of two planters wearing the telemetry system during pilot data collection trials completed in Alberta (October, 2004).

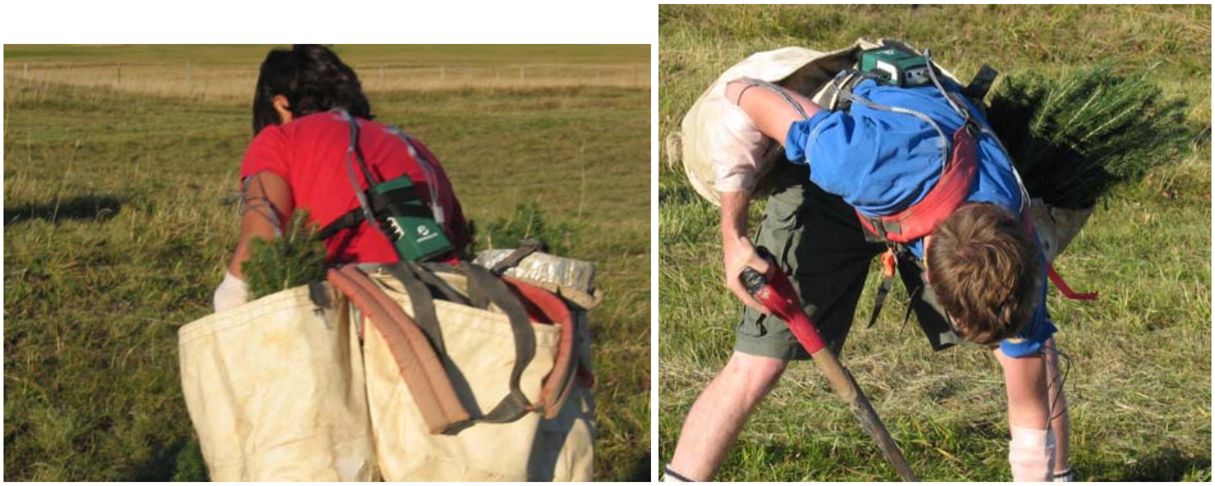


Figure 1. Tree-planters instrumented with EMG telemetry system.

Muscles were selected based on expected motion activation patterns of the hand-arm system determined from video recordings of tree planters obtained in Part One.

In March, 2005, pilot experiments with 5 tree planters (4 male, 1 female) in Nanaimo, BC were completed. The protocol for EMG collection was approved by the Ethics Review Committee of the Faculty of Physical Education and Recreation at the University of Alberta. Each participant signed an informed consent form prior to the study. Four participants were right-hand and 1 was left-hand dominant (shovel handle) and all planters had at least 2 seasons of tree planting experience. For data analysis purposes, all of the EMG data from the shovel side were labeled as right-sided and the seedling side is labeled as the left side.

EMG was recorded from the following muscles in each arm: *flexor pollicis longus* (thumb flexor), *flexor digitorum superficialis* (finger flexor), *flexor carpi radialis* (wrist flexor), and *extensor carpi radialis* (wrist extensor). The EMG signals for each muscle were bandpass-filtered (10 – 500 Hz), rectified and smoothed with a 100 ms moving r.m.s. filter. The rectified signals were normalized to the maximum voluntary contraction (MVC) recorded at the beginning of each planting session, and the amplitude of each EMG is expressed as a percentage of MVC (%MVC).

3. Shock and vibration in planting tools.

REVIEW OF ISO STANDARDS

The principles involved in measurement of both shock and vibration are similar but the methods of analysis are different. The human response to shock and vibration are both defined by the characteristics of the system. The difference is the steady state nature of vibration and the transient nature of shocks. Steady state vibration can be described by the "RMS" value of the signal and the frequency spectrum. In contrast "RMS" measures of transient shocks can be misleading. For transient shocks, peak amplitude or a weighted "dose" value generally provides a superior measure of shock characteristics. In the context of tree planting shock and vibration are both transient in nature. As the planting tool strikes the ground, or an immovable object such as a root or a rock, there is an immediate shock loading as the tool decelerates. This is accompanied by a super imposed non steady state (transient) vibration. Both of these characteristics can potentially contribute to hand-arm musculoskeletal injury.

ISO Standards for the measurement and analysis of hand-arm vibration were reviewed and where appropriate the ISO methodology was adopted as part of the guidelines for evaluating shocks during tree planting. The ISO standards are primarily designed to evaluate steady state hand-arm vibrations from power tools. This methodology is unsuited to the type of isolated repeated impacts experienced by tree planters. Therefore, although the ISO methodology was adopted for specifications of measurement instrumentation, placement of accelerometers and axes of measurement, the methods of analysis adopted for this study are based on a separate ISO Standard that concerns measurement of repeated shocks.

ISO 5349 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration: The main standard for measurement and evaluation of hand-arm vibration is ISO 5349 parts 1 and 2. ISO 5349-1 contains general guidelines and refers to other standards for details of accelerometer mounting (ISO 5348) location and orientation (ISO 8727) and instrumentation (ISO 8041). The standard requires that steady state vibrations should be measured as the RMS acceleration value. The standard also defines a frequency weighting curve for hand-arm vibration (W_h) that represents the transmissibility of acceleration from the tool to the hand Acceleration should be measured in three axes: x, y and z. Accelerations should be reported for each individual axis as frequency weighted RMS acceleration values: a_{hwx}, a_{hwy}, and a_{hwz}. The total vibration value a_{hv} should also be calculated and reported, where a_{hv} represents the square root of the sum of squares of the x, y and z weighted RMS accelerations:

$$a_{hv} = (a_{hwx}2 + a_{hwy}2 + a_{hwz}2)^{1/2}$$

The standard also recommends that in order to compare exposures across tools and work environments, an eight hour energy equivalent vibration total value A(8) should be calculated and reported where:

$$A(8) = a_{hv(eq.8hr)} = a_{hv}\ (Te/8)$$

represents the eight hour equivalent exposure of the worker,

and Te is the actual daily exposure in hours.

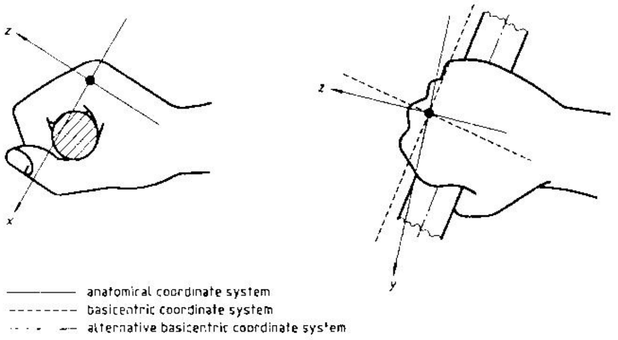
ISO 5349-2 provides practical guidance for measurement in the workplace. This standard includes the organization of measurements, duration of vibration measurements, estimates of daily vibration duration and the vibration magnitude and frequency range requirements of accelerometers. The standard recommends that accelerometers should have a resonance frequency > 6250 Hz and preferably > 30,000 Hz.

The standard provides guidance for mounting of accelerometers including two types of hand held adapters to be used when a fixed mounting system is not feasible. One consists of a curved bar that is held against the handle of the tool by the palm of the hand. The accelerometer is attached to the bar where it extends beyond the hand. The other consists of a curved molded shape into which the accelerometer is inserted. The molded shape containing the accelerometer is then held against the handle of the tool by the palm of the hand. These hand held adapters rely on the operator's grip force to hold the adapter in place against the handle, but it is also advisable to lightly hold the adapter in position using elastic adhesive tape.

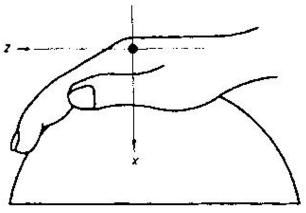
ISO 15694 Mechanical Vibration and Shock - Measurement and Evaluation of Isolated Shocks Transmitted from Hand Held and Hand Guided Machines to the Hand-Arm System:

This standard states that there is insufficient knowledge to establish whether the measurement methods of ISO 5349 can be used for assessment of health risks in the presence of shock type loading of the hand-arm system. This applies to measurements that include shocks having peak values > 100 g and short durations (e.g. approximately 10 ms) and where the period between two shocks is longer than the shock period itself (e.g. > 200 ms). Both of these characteristics apply to tree planting. For analysis of repeated shocks to the hand-arm system, the ISO 15694 defines additional measures that characterize shock loading including the repetition time (or strike rate), the route mean quad (RMQ) acceleration value, and peak acceleration value. The standard includes two indices that measure the impulsiveness of the signal. These are the crest factor (peak acceleration/RMS acceleration) and shock content quotient, SCQ (RMS acceleration/RMQ acceleration). These acceleration values are measured using a flat band pass filter with a cut-off at 6.3 Hz and 1250 Hz. In some cases, where tools are known to have low frequency components of acceleration, a wider band pass may be required and this should be noted. The standard recommends that the values of RMS and RMQ acceleration are also measured using the hand-arm weighting filter. It is recommended that when reporting peak acceleration value and crest factor the 50th percentile peak value should be used. Where there is a wide variance in individual acceleration peaks, the 50th percentile value is more representative of the expected peak acceleration of the tool.

ISO 8727 Mechanical Vibration and Shock - Human Exposure - Biodynamic Co-ordinate Systems: This standard defines the biodynamic co-ordinate systems to be used in the measurement of whole body and segmental vibration. It includes two co-ordinate systems for measurement of hand-arm vibration. These are the anatomical co-ordinate system and the basicentric co-ordinate system, Figure 2.



a) "Handgrip" position



b) "Flat palm" position

Figure 2. Anatomical and basicentric coordinate systems for measurement of hand-arm vibration and shock

The anatomical co-ordinate system aligns with the geometry of the hand, whereas the basicentric co-ordinate system aligns with the axes of the tool handle. In both systems, the origin is in the head of the third metacarpal bone (middle knuckle), and the x axis is directed anterior to the palm of the hand. In the anatomical system the z axis is in the long axis of the third metacarpal bone and the y axis is in the lateral (left direction). In the basicentric system, the x axis approximates the principle functional axis of the tool (i.e. the direction in which force is applied), and the y and z axes are perpendicular to the x axis in accordance with a right-handed orthogonal co-ordinate system with the y axis being parallel to the long axis of the handle. Thus in the case of a tree planting shovel, having a D type handle, the x axis will be in the direction of the shaft and the y axis will be parallel to the handle in the lateral (left) direction.

ISO 10819 Mechanical Vibration and Shock - Hand-Arm Vibration - Method for Measurement and Evaluation of Vibration Transmissibility of Gloves at the Palm of the Hand:

This standard is designed to measure the vibration transmissibility of gloves manufactured from a vibration absorbent material. Measurements are made in a specially designed test station where vibration is generated at a handle. The handle is mounted in a vertical orientation. Two vibration spectra are applied at the handle in the range of 31.5 to 200 Hz and 200 - 1000 Hz respectively. The RMS vibration levels at the palm of the hand are measured using a palm adapter. Measurements are repeated with the operator grasping the handle with a bare hand and then with a gloved hand. The transmission factors for the two frequency spectra are measured as the difference between the RMS acceleration levels measured at the palm adapter when using a bare hand, and when wearing the glove. The criteria for anti vibration gloves require that they should have a transmission factor < 0.6 for the high frequency spectrum and a transmission factor of < 1 for the low frequency spectrum. It is noted in the standard that anti vibration gloves generally do not provide sufficient attenuation of frequencies below 150 Hz.

ISO 13753 Mechanical Vibration and Shock - Hand-Arm Vibration - Method for Measuring the Vibration Transmissibility of Resilient Materials when Loaded by the Hand-Arm System: This standard is designed to determine the vibration transmissibility of resilient materials. The purpose is to permit comparison and enable rank ordering of different vibration absorbent materials. The standard states that it will not necessarily predict the transmissibility of gloves fabricated from these materials. The transmissibility of the material is measured when compressed with a load typical of the hand-arm system. Measurements are made in the frequency range of 50 to 500 Hz.

ISO 2631 - 5 Mechanical Vibration and Shock - Evaluation of Human Exposure to Whole Body Vibration - Method for Evaluation of Vibration Containing Multiple Shocks: Although this standard refers to whole body vibration, it was developed in order to assess the effects of vibration signals that contain multiple shocks. Its development was based on the assumption that the measurement of an RMS acceleration level used for steady state vibration does not accurately reflect the health effects of a signal containing multiple shocks. The standard contains human lumbar acceleration response functions for the x, y and z axes. The peak value of lumbar acceleration is calculated for each shock event. An acceleration dose, D, is then calculated based on the sum of the sixth power of the individual acceleration peaks. The duration of daily exposure to repeated shocks is used to obtain a daily acceleration dose. An informative annex to the standard is provided for guidance on assessment of health effects of multiple shocks.

INSTRUMENTATION, DATA COLLECTION AND ANALYSIS

Objectives: A series of pilot studies were conducted with the following objectives:

a) To determine the range of accelerations experienced at the handle when planting. This information was required in order to determine accelerometer specifications.

b) To select an appropriate battery powered signal conditioning system that can be used to collect hand-arm acceleration data from planters working in the field in rough terrain.

c) To design and test a suitable hand held adapter to secure the triaxial accelerometer when measuring accelerations at the handle-hand interface and the glove-hand interface.

d) To collect sample accelerometer data when using shovels with and without gloves.

e) To investigate the effect of absorbent gloves on the acceleration signal (magnitude and frequency) measured at the hand when using a tree planting shovel.

e) To develop and test suitable signal processing and analysis software that will characterize the handle-hand acceleration data.

e) To investigate an appropriate data collection system to be used for storing acceleration data in the field.

Pilot Study 1

The objective of this study was to determine the magnitude of accelerations experienced at the shovel handle in order to determine accelerometer specifications; to select a suitable triaxial accelerometer and to evaluate and select a suitable signal conditioning and data collection system.

Experiment 1

A test set-up was constructed in the laboratory to allow simulated tree planting activity. This consisted of two planting boxes, one filled with sand and gravel containing some stones and rocks, and one filled with loose earth; and a selection of tree planting shovels and vibration absorbent gloves.

Following a review of available instrumentation, a Bruel & Kjaer Nexus 2693 conditioning system was obtained on loan for trials. The Nexus is a 4 channel conditioning amplifier that provides a selectable range of high and low pass filters and can be powered by 120 V AC or battery. Acceleration data were collected using a single axis B & K 4384 accelerometer (that was available in the laboratory) powered by the Nexus 2693 conditioning amplifier. The accelerometer was attached with a stud to a hand-held adapter designed to be held firmly between the third and fourth finger. Output from the Nexus 2693 was digitized at 2000 Hz using an IO-tec DaqBook 200 data acquisition system and stored to a lap-top computer.

Data were collected from two subjects using a D-Handle shovel with impacts experienced in various ground (soil) conditions, ranging from loose earth, to sand, fine gravel, and rocks. The data were analyzed using IO-tec Daq-view software to plot the time history of acceleration impulses measured at the handle.

Experiment 2

A Larson Davis HVM100 signal conditioning and data acquisition system was obtained on trial. This system came complete with a tri-axial accelerometer (± 500 g) and output cable, and a palm accelerometer adapter and bar accelerometer adapter. The HVM100 is capable of conditioning accelerometer signals, digitizing the data, filtering, and storing the 1 sec rms acceleration and 1 sec peak acceleration values. It does not store the raw accelerometer data, and therefore no further signal processing or data analysis is possible if it used in the field as a stand-alone unit. However, the HMV 100 provides an analog output of the accelerometer signal that can be digitized and stored to a lap-top computer in real time.

Data was collected in the laboratory using the same test set-up as in Experiment 1. Data was RMS averaged and stored to the HVM 100 at 1 second intervals. Analog output from the HVM 100 was digitized using an IO-tec DaqBook 200 data acquisition system and stored to a lap-top computer. Data were collected from two subjects using a D-Handle shovel with impacts experienced in various ground (soil) conditions, ranging from loose earth, to sand, fine gravel, and rocks. Data was collected with and without vibration absorbent gloves using the handle accelerometer adapter.

A second series of data were collected using the HVM 100 under field conditions. Data were collected from two subjects whilst digging with a D-handle shovel in soil containing undergrowth and tree roots.

Pilot Study 2

The equipment used in this study consisted of the Endevco 65-10 triaxial accelerometer, Nexus 2693 conditioning amplifier, IO-tec DaqBook 200 and a laptop computer with IO-tec Daq software. The equipment was initially tested in the laboratory using the test set-up described in Pilot Study One. The test set up and equipment is shown in Figure 3.

A bar type accelerometer adapter was manufactured and tested using this set-up. The bar adapter is shown in Figure 4. Methodology was developed for attaching the bar accelerometer adapter at the shovel handle-hand interface. For tests of tree planting with no gloves, the bar accelerometer adapter was taped lightly to the handle of the shovel or to the surface of the handle wrap material. For tests in which the subject wore gloves, the bar adapter was inserted through an incision cut in either side of the glove and held firmly between the handle/glove and the palm of the hand.

The test data collected in the laboratory was used to develop and test a series of computer programs written in MATLAB for data analysis.

Figure 3. Laboratory set up for testing instrumentation and data collection system.

Figure 4. Bar accelerometer adaptor for handle-hand interface.

Analysis: The data analysis programs were written as a series of call functions and performed the following functions:

- Browse and locate the IOtech DAQ acceleration data file;
- Apply calibration factors to each axis of acceleration data;
- Transform axes to hand-arm coordinates and save data to files;
- Open graphical user interface and enter filenames, sampling frequency, peak detection thresholds, and daily exposure duration.
- Plot and display the acceleration time histories $a = f(t)$ in the x, y and z axes;
- Calculate the RMS acceleration values ($m.s^{-2}$) of x, y and z axes, where
  $a_x\_RMS = [\ (1/n)\ (\sum a_x(i)^2\ )]^{0.5}$ ($m.s^{-2}$)
  and, n = number of points in data sample;

- Calculate the RMD acceleration values ($m.s^{-2}$) of x, y and z axes, where
  $a_x\_RMD = [(1/n) (\sum a_x(i)^{10})]^{0.1}$ ($m.s^{-2}$)
- Identify and store the individual positive and negative peak acceleration values of each impact in the x, y and z axes;
- Calculate cumulative acceleration doses for the x, y and z axes, Dx, Dy and Dz, where
  $Dx = [\sum (a_x(pos\_peak)^6 + \sum (a_x(neg\_peak)^6]^{1/6}$ ($m.s^{-2}$)
- Calculate a combined acceleration dose (Ds) for all three axes, for the data sample, where
  $Ds = [Dx^6 + Dy^6 + Dz^6]^{1/6}$ ($m.s^{-2}$)
- Calculate the equivalent dose for a single impact, Dpeak, where
  $Dpeak = [Ds^6 (1/n)]^{1/6}$ ($m.s^{-2}$)
  and n = number of impacts;
- Calculate an extrapolated dose representing the daily exposure (eight hour equivalent acceleration dose), where
  $D(8) = [Ds^6 (Te / Ts)]^{1/6}$ ($m.s^{-2}$)
  and Ts = sample time; Te = daily exposure time;
- Display the accumulated daily dose as a function of time $D = f(t)$.

The program modules are described in Appendix 2.

Output from Data Analysis Programs: The output of the data analysis includes the following measures:

- a_x_RMS; a_y_RMS; a_z_RMS;
- a_x_RMD; a_y_RMD; a_z_RMD;
- Sample (measured data) acceleration doses in the x, y and z axes: Dx, Dy, Dz;
- Single impact mean peak acceleration doses in the x, y and z axes;
- Daily exposure acceleration dose D(8);
- Total extrapolation time for daily exposure

Field Trials

The data collection and analysis system was tested under simulated field conditions. Data were collected at a sampling rate of 4000 Hz from two subjects digging in loose soil with some stones (Figure 5) and in hard packed soil with a moss-turf surface layer.

Figure 5. Subject digging in loose soil in simulated field conditions.

Accelerations at the hand were measured in the x, y and z axes as described in the previous section. Subjects used two types of shovel:

- a D-handle shovel having a compliant synthetic rubber handle (Figure 6)
- a D-handle shovel having a rigid plastic handle (Figure 7)

Both shovels were used by the subjects in two conditions:

- wearing no gloves
- wearing Impacto anti-vibration air gloves model BG401 (Figure 8)

Figure 6. Rigid D-Handle Shovel

Figure 7. Synthetic Rubber D-Handle

Figure 8 shows the bar accelerometer adaptor inserted between the glove and the palm of the hand during field testing.

Figure 8. Tree planting shovel with Impacto anti-vibration glove and bar type accelerometer adaptor inserted between the glove and the palm of the hand.

Research findings

Part 1 – Tree Planting Task Analysis

The following subject profile was determined: Mean height 183 cm [sd 8 cm], mean weight 79 kg [sd 12 kg], mean age 28 years [sd 6 years], mean experience 5.9 seasons [sd 4.4 seasons]). The average work cycle was 10.18 seconds +/- 4.88 seconds (n=480). Planters had significantly different average planting times. Work cycle times were faster for planters with 5 years of experience but age did not have any effect on work cycle times.

Table 1 shows the maximum joint postures observed for elements of the tree planting task, averaged across all subjects. Postures are displayed as percent falling into 'not awkward' or 'awkward' categories according to ergonomics literature (Hagberg et. al, 1995). Figure A1 (Appendix 1) shows element descriptions of the tree planting task (left side) and corresponding postures (right side) averaged to a normalized work cycle.

The shovel striking motion occurs with the dominant arm ('shovel shoulder') and is a combination of shoulder flexion (bending) and abduction (moving away from body) that happens one-third of the way into the work cycle. Planters use quick, forceful motions to penetrate the soil. One-to-two shovel strikes into the ground were most commonly observed for planters in the study. Forty-three percent (43%) of shoulder abduction and 27% of shoulder flexion observations for the shovel shoulder were categorized as greater than 60°, which is considered an awkward shoulder posture.

Seedling extraction from the bag occurs with the non-dominant arm ('seedling shoulder'). The seedling shoulder undergoes extension or abduction (or a combination thereof) in combination with internal rotation. Arm extension, abduction and internal arm rotation begins while the planter is traveling to the next planting spot. The arm remains in the bag until the seedling is extracted from the bag 30-40% into the work cycle or after 3-4 seconds. When extracting the seedling from the bag, the shoulder was abducted greater than 60° in forty-four percent of observations (Table 1). For a few subjects it was noticed that neck flexion and rotation also occurred when they looked into the bag while extracting the seedling, although these postures were not recorded.

Table 1: Percent of awkward and not awkward postures observed (based on Hagberg et. al., 1995).

Body Part	**Joint Motion**	**Not Awkward**	**Awkward**
Shovel shoulder	Flexion	0-60° 68%	61-90° 27%
	Abduction	0-60° 54%	61-90° 43%
Seedling shoulder	Extension		98%
	Abduction	0-60° 44%	61-90° 44%
	Rotation	Medial 38%	45° Medial 34%
	Neutral	23%	
Seedling wrist	Flexion	0-45° 38%	>45° 24%
	Extension		5%
	Neutral	17%	
	Not visible	15%	
Trunk (soil penetration)	Flexion	0-45° 59%	46-90° 39%
	Rotation		64%
Trunk (seedling insertion)	Flexion	46-90° 16%	>90° 84%
	Neutral	23%	
	Rotation		91%

To grasp a seedling from the bag, the hand pinch-grips the seedling. Pinch-grips require 25% more force on the tendons compared to a stronger power grip (Hagberg et. al, 1995). Almost one-third of observations showed the wrist flexed more than 45° or extended, both awkward wrist postures. Wrist motions were of short duration, sometimes involving a ‘flicking’ of the wrist i.e. snapping.

To penetrate the soil with the shovel, trunk flexion and trunk rotation was observed. Trunk flexion in the range of 0-45° was observed 59% of the time and >45° was observed 39% of the time. This period of flexion is followed by more severe trunk flexion (45°or greater 91% of the time) to insert the seedling. The total duration of time spent in trunk flexion for an average work cycle occurs from 40% to the end of the work cycle, or 6 seconds on average.

The shovel wrist motion was difficult to analyze because of the speed of shovel-arm motions and natural objects that blocked view of the wrist.

Shovels

Shovel length ranged from 63-171 cm. Nine (56%) planters had a shovel length that, when placed upright beside the planter, reached up to between their fingertips and wrist while planter was standing erect with arms hanging straight down. Remaining planters used shovels that were longer (3, 19%) or shorter (4, 25%).

None of the shovel lengths were 5-10 cm below planters’ elbow levels, the recommended working height for handwork while standing to prevent stooping (Kroemer & Grandjean, 1997). Staff handle users had shovel lengths that ranged from 1 cm below elbow height to 57 cm above elbow height. D-handled, Ergo-D and Oval-D shovel lengths ranged 14 cm below elbow height to 52 cm below elbow height. Seven planters had shovel lengths that were 15-40 cm below elbow level, which is the recommended standing work height if it involves much effort and makes use of the weight of the upper part of the body (Kroemer & Grandjean, 1997).

There was a significant effect of shovel length (relative to the planter) on shoulder abduction and trunk flexion postures. Shovel lengths ‘below-fingertips’ and ‘above-wrist-to-elbow’ height resulted in significantly less shovel shoulder abduction compared to shovel lengths that were ‘fingertip-to-wrist’ height. When penetrating the soil, the least amount of trunk flexion was observed for shovel lengths that were above wrist relative to the planter. When inserting the seedling, the least amount of trunk flexion was observed for shovel lengths in the ‘above-wrist-to-elbow’ category. There was a trend of greater shovel shoulder flexion postures for longer shovels.

Shovel shoulder abduction was significantly less for the Oval and Ergo D handled shovels compared to the standard D.

Staff users had significantly less trunk flexion when penetrating the soil compared to D handled users. This effect was not seen during the more severe bending observed when inserting the seedling.

Three straight D-handle users had hands wider than the measured inside dimension of the handles.

Bags

Full bag weights ranged from 13-24 kg which is greater than the Ministry of Forests recommendation of 10-15 kg (Bell, 1985), and greater than seen in a previous study that measured average bag weight at 14.5 kg (Smith, 1986). Tree bag loads as a percent of body weight ranged from 12-35.8%. This range is higher than found in a previous study where payloads were 19-21% of body weight (Smith et. al, 1986).

Twelve out of 16 planters wore shoulder harnesses as well as a hip harness. All harness clips observed were functional but planters reported harness clips break (plastic 3-prong male-female design). Full bags, as observed on the planter, rested on the iliac crests (hip bones) for 7 planters, below hips for 3 and above hips for 3 planters (not observed for 3 planters). Planters commented that hip harnesses did not remain tight enough to prevent the bags from slipping down. Except for the four planters who did not wear shoulder straps, the average percent of the full bag weight supported on the hips was 76% and 24% on the shoulders, as estimated by the planter.

Discussion:

Shorter shovels caused significantly more bending and it appears D-handle shovels below fingertip height are too short. However, shovel length did not account for all the trunk posture differences; therefore technique must also have an effect. Previous research determined that the trunk was twisted more often with shorter D-handled shovels (Giguère et al., 1993). However this study did not reproduce that finding.

The effect of using longer shovels on shoulder posture was not as clear. Although Staff shovels were the longest, the planters did not place their hands at the highest spot on the shovel, so more investigation into actual shovel length (measured from tip of blade to where hand is placed on shaft) is required.

Half of the planters had a shovel length that corresponded to industry guidelines which recommends a length that reaches up to the fingertip-wrist but none had shovels that were 5-10cm below elbow level (most favourable working height while standing, Kroemer & Grandjean, 1997). However 7 planters had a shovel length that was 15-40 cm below elbow level, the recommended working height when effort is forceful and downward (Kroemer & Grandjean, 1997). If the shovel insertion motion is classified in this way, then those planters have selected the most appropriate shovel length to minimize both awkward trunk and shoulder postures.

D-handle diameters were all within ergonomics guidelines (Eastman Kodak Company, 1983; Kroemer & Grandjean, 1997; Bell, 1995) but they were measured as modified. Many of those handles were wrapped with neoprene and/or tape, therefore it may be important to advise planters to increase small handle diameters with some form of extra material. Staff handles however did not have added materials and measured 2.8-3.0 cm in diameter – smaller than guideline recommendations. It is unclear what the effect of smaller diameter Staff handles may have on grip fatigue since the hand slides up and down the shaft of a Staff handle, unlike D-handles.

Full bag loads are getting heavier compared to previously measured bag weights and guidelines (Smith, 1986; Bell, 1985). This comparison is limited however, since the time of day and time into contract is not known. As well productivity motivation may be higher with this crew, or the terrain 'easier'. The tendency towards heavier bag weights may have influenced the most common bag complaint voiced in this study, which was that the bags were slipping down the hips despite the harnesses being tightened as much as possible.

The seedling arm and wrist awkward postures are necessary because of the height the bags are carried on the body and the top opening bags. It would be useful to redesign the bags to reduce awkward postures. In theory a forward angled opening would reduce awkward posture but the angle would have to be slight enough to prevent spilling the seedlings. This may also impact the number of seedlings that can be carried in the bag at once.

Despite the heavier payloads, planters rated the comfort of their bags fairly high. A common complaint was padding, but it was observed that extra padding is available that can fit with existing hip harnesses. Again the reason for planters not acting on this comfort improvement may be financial. Future studies should measure waist circumference to determine customer needs for more adjustable or smaller sized bags.

Part 2 – Biomechanical methods research

An example of the EMG recorded during one planting cycle from digging the hole to tree insertion is shown in Figure 9. The green and red traces correspond to the right and left side EMG, respectively. During digging to open the hole for the seedling, there are high levels of EMG produced in the left-side muscles, especially in the wrist flexor (FCR) and extensor (ECR) muscles. During tree insertion with the right hand, there are high levels of muscle activity in all muscles, but the FCR and ECR muscles again show the highest sustained levels of activity.

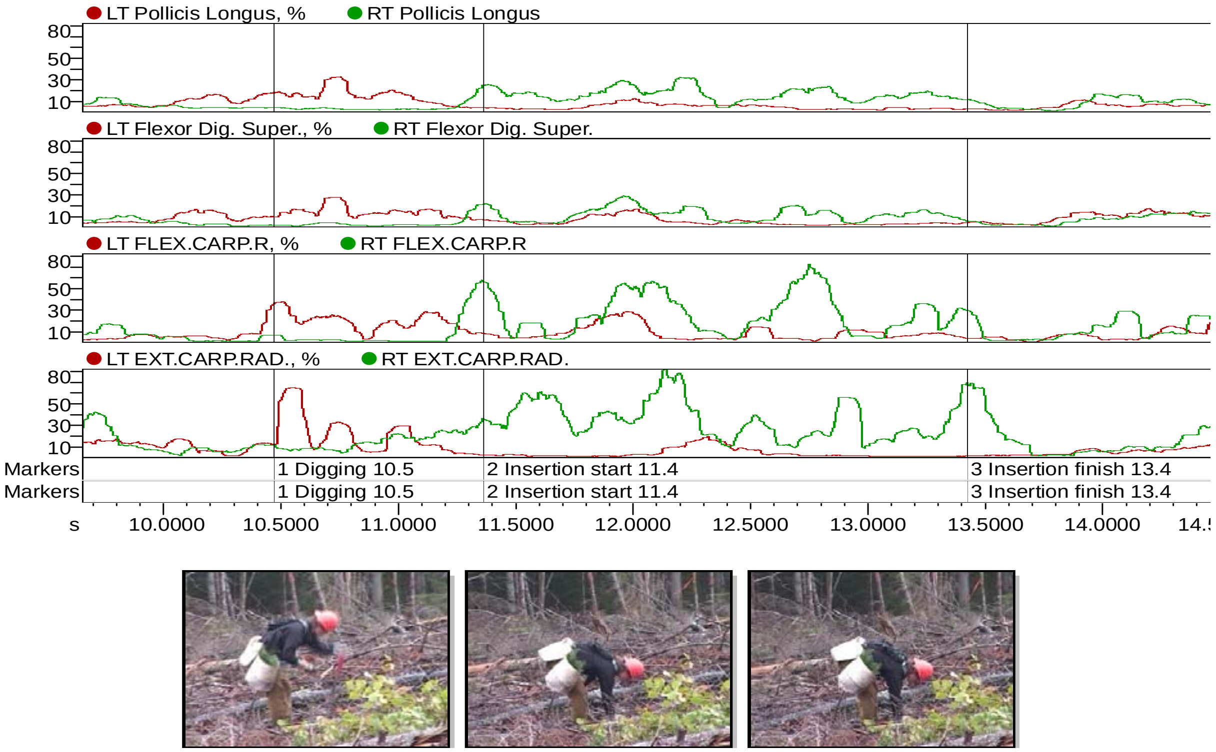


Figure 9. EMG from left and right forearm muscles during one planting cycle. The pictures are snapshots from the video taken during data collection.

Muscular Effort Analysis

To assess the levels of muscle activity (termed muscular effort) produced during tree planting, we measured the amount of time when each muscle was active at low, moderate, and high intensity levels. A low level of muscle activity was defined as less than 10% of MVC, moderate levels correspond to 10-35%MVC, and activity levels above 35% are considered high intensity.

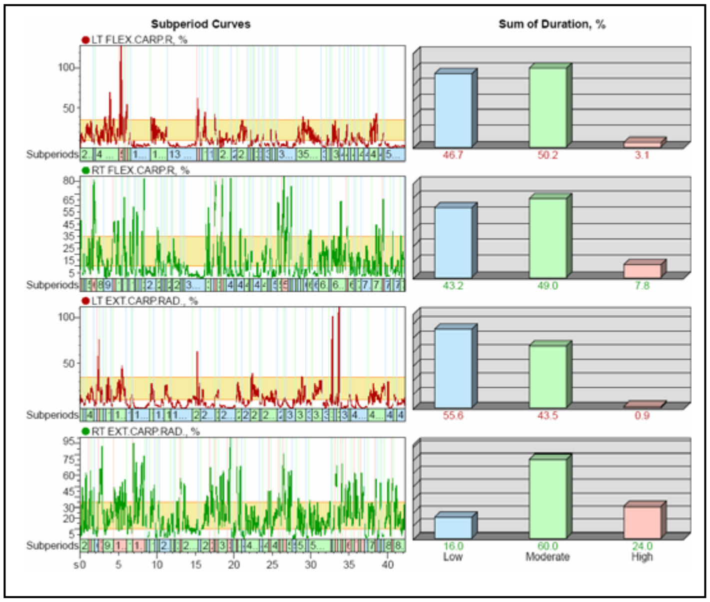


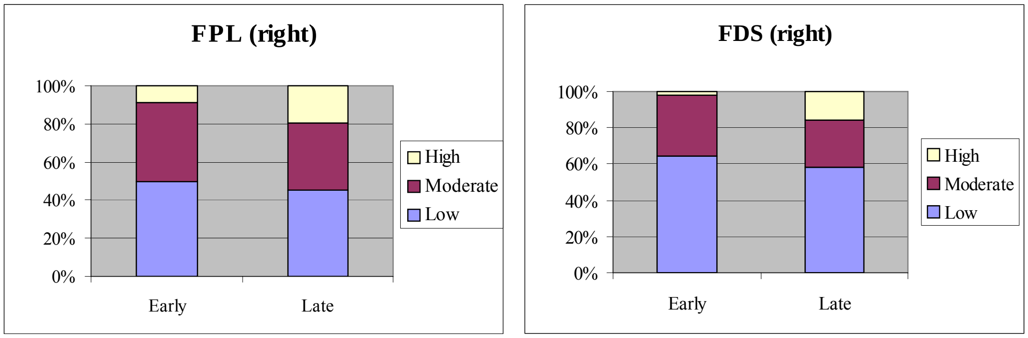
Figure 10. Muscular effort period analysis. The orange shaded region indicates the range of moderate intensity levels. The amount of time spent at each effort level was quantified as a percentage of total time as shown by the bar graphs at the right.

This classification provides a duty cycle measure that indicates the percentage of time that a given muscle is used at each intensity level. Figure 10 shows an example of the muscular effort period analysis for the FCR and ECR muscles for both arms of one subject during a 45 second recording. The analysis shows that the muscles are used at a low or moderate intensity level most of the time, but the right ECR is used at a high intensity for 24% of the total planting time.

The muscular effort analysis was applied to the EMG records for all five subjects and the effort periods were averaged across the 5 subjects. Since each "bag-up" session spanned about 45 minutes, we analyzed separately the data from the early part of the bag-up session (first 5 minutes) and the late part (last 5 minutes). Comparing the early and late muscular effort periods provides insight into the effects of fatigue on the amount of muscular effort that is exerted during planting.

Figure 11 shows the averaged muscular effort periods for the shovel-sided muscles (labeled as right-sided). During the early part of the planting session, the thumb and finger flexor muscles (FPL and FDS) are rarely used at high intensity, but by the end of the planting session both muscles are used at the high intensity level for nearly 20% of the planting time. This is consistent with a fatigue effect in which a greater muscular effort is required to overcome the reduced force generating capacity of the muscle. The wrist flexor muscle (FCR) shows a similar trend and is used at high intensity for over 20% of the time in the late phase of the planting session. The ECR (wrist extensor) was consistently used at high intensity for over 20% of the planting time.

Hand muscles



Wrist muscles

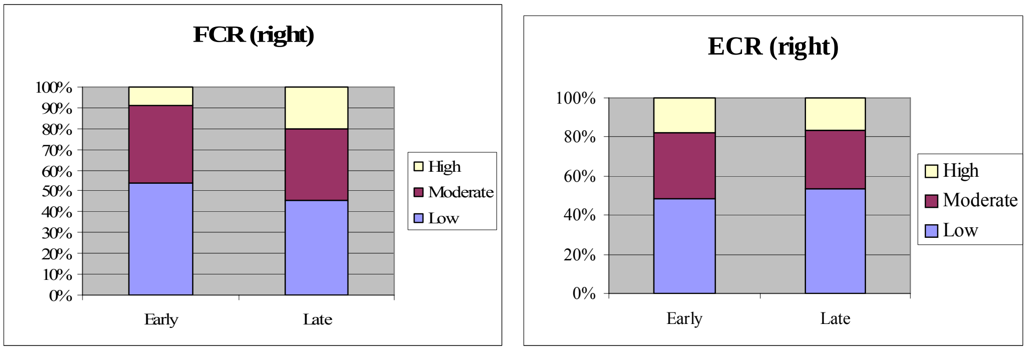


Figure 11. Muscular effort periods for the muscles of the shovel side (right).

Part 3 - Shock and vibration in planting tools.

ISO Standards: A review of the relevant standards for human response to vibration and repeated shocks led to the following conclusions.

(1) The effectiveness of vibration absorbent gloves and absorbent materials can be measured either in the laboratory using a standard testing apparatus (ISO 10819 and ISO 13753) or in the workplace while the worker is using the appropriate tool (ISO 5349 and ISO 15694). Laboratory testing is most suitable for determining the frequency response characteristics of absorbent materials and for comparison of different materials. The effectiveness of a glove or wrap material in absorbing shocks and vibration at the handle of a tool will be dependent on the frequency spectrum of vibration of each particular tool. The frequency content of impacts measured at the handles of tree planting shovels is unknown and will vary depending on the manufacturer. The ISO 10819 and ISO 13753 may not be representative of the response to the type of transient shock event experienced in tree planting. It was concluded that the laboratory test methods described in ISO 10819 and ISO 15753 are not appropriate to the objectives of this study. Measurement of the effectiveness of absorbent gloves and handle wrap materials should be made either in the workplace (tree planting) or under simulated working conditions using the appropriate tree planting tool and ground.

(2) Hand arm vibration can be measured either in the anatomical co-ordinate system of the hand or in the basicentric co-ordinate system referenced to the handle of the tool (ISO 8727). The differences in orientation of the handles of a D-handle, Ergo-D handle, Oval-D and staff handle shovel may lead to difficulties in the measurement and interpretation of the basicentric co-ordinate system. The axes would have to be redefined for each handle type.

It was therefore concluded that in this study, measurements of acceleration should be made as closely as possible to the anatomical co-ordinate system. The co-ordinate system is defined as follows: origin in the distal head of the third metacarpal bone of the hand; x axis directed anterior and normal to the palm of the hand; y axis directed lateral left and perpendicular to the third metacarpal bone; and z axis directed distal to the long axis of the third metacarpal.

(3) ISO 5349 provides the measurement methods for evaluation of hand arm vibration in the workplace. This standard relies on a RMS measure of acceleration and is suited to evaluation of hand held tools that produce a steady state vibration signature. The RMS acceleration measure provides little information on the impulsiveness, or peak acceleration amplitude, experienced from tools having a non steady state, repeated shock signature.

The methods of measurement described in ISO 15694 are more suitable to the repetitive shock signatures experienced in tree planting. This standard recommends that hand arm accelerations should be measured using a flat response band-pass filter with cut-offs at 6.3 and 1250 Hz. Although the methods for evaluating repeated shocks to the hand/arm provided in ISO 15694 provide some indication of the impulsiveness of a non steady state vibration signal, experience has shown that the SCQ (ratio of RMS/RMQ) acceleration is not very sensitive to infrequent shocks (< 1/s) experienced in tree planting (Rodden et al. 1993). A more informative measure can be obtained for the root mean of the 10th or 12th power of acceleration (RMD or RMT), and the ratio of this value to the RMS. These higher root mean values provide are more sensitive to the peak values of acceleration rather than the mean acceleration level. For example for a randomly distributed acceleration signal the ratio of RMD/RMS is 1.96, whereas for an acceleration signal having isolated shock events, the RMD/RMS ratio is likely to be in the range 2.5 to 20 depending on the shock frequency and the impulsiveness of the signal.

It was conclude that the RMS and RMD values of acceleration and the RMD/RMS ratio should be calculated for each axis of acceleration.

(4) The ISO 15694 standard does not include a measure of daily exposure such as the 8-hour equivalent exposure value, A(8), provided in ISO 5349, or the number of shocks occurring in a day's exposure. It was concluded that a daily exposure (dose value) should be calculated similar to that defined in ISO 2631-5. This dose measure, using the 6th power of peak accelerations, is designed for whole body vibration that includes repeated shocks (Morrison et al. 1997, 1999). There is no comparable measure for hand arm vibration that includes repeated shocks. For evaluation of tree planting exposures, it was decided that a daily exposure value D should be calculated based on the 6th root of the cumulative 6th power of peak accelerations (for each shock), measured in the ± x, ±y and ±z directions. The total daily acceleration dose D(8) should be reported together with the sample period (min.), the number of acceleration peaks (shovel strikes) in the sample, the magnitude of acceleration peaks in each axis, and the 1-minute (peak) acceleration dose in each of the x, y and z axes.

(5) In order to establish a daily acceleration dose based on a sample period of less than one day, it is necessary to have a measure of the work rate (trees planted/ min) and hours of active tree planting contained in a typical workday. If measurements are made in the workplace (forestry planting), then the planting rate can be calculated from the sample data. However, if measurements are made in a simulated planting environment, then the planting rate should be corrected to field observations. Planting rates and exposure times vary greatly depending on planter, company and terrain. Smith (1987) reports an average tree planting rate of 3/ min., with a range of 1.9/min. to 3.5/min; and an average working day of 7.8 hr. with 7.15 hr. of planting (based on observation of 17 planters). In Phase 1 of the present study, the average tree planting rate of 16 experienced planters was 6/min. with a range of approximately 4/min. to 10/min. Data

provided by FERIC for 14 planters indicated an average planting rate of 1534 +/- 272 trees per day.

It was conclude that calculations of daily acceleration dose value D(8) from laboratory or simulated field conditions should be based on a total of 1500 trees with a strike rate of approximately 3.5 shocks/min. and a work day of 8 hr. with 7 hr. of planting and 1 hr. breaks. When measured in real tree planting conditions the D(8) should be based on the actual planting time per day, excluding breaks for food intake and bag-ups.

Pilot Study 1:

Experiment 1: Results indicated that peak accelerations varied from 10 - 20 g (100 – 200 $m.s^{-2}$) when digging in compact earth, to 50 – 100 g when digging in fine gravel, and 200 – 300 g when digging in gravel and striking rocks. It was also determined that the Nexus 2693 conditioning amplifier provided excellent signal to noise characteristics for accelerations ranging from 1 $m.s^{-2}$ to 5000 $m.s^{-2}$.

Conclusions: Although the Nexus signal conditioning system provides excellent results, and can be powered by either 120 volts AC or battery, it requires a separate data acquisition and storage device. For purposes of this pilot study, an available IOtec system and lap-top computer were used. However, for data collection in the field, this instrumentation will prove to be bulky and would require a wire connection between the planter and the researcher. An alternative system that is more compact and includes signal conditioning, analysis and storage was therefore tested.

Experiment 2: Peak acceleration values measured and stored by the HMV 100 in the laboratory test conditions were similar to those obtained in Experiment 1. Peak accelerations measured under field conditions ranged from 20 – 70 g when digging in loose soil and undergrowth. In cases where the shovel struck against large tree roots close to the surface, peak accelerations ranged from approximately 100 – 450 g.

Analysis of the analog output data obtained from the HMV 100 revealed a high level of noise in the output signal. Following further analysis of signal output and discussions with an engineer at Larson Davis, it was determined that the analog output signal was attenuated by a factor of 10 compared to the accelerometer input. For this reason the instrument was not capable of providing a satisfactory signal to noise ratio over the relatively large range of acceleration amplitudes (1 to 500g) experienced in tree planting data.

It was found that when wearing vibration absorbent gloves, it was not possible to accommodate the size of the palm accelerometer adapter between the inner surface of the glove and the palm of the hand. However, the handle adapter could be used by cutting a slot on either side of the glove and sliding the bar between the glove and the hand.

Conclusions: Although the HVM 100 is the most compact of the signal conditioning and data acquisition systems available, when it used as a stand alone system, the information obtained is limited. As the time series acceleration data is not stored, the HVM 100 does not allow the type of analysis recommended in the first section of this report.

Recommendations:

1. It was determined that for measuring hand arm vibration and shock in tree planting, a triaxial accelerometer having a range of ± 500g and sensitivity of 10 mv/g is required.
2. For measurements of vibration and shock at the handle, the handle (or bar) adapter is the most suitable method of mounting the accelerometer.
3. The Nexus 2693 is the preferred signal conditioning system to be used in collecting hand-arm acceleration data from tree planters.

A Nexus 2693 4-channel Deltatron conditioning amplifier and an Endevco 65-10 triaxial Isotron accelerometer were purchased. The accelerometer has a sensitivity of 10 mv/g, a measuring range of ± 500 g in all three axes, and a frequency range of 0.5 to 10,000 Hz. The accelerometer was powered by the Nexus 2693 which provides a gain of -20 to +60 dB and selectable low-pass and high-pass filters in the range of 100 Hz to 100 KHz (LP) and 0.1 to 10 Hz (HP).

Pilot Study 2

Results are shown in Table 2. The mean values ± SD of the RMS and RMD acceleration values in each of the x, y and z axes, the mean peak dose value, and the eight hour equivalent dose value are provided for both types of shovel when used without gloves and with the Impacto anti-vibration gloves.

Results show no consistent differences in the values of RMS and RMD accelerations or in the acceleration exposure dose between shovel handles, or data collected with or without gloves. Mean peak acceleration values are generally in the range of 20 – 60 g (200 to 600 m.sec^{-2}). Two data samples provided considerably higher dose values than the others. This was due to a single large impact in each of the data files and most probably represents the shovel striking a stone or root. These impacts are shown in Figures 15 and 16 and have peak values of approximately 150 g. In these data files the remaining impacts were within the normal range of 20 – 60 g.

Analysis of RMD accelerations and mean peak acceleration dose values indicate that the anti vibration glove did not result in lower peak accelerations or dose values (measured with the accelerometer adapter inserted between the glove and the palm as shown in Figure 8). The time history data in Figures 13 and 14 show that the anti vibration gloves absorb the higher frequency vibrations when using a shovel with a hard plastic handle. This suggests that the anti vibration glove acts as a selective filter, attenuating the higher frequencies but that they are not effective in reducing the magnitude of the basic shock wave form which has a main frequency component of around 15 – 30 Hz.

The high magnitude impact shown in Figure 16 also showed a resonance of approximately 700 Hz superimposed on the initial shock wave form. This could represent vibration transmitted through the glove from the tool or resonance of the hand arm system. As this resonance was not present in the comparable impact using the synthetic rubber handle and anti vibration glove (see Figure 15), it is concluded that the resonance was transmitted from the tool handle through the glove.

Figure 12 shows the x and z axis accelerations in response to a typical impact when digging in loose soil with some small stones. The shovel handle is of compliant synthetic rubber, and the subject is not wearing gloves. The main acceleration component is recorded in the x axis, in line with the shaft of the tool, as a negative value (deceleration). The peak acceleration value of -48g (-470 $m.s^{-2}$) is typical of digging in loose ground. The period of the impact is approximately 35 ms.

Table 2. Results of tree planting data analysis: Values of RMS and RMD accelerations measured in the x, y and z axes; the mean peak acceleration dose and the daily acceleration exposure dose D(8); Measured from two different handles with and without anti-vibration gloves. H1: synthetic rubber handle; H2: Rigid plastic handle.

TEST	X RMS	Y RMS	Z RMS	X RMD	Y RMD	Z RMD	PEAK DOSE	DAILY DOSE
H1	22.7	7.4	15.9	173.4	75.5	164.5	322	1209
H1	32.3	13.6	17.5	211.1	110.1	134.3	368	1397
H1	27.3	13.2	15.0	186.1	83.0	92.1	316	1201
H1	25.5	10.4	19.4	205.3	58.4	107.9	386	1465
H1 Glove	31.3	9.8	15.8	225.2	66.9	124.8	411	1560
H1 Glove	30.9	8.2	13.8	227.0	57.6	78.1	354	1346
H1 Glove	46.1	14.4	20.6	600.6	253.4	345.0	1060	4027
H1 Glove	31.6	8.0	12.7	217.1	37.2	58.8	370	1406
H2	35.3	14.5	17.7	253.9	164.2	230.7	528	2006
H2	32.3	12.4	15.5	187.5	87.4	134.4	347	1318
H2	30.6	9.5	20.8	208.1	67.8	133.0	379	1439
H2	30.0	9.2	19.1	216.8	113.8	182.9	445	1689
H2 Glove	37.1	14.2	15.7	242.6	84.8	73.2	440	1670
H2 Glove	42.8	13.2	18.4	584.1	191.4	247.1	1093	4150
H2 Glove	27.7	8.6	9.6	147.7	49.0	62.6	237	899
H2 Glove	28.9	8.9	13.2	163.4	72.5	75.0	283	1073
MEAN	32.0	11.0	16.3	253.1	98.3	140.3	459	1741
SD	6.0	2.6	3.1	135.4	58.0	78.7	251	952

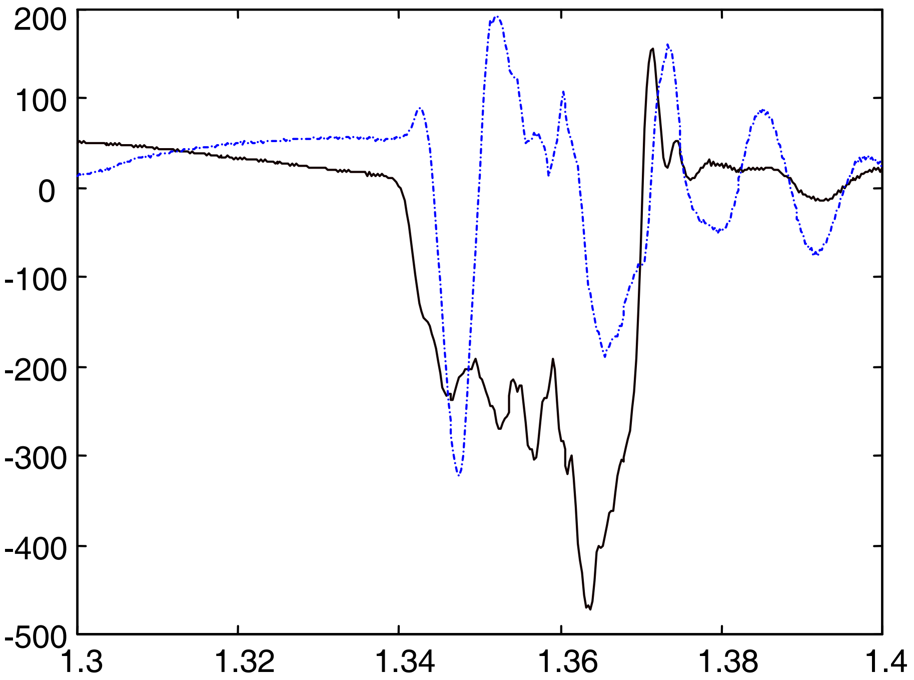


Figure 12. Acceleration (m.s^{-2}) v. Time (s) for x axis (solid line) and z axis (chain line). Synthetic rubber D-handle shovel; subject without gloves.

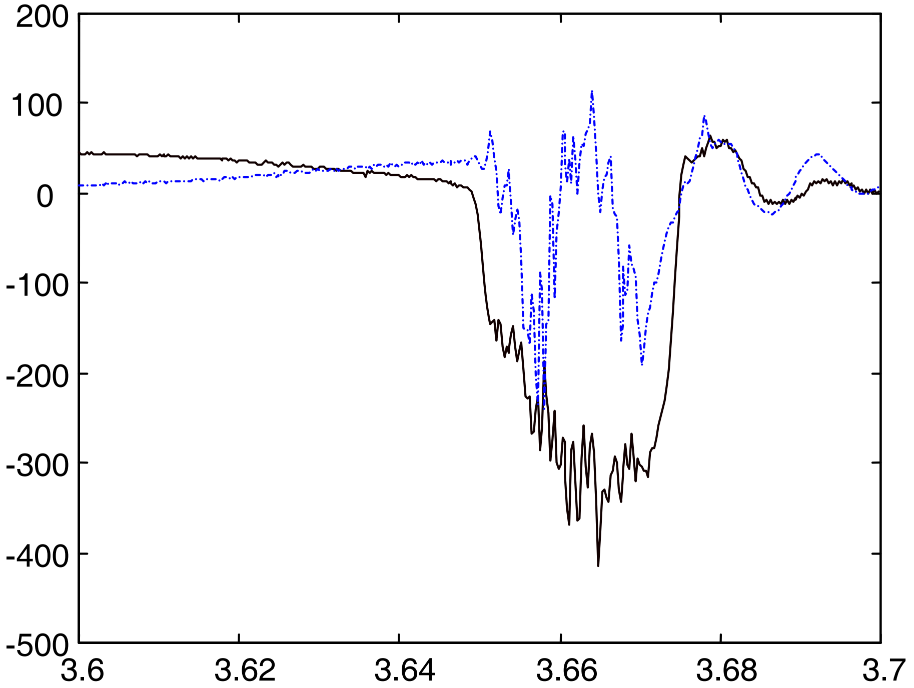


Figure 13. Acceleration (m.s^{-2}) v. Time (s) for x axis (solid line) and z axis (chain line). Rigid plastic D-handle shovel; subject without gloves

Figure 13 shows a comparable record when digging in the same area, but using a shovel with a rigid plastic handle. Although the peak x axis acceleration value is slightly lower than that of Figure 12, there is a considerable amount of high frequency vibration (approximately 700 Hz) superimposed upon the basic shock waveform.

Figure 14 shows the same subject digging in the same area with the rigid plastic D-Handle shovel, but when wearing an Impacto anti-vibration air glove (model BG401). Although the magnitude of the impact is similar to Figure 13, the high frequency vibrations are largely eliminated from the acceleration signal in both the x and z directions. This indicates that the higher frequency vibrations are mostly absorbed by the glove and not transmitted to the hand. However, the overall magnitude of the shock is a function of the lower frequency waveform and remains unchanged from that of Figure 13.

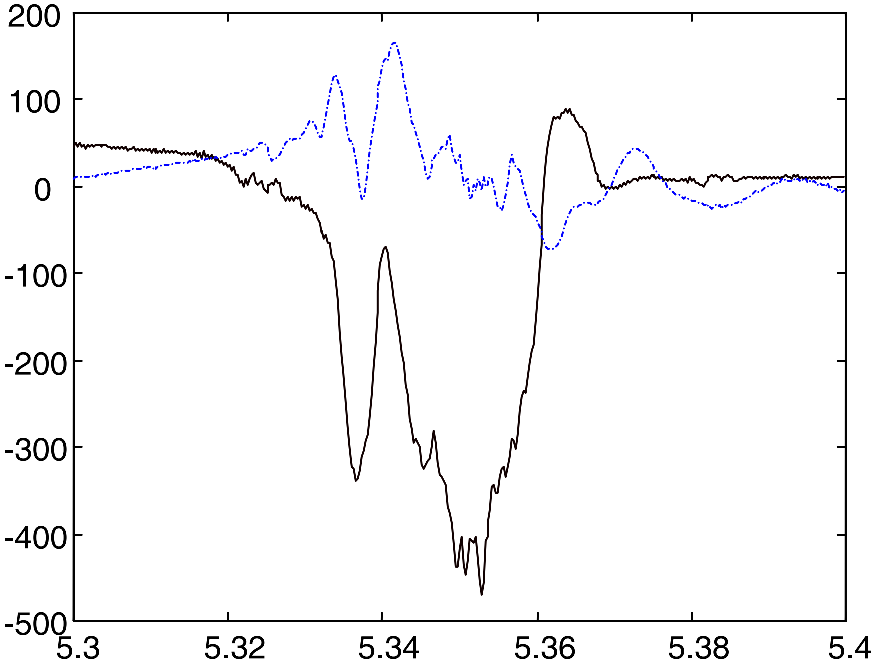


Figure 14. Acceleration (m.s^{-2}) v. Time (s) for x axis (solid line) and z axis (chain line). Rigid plastic D-handle shovel; subject wearing Impacto anti-vibration glove

Figure 15 shows an example of a higher magnitude impact when digging with the synthetic rubber D-handle shovel, and wearing the Impacto glove. Peak acceleration in the x axis is -145g (-1427 m.s^{-2}). The period of the shock (approximately 15ms) is about half that in the previous examples of lower amplitude shocks. Again there is no evidence of high frequency vibrations in the shock waveform transmitted to the hand, although there is some vibration around 200 Hz, particularly in the z direction.

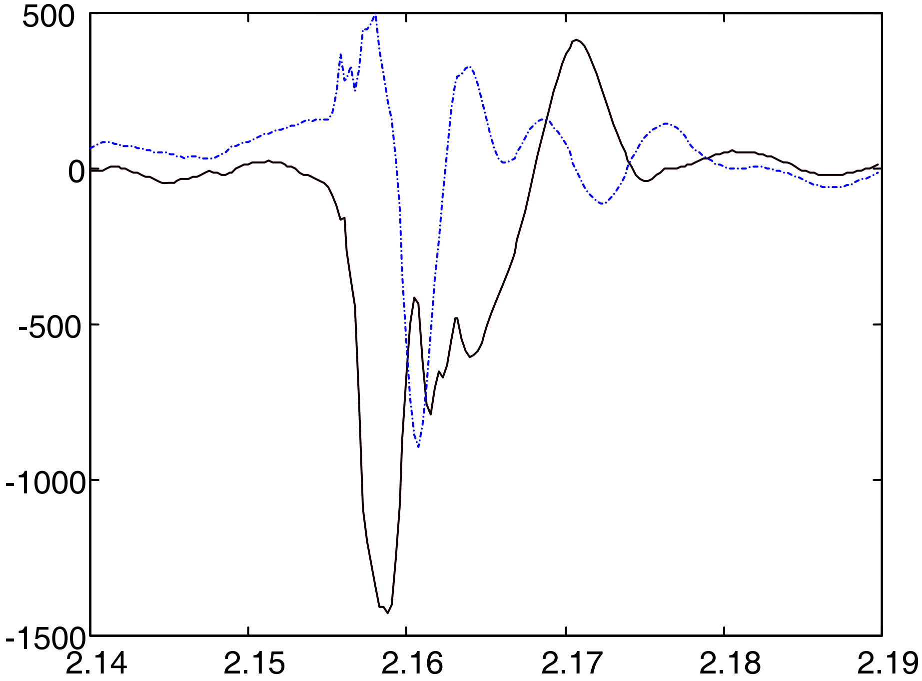


Figure 15. Acceleration (m.s^{-2}) v. time (s) for x axis (solid line) and z axis (chain line). Synthetic rubber D-handle shovel; subject wearing Impacto anti-vibration glove

Figure 16 shows an example of a higher magnitude impact when digging with the rigid plastic D-handle shovel, and wearing the Impacto glove. Although the shock peak acceleration (-157g) is of the same magnitude as in the example shown in Figure 15 (synthetic rubber D-handle), in this case there is more evidence of higher frequency vibrations at approximately 700Hz transmitted to the hand.

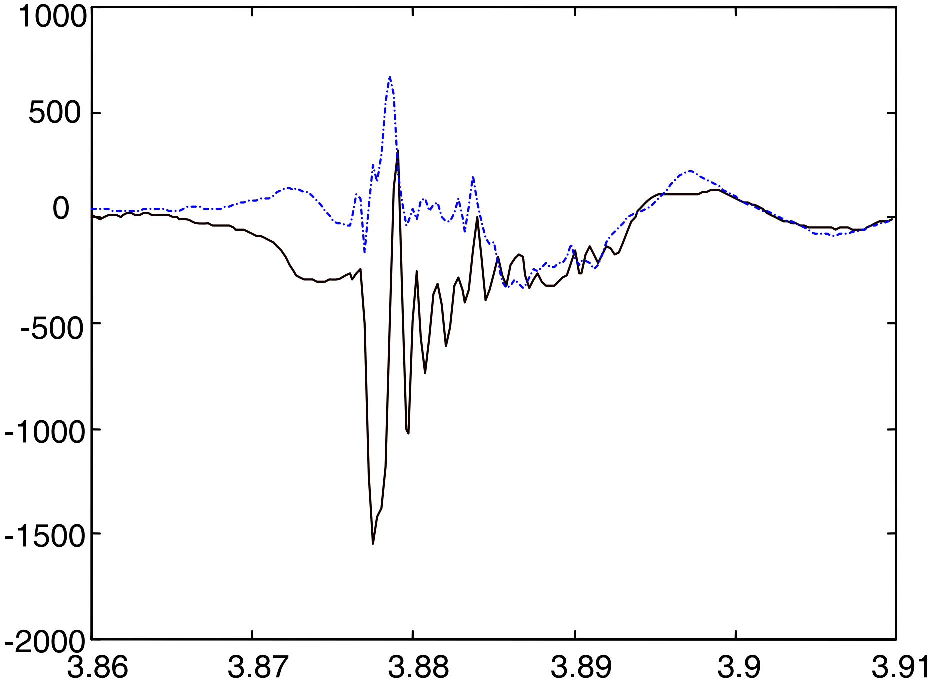


Figure 16. Acceleration (m.s^{-2}) v. Time (s) for x axis (solid line) and z axis (chain line). Rigid plastic D-Handle shovel; subject wearing Impacto anti-vibration glove

CONCLUSIONS

In this study methods were developed for measurement and analysis of accelerations at the hand of tree planters. Results indicate that the measurement and analysis techniques developed are sensitive to the high peak accelerations experienced in tree planting. Hence the methods will provide a good measure of the relative severity of different acceleration exposures experienced by tree planters using different tools and working in different terrains.

Results indicate that an anti-vibration glove is not effective in reducing the peak acceleration experienced at the hand. This finding is in agreement with ISO 10891 which note that anti vibration gloves generally do not provide sufficient attenuation of frequencies below 150 Hz. However, results show that it does attenuate the higher frequency components of acceleration. Therefore, it is recommended that a 3rd octave band analysis of the frequency spectrum of the acceleration data is included in the analysis in order to determine the relationship between vibration frequency and the attenuation (protection) afforded by the anti-vibration glove. This can be accomplished by comparing the spectrums (PSD) obtained when planting with and without gloves.

When collecting data under real field conditions, a more compact data acquisition system will be required, to be used with the Endevco accelerometer and the Nexus signal conditioner. It is likely that a PDA/Pocket PC and data acquisition card (e.g. HP Compac IPAC 5500 and National Instruments CF 6004 DAQ) can be used for this purpose.

Although the peak acceleration at the hand is most probably the main determinant of injury risk in tree planting , the role of high frequency vibration in shock loading of the hand-arm system is not well understood. The pressure distribution of the force applied to the hand may also affect the transmission through the hand-arm system. Therefore, in addition to collection of objective acceleration data it is recommended that subjective measures should be collected from tree planters. A set of modified Borg scales should be used rate comfort at the hand-tool interface during impact, force at the hand, and muscular exertion of planting with different tools and anti-vibration materials. The modified Borg scales are provided in Appendix 3.

GUIDELINES FOR MEASUREMENT AND ANALYSIS OF HAND-ARM ACCELERATIONS IN TREE PLANTING.

- Measurement of the effectiveness different tools, shock absorbent devices, absorbent gloves and absorbent handle wrap materials should be made either in the workplace (tree planting) or under simulated working conditions using the appropriate tree planting tool and ground.

- For measuring hand-arm vibration and shock in tree planting, a triaxial accelerometer should be used, having a measurement range of ± 500g, frequency range 1.0 to 5,000 Hz, a resonance frequency >30,000 Hz, and peak acceleration (overload) of 10,000 g.
- For measurements of vibration and shock at the handle, the accelerometer should be mounted on a bar accelerometer adapter as described in ISO 5349-2.
- Measurements of acceleration should be referenced to the anatomical co-ordinate system described in ISO 8727. The co-ordinate system, shown in Figure 2, is defined as follows: origin in the distal head of the third metacarpal bone of the hand; x axis directed anterior and normal to the palm of the hand; y axis directed lateral left and perpendicular to the third metacarpal bone; and z axis directed distal to the long axis of the third metacarpal.
- Hand-arm accelerations should be measured using a flat response band-pass filter with cut-offs at 6.3 and 1250 Hz as described in ISO 15694.
- The RMS and RMD acceleration values and the RMD/RMS ratio should be calculated for the x, y and z axis of acceleration.
- A daily exposure acceleration dose value should be calculated similar to that defined in ISO 2631-5. The acceleration dose (D) should be calculated based on the 6th root of the cumulative 6th power of peak accelerations (for each shock), measured in the ± x, ±y and ±z directions. The total daily acceleration dose D(8) should be reported together with the sample period (minutes), the number of acceleration peaks (shovel impacts) in the sample, the mean peak acceleration dose for a single impact, and the 1-minute acceleration dose in each of the x, y and z axes.
- Calculations of daily acceleration dose value D(8) from laboratory or simulated field conditions should be based on a total of 1500 trees with a strike rate of approximately 3.5 shocks/min. and a work day of 8 hr. with 7 hr. of planting and 1 hr. breaks. When

measured in real tree planting conditions the D(8) should be based on the actual planting time per day, excluding breaks.

- A 3rd octave band analysis of the frequency spectrum of the acceleration data should be included to determine the relationship between vibration frequency and the attenuation (protection) afforded by the anti-vibration glove.
- Subjective data of perceived comfort, perceived force at the hand, and perceived muscular exertion of planting should be collected during testing of different tools and anti-vibration materials. A set of modified Borg scales (Appendix 3) should be used to rate comfort, force and exertion.

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Implications for Future Research on Occupational Health

This study was designed as a pilot study to test the methodologies for data collection, to determine stressful exertions using posture analysis techniques, to compare the fit of tree planting equipment to ergonomic guidelines and to provide a baseline for future research. The results confirm the need to carry out a large scale study on this subject area even though the extent of this study was intentionally kept limited so the sampling size was small and taken from only one geographic area. The methodologies we used worked well and with some adjustments are suitable for the large scale study that is planned to follow. Every joint motion observed had awkward postures to varying degrees which suggests that the guidelines of how to avoid and reduce such postures are needed. The equipment used by the planters to a large extent does not fit their bodies and the existing ergonomic guidelines but further sampling is necessary to get a better understanding of the problem. This study provides a baseline for future research.

Results of the pilot studies of vibration and shock at the hand also indicated a need or further research. Review of ISO Standards for hand-arm vibration revealed that measurement methods for repeated shocks at the hand-arm are not as well developed as methods for whole body vibration and shocks. In addition, guidelines for assessment of health effects of impulsive loading of the hand-arm are not included in the standard. The methods developed in this study (for measurement and analysis of the accelerations at the hand of planters) require further validation. This will be done in a more comprehensive field study of tree planter activity that encompasses different types of terrain, different tools, and methods of shock mitigation. Health guidelines are required for determination of a physiologically acceptable exposure (daily acceleration dose). The pilot study also suggests that while vibration absorbent gloves may be effective when used with vibrating tools that have a steady-state Gaussian or tonal vibration signature, they are ineffective in protecting tree-planters from the type of low frequency, high acceleration magnitude, impulsive loading experienced in this occupation. Further research is required using the methods developed in this study to evaluate different vibration absorbent materials and devices that may protect the tree planter from excessive shock loading at the tool-hand interface.

Policy and Prevention:

Prevention implications from the research

Because this was a pilot study, the data are limited in scope. However, the severity and duration of trunk bending, twisting, shoulder abduction, and wrist flexion found validates the need for injury prevention guidelines. These will be developed based on the full scale project using the methodologies tested in this study. As an example of what can be expected in terms of the guide lines that will be developed to reduce or prevent musculoskeletal injuries, consider the following:

a) The low back is at risk from the awkward postures of flexion and twisting occurring concurrently, and the duration of trunk flexion in each work cycle.

Recommendation: Reduce the duration of trunk flexion by keeping trunk bending to 20° or less during soil penetration. In addition to technique, shovel length should be selected to enable this upright posture. Preliminary examination has determined that shovel lengths greater than wrist height of the planter result in less trunk bending. Also Staff shovels result in less trunk bending compared to standard D shovels.

b) The shovel shoulder is at risk from abduction or flexion postures greater than 60°.

Recommendation: Keep the elbow within 60° of the body. In addition to technique, shovel length and style should be selected to enable this posture. Preliminary examination determined that Oval and Ergo-D handle shovels result in a better shoulder posture compared to a standard D.

c) The seedling wrist is at risk from flexion or extension postures greater than 45° while grasping the seedling to extract it from the bag.

Recommendation: Keep the wrist straight. This may require looking at bag design to enable this. Grasp force should also be minimized to minimize risk of injury. Since planters grasp with a pinch grip, grip force may be an issue and should be minimized such as by not packing seedling in the bag too tight.

d) There is risk to the seedling shoulder from abduction postures greater than 60°. Repeated movement of internal rotation increases risk of impingement of soft tissues of the shoulder.

Recommendation: Keep the elbow within 60° of the body. Minimize extreme shoulder extension or internal rotation positions when reaching for seedlings in the bag.

Another important part of prevention of musculoskeletal injuries involves the use of tools and equipment that are designed based on ergonomic guidelines. In this respect, the pilot study found that:

e) Ergonomic guidelines for shovel fit are not well met in this sample except for D-handle diameters which are modified by planters to their benefit.

f) Bag design leads to awkward shoulder and wrist postures.

g) Other bag design features to consider for improvement, based on feedback from subjects in this study include:

- Smaller waist harness sizes
- Non-slip belts

h) There is a benefit to shovel shoulder abduction posture using a modified D-handle such as the Oval-D or Ergo-D.

i) Shovel length affects trunk flexion posture. D-handle shovels below fingertip length result in more trunk flexion, and Staff handle shovel users tend to flex less when opening the hole for the seedling.

Part 3 of the study produced a comprehensive set of guidelines for measurement and analysis of hand-arm accelerations in tree planting. These guidelines are defined in detail in the report. The guidelines can be used for evaluating new tool designs, investigating the effectiveness of different types of absorbent materials and protective devices, and evaluating the relative severity of daily exposure to vibration and shock of tree planters working in different terrains and using various tools. A better and more consistent assessment method for evaluation of tool design, protective materials, and daily acceleration exposures should lead to improved methods of injury prevention.

Relevant user groups for the research results

The results that will come from the full scale project following this pilot project will be used to develop guide lines for reducing tree planter injuries.

The end users of the guidelines will be the thousands of tree planters that are employed by Silvicultural Planting Contractors to plant roughly 200 million trees in British Columbia each year. It will be equally useful to tree planters in other jurisdictions.

The guide lines will also be useful for the tree planting contractors as a tool in training the beginners and to reinforcing a culture of safety in their work environment. Further, the guide lines will be beneficial in not only reducing MSI and lost time but also in increased productivity.

Dissemination/Knowledge Transfer

The results of “Part 1- Tree Planting Task Analysis” of the pilot study were presented in a Power Point format to the Annual General Meeting and Conference of the Western Silvicultural Contractors Association in Prince George, January 2005. Draft copies of the “Interim Recommendations for Preventing Tree Planting Injuries” were made available to the contractors.

Results from “Part 2 – Biomechanical Methods Research” and “Part 3- Shock and Vibration in Planting Tools” of the pilot study will be not be distributed since this research was conducted to establish the methodologies to be used in the main data gathering study.

When the main study is completed, the guide lines for reducing tree planting injuries will be published by the Forest Engineering Research Institute of Canada in its regular Advantage Report series. They will also be made available to tree planting related websites such as www.tree-planter.com and consideration will be given to publishing the results in a booklet type of format that is easy for the tree planter community to handle and use. Distribution of such a booklet will be done by tree planter contractors.

Appendices

Appendix 1 - Part 1 – Tree Planting Task Analysis

Element Description	% Normalized Work Cycle	Posture Observed
	0	
* Look for next planting spot. * Carry shovel to next planting location in right hand (2m away).	23	
	25	
(a) Feel for next seedling in bag with left hand		(a) Seedling shoulder flexion-extension (a) Seedling arm rotation
* Remove duff layer by kicking or using shovel if necessary.	31	(a) Seedling shoulder abduction
(b) Penetrate soil with shovel in right hand to make or determine location for hole.	36	
(c) Extract seedling from bag with left hand.	38	(d) Trunk twisting (penetrating soil) (b) Shovel shoulder abduction (b) Shovel shoulder flexion
(d) Penetrate soil with shovel in right hand to make a hole for seedling 10-15 cm deep.	40	(c) Seedling wrist flexion/extension
	44	(d) Trunk flexion (penetrating soil)
	50	
(e) Bend to hole with seedling in left hand.	61	(e) Trunk flexion (inserting seedling)
(f) Insert seedling into hole with left hand.	70	(f) Trunk twist (inserting seedling)
* Close hole with foot or left hand.	100	

% Normalized Work Cycle

Figure A1: Element descriptions for tree planting (shovel in right hand) and corresponding joint movements in a normalized tree planting work cycle

Appendix 2 - Part 3 – Shock and vibration in planting tools

Program modules:

F_cal Opens browser in which to find and enter data file name; reads x, y and z acceleration data; applies calibration factors to convert data to $m.s^{-2}$, transforms axes to hand-arm coordinates and writes data to separate x, y and z data files.

hha_gui This program opens a graphical user interface into which the user can select and enter the names of the x, y and z data files to be analyzed, the sampling frequency, the peak detection threshold, and the required exposure time. The program plots the acceleration time history for each axis; calculates the RMS and RMD acceleration values for each axis; calls the acceleration dose and peak detection sub routines, calculates the cumulative daily acceleration dose value based on daily exposure time, plots the cumulative acceleration dose time history; and writes results to the screen.

hha_Peaks: Reads the acceleration data and identifies the maximum acceleration value of the highest peak; sets an exclusion window (± 1 s.) around the identified peak and repeats this process until all peaks above the threshold are identified; prints the resultant peak acceleration values for each impact.

hha_Dose This program calls the hha_Peaks subroutine; calculates and stores the positive and negative acceleration peaks in the x, y and z directions; calculates the resultant x, y and z acceleration dose for the sample data and the mean acceleration dose value for a single impact.

Appendix 3 - Part 3 – Shock and vibration in planting tools

Perceived Comfort Scale

Use the scale below to rate the comfort at the hand/arm when driving the shovel into the ground. Circle the number that best describes the comfort of the task. You can use decimal points, or circle 2 numbers if comfort falls between 2 ratings.

0	**Very comfortable**
0.5	**Comfortable**
1	**Fairly comfortable**
2	**Slight discomfort**
3	**Moderate discomfort**
4	**Somewhat severe discomfort**
5	**Severe discomfort**
6	
7	**Very severe discomfort (hurts)**
8	
9	**Extreme discomfort (painful)**
10	**Maximal discomfort (can’t tolerate)**

Perceived Hand Force Scale

Use the scale below to rate the peak force at the hand when driving the tool into the ground. Circle the number that best describes the peak hand force. You can use decimal points, or circle 2 numbers if exertion falls between 2 ratings.

0	**No force at all**
0.5	**Just noticeable**
1	**Very low**
2	**Low force**
3	**Moderate force**
4	**Somewhat high**
5	**High force**
6	
7	**Very high force**
8	
9	**Extremely high force**
10	**Maximal force**

Perceived Exertion Scale

Use the scale below rate the effort of driving the shovel into the ground. Effort represents the muscular work done to accomplish the task. Circle the number that best describes the effort exerted to do the task. You can use decimal points, or circle 2 numbers if exertion falls between 2 ratings.

0	**No exertion at all**
0.5	**Just noticeable**
1	**Very light**
2	**Light**
3	**Moderate**
4	**Somewhat hard**
5	**Hard**
6	
7	**Very hard**
8	
9	**Extremely hard**
10	**Maximal exertion**