OCCUPATIONAL BIOMECHANICS OF TREE-PLANTERS

A Study of Musculoskeletal Symptoms, Posture, and Joint Reaction Forces in Ontario Tree-Planters

By

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Abstract

Tree-planters are likely to suffer from musculoskeletal injuries during their short work season. The objective of this research is to identify the biomechanical mechanisms that contribute to these injuries with an overall goal of reducing injury frequency and severity.

Pre- and post-season discomfort questionnaires were administered to workers in two tree-planting camps to identify areas of the body most prone to injury. Musculoskeletal pain and discomfort were significantly higher post season. Greatest pain and discomfort were reported in the feet, wrists and back, while the highest frequency of pain was reported in the back.

Upper body and trunk postures were recorded during the tree-planting task in the field using digital video and inclinometers. Results indicated that deep trunk flexion occurred over 2600 times per day and workers spent at least half of their workday in trunk flexion greater than 45 degrees. Although results provide useful insight into injury mechanisms, postural data were two dimensional.

Inertial motion sensors were used in a second field study the following season to examine differences in three-dimensional upper limb and trunk relative joint angles during commonly used tree seedling unloading methods. Results showed trunk rotation up to 50 degrees combined with deep trunk flexion during parts of the task. Trunk flexion and rotation were significantly less when the tree seedling load was distributed asymmetrically as compared to symmetrically.

Joint reaction forces in the lower body and trunk during the same unloading methods was examined during a simulated planting task in a lab environment. Greatest

joint reaction forces and non-neutral postures occurred when the tree was inserted into the ground. Right-loaded planting bags resulted in more substantial differences in posture and joint reaction forces than either left-loaded or even-loaded bags. Axial forces were greater in the right leg than the left throughout the task, regardless of loading condition.

In conclusion, underlying biomechanical mechanisms for injury during tree-planting seem to be a combination of awkward postures (particularly the trunk), repetitive motions, and carrying of heavy loads. Different seedling unloading strategies did not result in substantial overall differences in posture or joint reaction forces.

Co-Authorship

This dissertation contains material from a published manuscript (Chapter 2), a submitted manuscript (Chapter 4), and manuscripts in final preparation (Chapters 3 and 5). The authorship and intended authorship is as follows:

Chapter 2: Upjohn, T. and Dumas, G.A. (2009). Musculoskeletal symptoms in tree-planters in Northern Ontario. *WORK*: *A journal of prevention, assessment and rehabilitation*. In Press.

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Data presented in chapter 6 were collected concurrently with data presented in chapter 5. Authorship is the same.

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Chapter 1 : General Introduction

1.0 A brief introduction to the forestry industry

Canada holds over ten percent of the world's forests (402 million hectares (Ha)) and is the number one exporter of newsprint, softwood lumber and wood pulp, contributing nearly 36 billion dollars annually to the nation's gross domestic product (Natural Resources Canada, 2001). Ontario has the second largest revenue from sale of timber from provincial crown land in Canada, surpassed only by British Columbia (NFDP, 2007).

In 2007, nearly 650 000 hectares of Canadian forest land were clear cut. The province of Ontario had the largest amount of harvested land (170 514 Ha), followed by British Columbia (164 823 Ha), Quebec (134 277 Ha), New Brunswick (63 071 Ha) and Alberta (54 219 Ha) (NFDP, 2007). The remaining Canadian provinces harvested substantially less land. While forestry is important in every province, the forestry industry in Ontario is an especially important contributor to Canada's gross domestic product, with over 9 billion dollars in forest product exports.

Harvested land is eventually replanted with tree seedlings to ensure sustainability of natural resources for future generations. In 2007, 451 314 hectares of harvested land were replanted with over 684 million seedlings. Each seedling is manually planted by silviculture workers, more commonly known as tree-planters (NFDP, 2007).

Silviculture practices vary between provinces. This dissertation will focus solely on the occupational biomechanics of tree-planters in Ontario.

2.0 A brief overview of tree-planting

The Ontario tree-planting season takes place between early May and early July when temperatures are ideal for seedling survival. Environmental conditions vary considerably with temperatures ranging between -10C in early May to +30C in early July (Figure 1-1).

Work cycles differ, but are generally either 4:1 or 6:1 (workdays:rest days). In a given 24-hour period, on average, workers dedicate 10.5 hours to tree-planting-related work, 2 hours to camp chores, 5 hours to leisure, and 6.5 hours to sleep. Within those 10.5 hours of work, only 0.75 hours are dedicated to rest (Banister *et al,* 1990). Compensation is provided on a piece-work basis and it is therefore beneficial to workers to plant as many seedlings in any given workday as possible, often resulting in very little rest during the workday. In Ontario, the average experienced tree planter plants 1 tree every 5.6 seconds, equivalent to over 10 trees/minute (Stjernberg, 1988).

Figure 1-1: Typical environmental planting conditions in Ontario - early May.

A planter (center) takes a break in a snow-covered clear-cut north of Manitouwadge in early May, 2002.

The objective of the tree-planting task itself is relatively straight forward – plant the seedling in the soil; however, accomplishing the objective is often more challenging than one might imagine. The tree planter may have to maneuver over or under fallen trees, around new growth, through swamp, and/or up hilly terrain in order to plant a single tree seedling in a micro site that is ideal for its survival (Figure 1-2). There is often a great deal of 'slash' – fallen forest material left behind by the logging operations and/or the machinery that prepares the terrain for planting by overturning parts of the soil. The area to be planted may have been clear cut many years ago and have a substantial amount of overgrowth to navigate through. Micro sites are selected 6 feet apart to create the ideal forest density when the trees mature.

Figure 1-2 Micro-site selection

Selection of micro site in un-scarified (non-site prepped) land (left), and a year-old seedling planted in an appropriate micro site (right).

Once an appropriate micro site has been selected, the top layer of dirt is removed by kicking it away, or scraping it away with the hands to expose the mineral soil beneath (screefing). A hole is then created large enough and deep enough to plant the seedling in, but not so deep to cover the lateral branches located approximately 1 cm above the soil plug. Once the seedling is inserted into the hole, the hole is closed by 'kicking' it shut with the boot, or by hand-closing it in more delicate soil conditions.

2.1 Physiological and Biomechanical Stress in Tree-planters

Tree-planters exhibit many signs of physiological stress during the work season such as decreased serum enzyme levels, decreased blood glucose levels, elevated heart rate and elevated oxygen consumption (Trites *et al* 1993; Roberts, 2002). Physiological stress alone may increase risk of injury, and certainly increases likelihood of burnout - characterized by increased fatigue, apathy, and non-specific illness, that contributes to an overall disinclination to continue working and increased accident proneness (Banister *et al*, 1990).

Biomechanical stress to workers is due to a combination of repetition, heavy loads and awkward postures (Figure 1-3). Each workday tree-planters travel an average of 2.4 km, while carrying 16.8 kg and planting over 1200 tree seedlings. Loads carried increase up to 32.9 kg as the tree planter transports supplementary seedlings to locations closer to the work area. The average weight of a planting tool is 2.3 kg; therefore the average cumulative load lifted each day approaches 3000 kg, in addition to the load of the tree seedlings carried in the planting bags (data from tree-planting work in Quebec, Giguere *et al*, 1993).

Figure 1-3 Causes of biomechanical and physiological stress in tree-planters

Tree-planters experience both biomechanical and physiological stress due to carrying heavy loads (left and right), and travelling several kilometers while navigating substantial obstacles (center).

3.0 Injuries in Silviculture

Given the biomechanical stress to the worker, it is not surprising that many injuries to tree-planters are musculoskeletal injuries. Of the four forestry sectors in Ontario (logging, sawmills, veneer/plywood, silviculture), only silviculture saw a rise in injury totals and injury frequency in 2008 (OFSWA, 2009). Substantial increases in frequency rates for total injuries, lost-time injuries, and no-lost-time injuries were reported; days lost and injury severity rate also rose. Strains, sprains and tears are the most common lost-time injury type in forestry work, accounting for 62% of lost time injuries in silviculture operations (OFSWA, 2009). Bodily reaction (an ergonomics-related problem resulting from repetitive motion and awkward postures) and falls on the same level are the second most common injury causes (OFSWA, 2009). In their health and safety news for fall/winter 2009, the Ontario Forestry Safe Workplace Association reports that:

> "Lost-time injuries increased slightly from 26 in 2007 to 29 in 2008. The LTI frequency rate rose from 4.26 injuries per 200,000 hours worked in 2007 to 6.99 injuries in 2008. Total hours worked declined from 932,140 in 2007 to 881,036 in 2008, yet days lost because of injuries jumped by more than a third, from 2,423 days in 2007 to 3,756 in 2008" (OFSWA, 2009)

Given these statistics, it seems clear that musculoskeletal injuries in silviculture are a cause for concern and should be addressed.

4.0 Dissertation Outline

Though some progress has been made in examining the ergonomic challenges in tree-planting work, the biomechanical causes of musculoskeletal injuries sustained by workers have not been clearly identified.

4.1 Objectives

The goal of this thesis is to identify the biomechanical mechanisms that contribute to the musculoskeletal injuries sustained by tree-planters due to the physically demanding nature of the job. The objectives of the thesis research are to:

(1) identify musculoskeletal symptoms in tree-planters,

(2) provide a detailed biomechanical analysis of the tree-planting task,

(3) examine postural differences during various tree unloading strategies, and

(4) report biomechanical stresses (joint reaction forces patterns) during the tree-planting task.

4.2 Research Studies

Several related studies were conducted that resulted in the five manuscripts contained within this dissertation. The first study had two objectives: first, to assess musculoskeletal symptoms in tree-planters as they developed over the course of a planting season, and second, to provide a postural description of the upper body during the tree-planting task. Data were collected in tree-planting bush camps north of Hearst, Ontario. These data are presented in Chapters 2 and 3 – *Musculoskeletal symptoms in Ontario tree-planters*, and *Upper Body and Trunk Postures in Ontario Tree-Planters* respectively.

The second study took place during the last three weeks of the planting season in June 2008. Data were collected in a bush camp north of Armstrong, Ontario. In this study Inertial Motion Sensors were used to evaluate differences in joint posture in the upper body and trunk during three different tree unloading conditions. Data are presented in Chapter 4 – *Effect of Tree Loading Condition on Upper Limb and Trunk Posture*.

The third study took place in the Motor Performance Laboratory at Queen's University (Kingston, Canada) and served to identify biomechanical stress to the wrist, lower body and trunk during the same tree unloading conditions as are described in Chapter 4. Posture and joint reaction forces in the ankles, knees, hips, and trunk are described during the three unloading conditions, and data are presented in Chapter 5. Wrist postures are described in Chapter 6.

This research provides preliminary biomechanical data that can be used to develop larger-scale projects aimed at developing postural strategies and equipment re-design that will change loading patterns during the planting task, reduce cumulative loading throughout the day, and prevent or reduce the occurrence of musculoskeletal injuries in the tree-planting population.

This dissertation concludes with a discussion of cultural aspects of tree-planting, biomechanical implications for injury and suggestions to reduce injuries. Limitations of the research are presented, followed by summary of findings, general conclusions and suggestions for future research studies.

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Chapter 2 : Musculoskeletal Symptoms in Ontario Tree-planters

Abstract

Tree-planting requires workers to maintain high levels of physical exertion while performing repetitive motions throughout the workday, increasing their risk for developing repetitive strain injuries. This study identifies which body parts develop musculoskeletal symptoms during the tree-planting season and investigates whether a low level of pre-season physical activity is a risk factor for the development of these symptoms. Three questionnaires were completed by 132 tree-planters prior to the first workday of their planting season. Questionnaires included the International Physical Activity Questionnaire, a body map to report areas of musculoskeletal symptoms (MSS), and a series of questions about planter demographics. A subset of study participants (n = 14) also completed the MSS questionnaire each work shift during the planting season and at the end of the season. Musculoskeletal symptoms in each area of the body were compared pre-and post-season using a paired t-test on data from the MSS questionnaire. Musculoskeletal symptoms in the population subset were significantly greater at the end of the season than at the beginning of the season, but no significant differences were found between work shifts. Body areas with the highest reported musculoskeletal symptoms were the feet, wrists and back. The highest frequency of musculoskeletal symptoms was reported in the back both at the beginning and the end of the season. Ninety percent of all workers reported a high level of pre-season physical activity; pre-season level of physical activity could not be correlated with development of musculoskeletal symptoms throughout the season.

Keywords: Tree-planter, musculoskeletal symptoms, questionnaire, physical activity level.

1.0 Introduction

Canada holds over 10% of the world's forests (402.1 million hectares[1]) and is the world's leading timber exporter through logging of primary and old-growth forests (NRC, 2001). In order to ensure that these forests are sustained for future generations, over 400 000 hectares of harvested land are re-planted each year with over 600 million tree seedlings (NFDP, 2008). These seedlings are planted manually by silviculture workers, more commonly referred to as tree-planters.

Tree-planting requires sustained physical exertion and involves repetitive motion throughout the workday. Occupational health and safety standards suggest that a combination of repetitive motion and high levels of force or physical exertion puts workers at risk for developing repetitive strain injuries (RSIs) (WSIB, 2008). In fact, RSIs are the most frequently occurring types of injury in Ontario reforestation workers (OFSWA, 2006) ,and 90% of workers will likely suffer a work-related injury during their planting career (Smith, 1987).

This high incidence of injuries may be explained by repeated non-neutral postures assumed by workers during the planting task. On average, tree-planters engage in forward trunk bending over 2600 times per day, with peak flexion angles reaching over 100° (Upjohn *et al*, 2008). This likely results in cumulative loading of the spine, an independent risk factor for low back pain (Norman *et al*, 1998). In-vitro studies have shown that highly repetitive flexion/extension motions with even modest flexion/extension moments can result in disc failure (Adams & Hutton, 1985; Callaghan & McGill, 2001), suggesting that tree-planters are at risk for developing low back disorders due to repetitive trunk flexion motions.

[1] Hectare: Metric unit of area equal to 10 000 square meters (11 960 yards) or 2.47 acres

In addition to the back, the shoulder and wrist may be at risk for developing RSIs. When preparing to plant a tree seedling, the planter raises the shovel to a point where both shoulder flexion and abduction exceed 50° (Upjohn *et al*, 2008). This posture may result in localized muscle fatigue (Herberts *et al*, 1980) and when performed repetitively, may result in joint injury. Shoulder loading may be greatest during opening of the hole to insert the seedling, when the shovel is at the furthest point from the trunk. At this point shoulder flexion increases past 90° while force is being exerted on the shovel in a pushing motion, resulting in an internal (muscle) extensor moment and an external flexion moment about the shoulder (Upjohn *et al*, 2008).

Injuries often occur as a result of abrupt increases in physical stress, and are typically experienced at the start of intense physical training regimes. This is common in army trainees entering basic training programs after having participated in very little prior physical activity (Knapik et al, 2001). Low levels of pre-training occupational physical activity have been associated with a higher incidence of muscle strains, sprains, and overuse injury (Jones *et al*, 1993; Knapik *et al*, 2001). Tree-planting work is similar to basic training due to the short, intense work season and physiologically taxing work (Roberts, 2002; Trites *et al*, 1993). Tree-planters may therefore be likely to succumb to sprains, strains and tears if they begin the work season at a low level of physical activity. It is therefore postulated that a low level of pre-season physical activity in tree-planters may be a predictor of musculoskeletal symptom development during the planting season.

The goals of this study were:

a. to document self reports of musculoskeletal symptoms among tree-planters, categorized by body area, and
b. to determine if a low level of pre-season physical activity is a risk factor for the development of musculoskeletal symptoms in tree-planters.

Results will serve to guide future research on joint loading, postural modifications, equipment redesign, job redesign and other preventative measures (training, etc) in order to decrease future incidences of musculoskeletal injury. Results will serve as a basis for the development of pre-season training programs that increase pre-season level of physical activity. This research will allow such programs to focus specifically on strengthening the areas of the body most prone to developing musculoskeletal symptoms during the season.

2.0 Methods

2.1 Overview of Study

Workers began planting in early May and completed their contractual obligations by the end of June. Typically planters arrived at the worksite at 8 a.m. and finished work by 6 p.m. Work shifts were four days in length followed by a rest day.

Three questionnaires were completed by tree-planters in two reforestation camps prior to the first workday of the planting season. Questionnaires included the International Physical Activity Questionnaire (IPAQ), a body map used to report areas of musculoskeletal pain (MSS Questionnaire), and a series of questions about planter demographics, planting experiences, preferences and motivation (General Background

Questionnaire). A group of workers also completed the MSS Questionnaire at both the beginning and the end of each work shift during the planting season and at the end of the season (Figure 2-1).

2.2 Participants

Participants were divided into two distinct groups post hoc: initial population and population subset.

Initial population: The initial population was made up of workers who completed the first set of questionnaires the day before the planting season started. This population consisted of 118 planters from two reforestation camps (75 male, 43 female; age 21.4 (±2.1) yrs, height 1.76 (± 0.09) m, mass 72.1 (±10.5) kg).

Population subset: The population subset was a group of workers who completed the initial questionnaires *and* consistently completed the MSS questionnaire each shift during the planting season. This population consisted of 14 planters from two reforestation camps (7 male, 7 female; age 21.0 (±1.47) yrs, height 1.76 (± 1.11) m, mass 69.16 (±10.59) kg). Questionnaires were completed voluntarily - many workers in the initial population quit during the planting season, chose not to participate in the study throughout the season, or re-located to a different camp mid-season, resulting in a smaller number of participants in the population subset. The final population in a tree-planting camp is often only one-third of the initial population.

Ethics approval was obtained from the Queen's University General Research Ethics Board (GREB), and informed consent was assumed upon completion of the worker coded anonymous questionnaires as per GREB stipulations.

Figure 2-1: Study Timeline

Study timeline. Workers in the initial population (n = 118) and population subset (n = 14) completed three questionnaires (International Physical Activity Questionnaire, General Background Questionnaire, and Musculoskeletal Symptom Questionnaire (MSS)) prior to the first day of the planting season (Pre-Season). The MSS questionnaire was also completed by workers in the population subset (n = 14) during each shift (1 shift = 4 days of planting) throughout the season; eight shifts were worked in the season – with the eight shift being the End-Season.

2.3 Questionnaires

2.3.1 General Background Questionnaire

The General Background Questionnaire was created specifically for the study and was used to determine worker demographics and characteristics as well as planting techniques and preferences. The General Background Questionnaire was completed by both the initial population (n = 118) and the population subset (n = 14) pre-season. Detailed results from the questionnaire are presented in Table 2-1.

2.3.2 Musculoskeletal Symptoms Questionnaire

The MSS questionnaire was a modified version of the Corlett Body map (Corlett & Bishop, 1976). The questionnaire required participants to rate their level of musculoskeletal pain on a scale of 0 to 10 (0 indicating no pain and 10 indicating severe pain) using both frontal and posterior views with boxes throughout the body. Pain was defined as any numbness, stiffness, tingling, pulling, burning, or aching. Participants were asked to define the pain as having occurred as a single incident (trip, fall, etc) or as having occurred gradually due to repeated motions. Pain due to a single incident was excluded from data analysis. Frequency or duration of pain was not reported within the questionnaire.

Specific areas of the body were as follows: On the front of the body, both left and right: *neck, deltoid, forearm, wrist, hip, thigh, knee, ankle*, and *toes*. On the back of the body, both left and right: *deltoid, forearm, wrist, fingers, thigh, calf,* and *feet,* as well as *upper, middle* and *lower back* (Figure 2-2).

On the body map below please rate any pain (numbness, stiffness, tingling, pulling, burning, aching etc) that you are currently experiencing in each of the areas indicated. Please rate your pain on a scale of 0 – 10 as follows:

0	1	2	3	4	5	6	7	8	9	10

No Pain **Severe Pain**

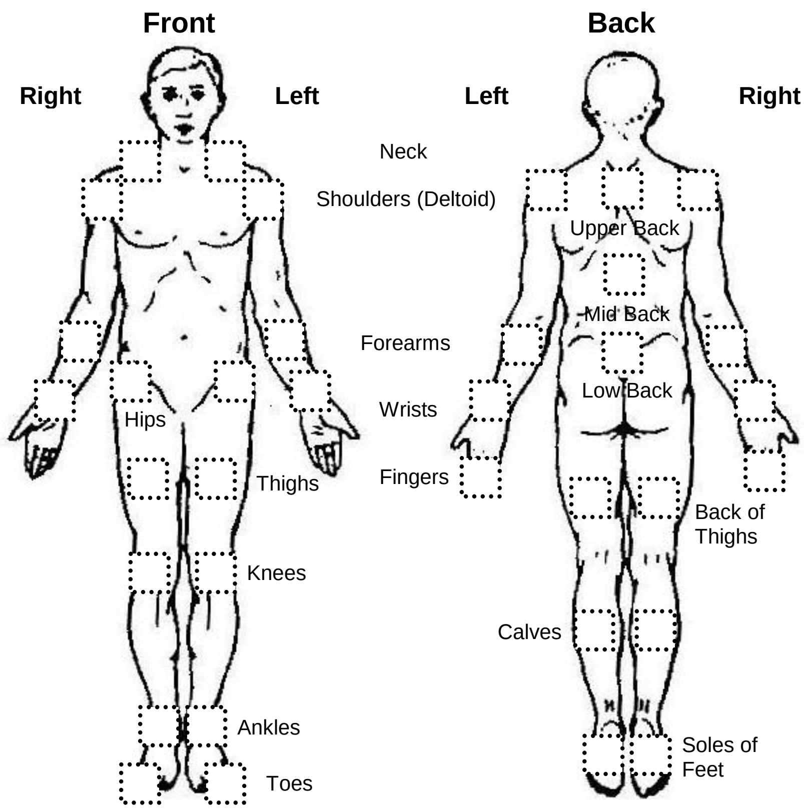

Figure 2-2: Modified Corlett Body Map

Modified Corlett Body Map for rating musculoskeletal pain (Corlett & Bishop, 1976).

2.3.3 International Physical Activity Questionnaire (IPAQ)

The IPAQ was completed by workers the day before the first day of the planting season to determine pre-season level of physical activity. The IPAQ is an internationally recognized instrument used primarily for population surveillance of physical activity among adults aged 15-69 yrs (Craig *et al*, 2003). The IPAQ assesses physical activity across the four domains of leisure time, domestic and gardening, work, and transportation. There are two separate IPAQ forms: the IPAQ short form and the IPAQ long form. This study used the short form, which asks about three specific types of activity (walking, moderate-intensity, and vigorous-intensity) undertaken in the four domains listed above. Answers were computed and provided a summation of the duration (in minutes) and frequency (in days) of walking, moderate-intensity, and vigorous-intensity activities. The total score was reported as a continuous score of energy expenditure per week, or MET minutes/week (IPAQ, 2005). Please see Appendix A for a more complete description of the IPAQ.

The IPAQ classifies level of physical activity into three categories: ‘Low’, ‘Moderate’ and ‘High’. A ‘High’ level of physical activity requires meeting one of the following two criteria. (1) Engaging in vigorous-intensity activity on at least 3 days achieving a total physical activity of at least 1 500 MET-min/week or (2) engaging in any combination of walking, moderate-intensity or vigorous-intensity activities for 7 days/week, achieving a minimum total physical activity of 3 000 MET-min/week. A ‘Moderate’ level of physical activity requires meeting one of the following three criteria. (1) Engaging in 3 or more days of vigorous-intensity physical activity of at least 20 minutes per day, (2) engage in 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day, or (3) engage in 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total physical activity of at least 600 MET-min/week. A 'Low' category of physical activity is designated if the criteria for either the 'High' or 'Moderate' categories are not met (IPAQ, 2005).

An amplitude probability distribution function (APDF) was performed on IPAQ scores and the 10^{th}, 50^{th}, and 90^{th} percentile scores were determined.

2.4 Statistical analysis

Student's T-tests were performed to determine differences in age, height, mass, pre-season level of physical activity and experience between the initial population and the population subset. IPAQ raw data were not normally distributed and a log function was performed on all MET-min/week scores to normalize data before the t-tests were done. A student's T-test was performed on MSS questionnaire data to determine differences between pre season and end of season scores in the population subset. An ANOVA was performed on MSS scores in the population subset from shift to shift during the season. T-tests were conducted in Microsoft Excel, while ANOVAs were conducted in SPSS software (SPSS, An IBM Company, Chicago, IL). ANOVA and T-tests were chosen because the populations were assumed to be normally distributed, and where not normally distributed, were corrected for using a log function, as above. Results should be considered only as trends due to the small sample size. The results of both the student's T-test and the ANOVA may be different with a larger sample size. Significance was reached when $p \leq 0.05$.

3.0 Results

3.1 Worker Demographics (General Background Questionnaire)

Worker demographics for the total population and the population subset are presented in Table 1. Tree-planters were young workers (mean age 21.4 years) and there were approximately twice as many male workers as female workers (62% male, 38% female). The majority were right handed (90.9%) and used the shovel with their right hand (74.2%). Almost all workers used a D-handle shovel (90.9%), while a small percentage used the modified ergonomic D-handle design (8.4%). The average worker had less than one season experience and worked 8-10 hours per day during a 6-day shift followed by one rest day. The average number of days a planter worked per season was between 41 and 45.

3.2 Population differences

No significant differences in height, mass, experience or level of physical activity were found between the initial population and the population subset. The population subset was significantly younger (21.0 *(1.47)* years) than the initial population (21.4 *(2.10)* years) by less than one year (Table 2-1).

Table 2-1: Mean scores from the General Background Questionnaire and International Physical Activity Questionnaire.

	Initial Population	Population Subset	t-test (p-value)
Age (yrs (sd))	21.4 (2.1)	21.0 (1.47)	0.04**
Height (m (sd))	1.76 (0.09)	1.76 (0.11)	0.96
Mass (kg (sd))	72.1 (10.5)	69.2 (10.6)	0.29
Gender			
Male (%)	62.1	50.0	
Female (%)	37.9	50.0	
Handedness			
Right (%)	90.9	78.6	
Left (%)	6.8	14.3	
Ambidextrous (%)	2.3	7.1	
Shovel			
D-Handle (%)	90.9	100.0	
Ergo D-Handle (%)	8.4	0.0	
Shaft (%)	0.7	0.0	
Shovel Hand			
Right (%)	74.2	58.3	
Left (%)	5.3	8.3	
Ambidextrous (%)	20.5	33.3	
Shoulder Straps			
Yes (%)	66.3	66.7	
No (%)	25.3	16.7	
Sometimes (%)	8.4	16.6	
Physical Activity*			
MET-minutes/week	6350 (5991)	8281 (6387)	0.37
Experience (Seasons (sd))	0.61 (1.29)	0.43 (0.65)	0.34
Workday (mode (hours))	8-10	8-10	
Work Rest Cycle (mode)	6 days on/1 off	4 days on/1 off	
Length of Season (mode (days))	41-45	46-50	

3.3 Musculoskeletal Symptoms

Mean pain scores for the initial population (n = 118), and the population subset (n = 14) are described in Tables 2-2 and Table 2-3. Mean non-zero scores and frequency of reporting are presented because they were thought to give a more accurate representation of the frequency and severity of musculoskeletal symptoms across the populations.

For the initial population, pre-season pain scores were highest in the toes (4.0(*2.8*)). For the population subset, all pre-season scores were reported as zero, and end-of-season scores were highest in the toes (5.0*(2.8)*), left and right wrists (5.0*(2.8)* and 4.7*(2.8)* respectively), and right and left feet (4.8*(2.6)* and 4.3*(2.4)* respectively). Mean-end-of season scores were significantly greater than pre-season scores in all areas of the body except for the right and left deltoid (p = 0.082 and p = 0.081), the forearms (p = 0.068 and p = 0.082), the hips (p = 0.061 and p = 0.091) and the back of the left thigh (p = 0.065). No significant differences in MSS scores were found from shift to shift in the population subset.

Frequency of pain reporting was greatest in the low back for both the initial population (40%) at beginning of season, and the population subset (71%) at end of season.

Table 2-2: Mean pre-season non-zero MSS scores and frequency of reporting in the initial population (n=118).

		Initial Population Mean non-zero pre-season pain scores (0-10)			
		Right Score *(sd)*	Freq (%)	Left Score *(sd)*	Freq (%)
Front of Body	Neck	2.7 (1.8)	30	2.8 (1.7)	31
	Deltoid	2.8 (1.8)	14	2.6 (1.9)	14
	Forearm	1.6 (1.0)	8	1.8 (1.0)	6
	Wrist	3.0 (2.2)	17	3.1 (2.3)	11
	Hip	2.6 (1.9)	17	2.8 (2.1)	18
	Thigh	3.9 (2.2)	8	3.7 (2.7)	8
	Knee	3.8 (2.5)	23	3.8 (2.7)	21
	Ankle	3.4 (2.7)	15	3.3 (2.9)	15
	Toes	4.0 (2.8)	11	4.0 (2.8)	11
Rear of Body	Deltoid	3.4 (2.2)	22	3.6 (2.3)	19
	Forearm	2.6 (1.7)	5	2.4 (2.1)	4
	Wrist	3.4 (2.8)	10	3.7 (3.1)	14
	Finger	3.5 (3.2)	13	3.7 (3.0)	8
	Thigh	2.8 (2.5)	11	2.9 (2.4)	11
	Calf	2.9 (3.0)	11	3.0 (3.1)	10
	Foot	3.0 (2.8)	22	3.1 (2.8)	22
		Score *(sd)*		Freq (%)	
Back	Upper	2.9 (2.1)		36	
	Middle	3.4 (2.0)		30	
	Lower	3.6 (2.0)		40	

Table 2-3: Mean MSS pain scores and frequency of reporting (pre-season and end-of-season) in the population subset. Scores higher than 4.0 and frequencies higher than 50% were considered 'high' and are indicated in bold in the table below.

		Population Subset Mean Pre - season pain scores (0-10)				Population Subset Mean non-zero end-of-season pain scores (0-10)			
		Right		Left		Right		Left	
		Score *(sd)*	Freq (%)	Score *(sd)*	Freq (%)	Score *(sd)*	Freq (%)	Score *(sd)*	Freq (%)
Front of Body	Neck	0 (0.0)	0	0 (0.0)	0	1.6 (0.7)	57	3.1 (3.1)	**57**
	Deltoid	0 (0.0)	0	0 (0.0)	0	1.5 (1.0)	29	**4.6** (4.2)	36
	Forearm	0 (0.0)	0	0 (0.0)	0	2.3 (1.5)	43	2.6 (1.8)	36
	Wrist	0 (0.0)	0	0 (0.0)	0	**4.7** (2.8)	**50**	**5.0** (3.5)	36
	Hip	0 (0.0)	0	0 (0.0)	0	3.8 (3.7)	43	3.0 (2.9)	36
	Thigh	0 (0.0)	0	0 (0.0)	0	1.8 (1.2)	43	1.8 (1.2)	43
	Knee	0 (0.0)	0	0 (0.0)	0	**4.0** (1.5)	43	**4.2** (1.2)	43
	Ankle	0 (0.0)	0	0 (0.0)	0	3.2 (1.9)	36	3.2 (1.9)	36
	Toes	0 (0.0)	0	0 (0.0)	0	**5.0** (2.8)	**50**	**5.0** (2.8)	43
Rear of Body	Deltoid	0 (0.0)	0	0 (0.0)	0	2.0 (1.3)	**64**	3.1 (3.1)	**57**
	Forearm	0 (0.0)	0	0 (0.0)	0	1.5 (1.0)	29	2.4 (1.9)	36
	Wrist	0 (0.0)	0	0 (0.0)	0	3.1 (2.2)	**50**	**4.0** (3.0)	36
	Finger	0 (0.0)	0	0 (0.0)	0	**4.5** (3.0)	43	3.0 (2.6)	43
	Thigh	0 (0.0)	0	0 (0.0)	0	2.5 (1.3)	29	2.5 (1.3)	29
	Calf	0 (0.0)	0	0 (0.0)	0	1.8 (1.3)	43	1.8 (1.3)	43
	Foot	0 (0.0)	0	0 (0.0)	0	**4.8** (2.6)	**57**	**4.3** (2.4)	**64**
		Score *(sd)*		Freq (%)		Score *(sd)*		Freq (%)	
Back	Upper	0 (0.0)		0		3.2 (1.8)		**64**	
	Middle	0 (0.0)		0		3.6 (2.5)		**57**	
	Lower	0 (0.0)		0		3.3 (2.6)		**71**	

3.4 International Physical Activity Questionnaire (IPAQ)

Scores from the IPAQ can either be categorized (low, moderate, and high physical activity levels) or reported on a continuous scale (MET-minutes/week). When calculated as categorical scores, the data did not give enough distinction in level of physical activity, and so they are presented here as continuous scores to give a better description of the population. The lowest score was 424 MET-min/week, while the highest score was 38527 MET-min/week with a mean of 6350 *(5991)*. The 10^{th}, 50^{th} and 90^{th} percentile scores were calculated and fell within the following categories respectively: 1500 - 1750; 4750 - 5000; and 15750 - 16000 MET-min/week (Table 2-4). It should be noted that the highest score for the initial population was not included in the APDF analysis as it was identified as a group outlier. Mean MET-min/week for the population subset was 8282 *(6387)* with a range of 968 – 19143 MET-min/week.

Table 2-4: Pre-season level of physical activity among workers as determined by the International Physical Activity Questionnaire (IPAQ).

	IPAQ Scores (MET-min/wk)			**APDF (MET-min/wk)**		
Population	Mean (*sd*)	Max	Min	10^{th} Percentile	50^{th} Percentile	90^{th} Percentile
Initial (n=75)	6350 (*5991*)	38527	424	1500-1750	4750-5000	15750-16000
Subset (n=14)	8281(*6387*)	19 143	968	1250-1500	8250-8500	19250-19500

4.0 Discussion

The objectives of the study were to (1) document self reports of musculoskeletal symptoms among tree-planters, categorized by body area and (2) to determine if a low level of pre-season physical activity is a risk factor for the development of musculoskeletal symptoms in tree-planters.

The main findings were as follows. (1) Body areas with the highest reported musculoskeletal symptoms were the toes, feet and wrists. (2) Body areas with the most frequently reported musculoskeletal symptoms were the upper, middle and lower back. (3) Musculoskeletal symptoms were significantly greater at the end of the season than at the beginning of the season, but no significant differences were found between work shifts. (4) Ninety percent of all study participants had a high level of pre-season physical activity but no conclusions could be drawn regarding the effect of pre-season physical activity on onset of musculoskeletal disorders throughout the season due to a lack of injury data.

4.1 Musculoskeletal Symptoms

4.1.1 Mean musculoskeletal scores in the population subset

In the population subset, mean musculoskeletal symptoms were significantly greater at the end of the season than at the beginning of the season. Areas reported as having the most pain were the feet, wrists, and back (upper, middle and lower). These results are supported by a recent online survey that indicates that the wrist is the body part that tree-planting is hardest on (Tree-Planter.com, 2004). Work-Safe BC reports that tree-planting injuries most often occur at the wrists (26%) and back (21%) during the first and last two weeks of the planting season, but does not specify these injuries as being either musculoskeletal injuries or repetitive strain injuries (Work-Safe BC, 2006). In this study Musculoskeletal pain reported in the back could be explained by extreme trunk postures assumed throughout the planting task. A recent study examining upper body and trunk postures during tree-planting suggests that workers spend 50% of the workday in trunk flexion greater than 45°; the same study reports 90^{th} percentile trunk flexion of over 125° (with respect to standing) (Upjohn *et al*, 2008). Sagittal trunk angle (trunk flexion) is one of five instrumental measures in predicting risk for developing low back disorders in industrial work (Marras *et al*, 1993). Postural assessment tools often assign a higher score to a task (indicating a greater risk for developing musculoskeletal injuries (MSIs)) if the task involves trunk flexion greater than 20° from vertical and the score is higher still if the task involves trunk twist or lateral bending or repetitive motions (Hignett & McAtamney, 2000; McAtamney & Corlett, 1993). In the current study the large amount of time spent in trunk flexion combined with repetitive motion and back pain reported may be an indication of future development of musculoskeletal injuries of the spine.

Reported musculoskeletal symptoms in the feet were likely due to prolonged periods of time (>8 hours/day) spent walking in rough terrain, and kicking to clear the ground of debris (grass, moss, fallen branches, root-mat, etc) before planting the seedling. These kicking motions (also called *screefing*) are much more prevalent in land that has not been site-prepped by forestry machinery.

Although MSS scores for the back were not as high as for the feet and wrists, the frequency of reporting was the highest for all body parts (57 – 71%), suggesting that a large *percentage* of tree-planters are likely to experience musculoskeletal symptoms in this area.

4.1.2 Pre-Season Musculoskeletal Symptoms in the Initial Population

Although pre-season scores in the initial population seem to be quite high when compared to the population subset, the frequency of reporting is quite low in all areas of the body, especially in the toes and wrists (reported to have the highest MSS score). In fact only 11% of the initial population reported having musculoskeletal pain in these areas of the body. There is anecdotal evidence that a very small number of the initial population (< 10 workers) participated in a pre-season planting contract, and so at the time that they completed the questionnaire they had already been working for 4 days. This first work-shift may have resulted in musculoskeletal symptoms in the pre-season workers, and the bulk of the 11% of subjects reporting symptoms may have already planted for a full work shift, thus skewing the MSS data. However, this explanation should be taken with caution, as there are no data to confirm it.

4.2 Physical Activity and risk of musculoskeletal symptoms

Mean pre-season physical activity in the initial population was 6350 MET-min/week, putting the group in the 'High' category. APDF scores indicate that the 10th percentile of the population scored between 1500 and 1750, which again results in a 'High' score. Therefore, over 90% of the initial population engaged in a 'High' level of physical activity before the planting season began. The mean score in the population subset was 8282 MET-min/week, much higher than the initial populations mean score, and also resulting in a 'High' score. However, even with a 'High' level of pre-season physical activity, the population subset developed musculoskeletal symptoms during the planting season. This suggests one of two possibilities. Either pre-season level of physical activity is not a predictor for onset of musculoskeletal symptoms or the measure of physical activity used in the study was not sensitive enough to distinguish onset of musculoskeletal symptoms.

4.3 Study Limitations

4.3.1 Population size

One of the primary goals of the study was to track the onset of musculoskeletal symptoms throughout the season by having workers fill out the MSS questionnaire once per shift. To encourage workers to do so, a 'planter liaison' was hired to facilitate the completion and collection of these questionnaires. However, only a small number of workers (n=22) filled out the questionnaires. Of these workers, only 14 were a part of the initial population, providing a base measure of physical activity and worker demographics. We postulated that although this subset was small in number, the data were representative of the initial population because the demographics and pre-season level of physical activity were not significantly different between the two populations. Had the population subset been larger, we may have obtained more significant results for onset of musculoskeletal symptoms from shift to shift throughout the season.

4.3.2 IPAQ

Although the IPAQ is a widely used tool for reporting physical activity level, it has been suggested that there are problems with over-reporting of physical activity and that reported physical activity may not be representative of fitness level (Fogelholm *et al*, 2006). While 90% of participants in the current study were classified as having a 'High' level of physical activity, this may not be indicative of their physical fitness level, which may be a better predictor of musculoskeletal symptom development and potential injury. In order to better predict onset of musculoskeletal symptoms, pre-season physical fitness should be tested using physical measures such as the Canadian physical activity, fitness and lifestyle appraisal (CSEP, 1998).

5.0 Conclusions

Musculoskeletal symptoms in a small subset of tree-planters were significantly greater at the end of the season than at the beginning of the season, but no significant differences were found between work shifts. Body areas with the greatest reported musculoskeletal pain were the feet, wrists and back (upper, middle and lower). Ninety percent of all workers reported a high level of pre-season physical activity; however pre-season level of physical activity could not be correlated with development of musculoskeletal symptoms throughout the season.

Results from the present study suggest that the areas of the body most likely to develop musculoskeletal injuries are the feet, wrists and back. Postures and joint loading in these areas should be further studied.

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Chapter 3 : Upper Body and Trunk Posture in Ontario Tree-planters

Abstract

This study describes upper body postures during the tree-planting task and compares two methods of quantifying trunk posture in a field setting (inclinometer and digital video). Fourteen tree-planters were recorded with digital video for 15 minutes at the start and end of the workday for three consecutive days. Trunk flexion/extension and lateral bending were recorded with an inclinometer in 6 of the 14 subjects during a full workday. Workers flexed their trunk an average of 2615 times per day and spent fifty percent of the workday with the trunk flexed over 45°. Shoulder flexion and abduction exceeded 90° and 60° respectively, and the elbow was almost fully extended (147°) just prior to inserting the tree. Inclinometer data showed that the 90th percentile trunk flexion angle was significantly greater than maximal trunk flexion recorded from video, suggesting that video for a limited duration may under-predict trunk posture.

Results will serve to guide future research on modifications to planting postures and equipment redesign to reduce joint loading, and decrease incidence of musculoskeletal injury. Results suggest that the inclinometer may be a viable alternative to visual data collection methods in a field setting and may better predict postural loading of the spine.

Keywords: Tree-planting; upper body posture; trunk posture; inclinometer; video

1.0 Introduction

In Canada, tree-planting is a seasonal occupation in which workers are under a great deal of physiological and biomechanical stress (Roberts, 2002; Sanders & McCormick, 1993). For example, in Quebec, tree-planters typically carry 16.8 kg of tree seedlings and equipment and plant an average of 1245 seedlings each workday (Giguere *et al*, 1993). The average weight of a planting tool is 2.3 kg, contributing to a cumulative load lifted of approximately 3000 kg per workday. This cumulative loading may increase the risk of injury, particularly in the spine, where cumulative loading has been associated with development of low back pain in industrial workers (Kumar, 1990; Norman *et al*, 1998).

Injuries are common among tree-planters: 90% of workers will likely suffer a work-related injury during their planting career, with a 75% chance of sustaining an injury during each work-season (Smith, 1987). Strains, sprains and tears are the most common lost-time injuries (LTI) in the forestry injury and account for 38% of all LTIs in silviculture operations. These injuries are most frequently caused by repetitive motion (OFSWA, 2006). A recent study examining the onset of musculoskeletal symptoms in tree-planters over the course of a work season reported significant increases in musculoskeletal symptoms from the beginning of the work season to the end of the work season in all areas of the body. The body areas with the most frequently reported symptoms were the back, wrists and feet, while the areas with the highest reported musculoskeletal pain were the toes, wrists and knees (Upjohn *et al*, 2009). An online survey for tree-planters recently reported that the wrists, feet, and back were the body areas most likely to suffer from ‘the demands of the job’, and 60% of survey respondents reported having sustained a planting-related injury (tree-planter.com, 2004).

Postures assumed during a work task are an important determinant for development of musculoskeletal symptoms and injuries, especially during tasks involving repetitive motions. When analyzing body position during the insertion of tree seedlings into the ground, Giguere *et al* (1993) found that posture was related to the length and the handle type of the planting tool. Trunk posture was observed to be more 'twisted' when using a 'D' handle shovel with a shorter shaft as compared to a shovel with a straight shaft. This may be problematic for tree-planters, as frequent twisting and bending in occupational tasks have been linked to increased risk of low back pain (Xu *et al*, 1997).

The study of postural loading in a field setting is challenging due to uncontrolled environmental and work conditions. Postures are often recorded using time-sampling and posture-matching approaches (Buchholz *et al*, 1996; McAtamney & Corlett, 1993), or video. Video-based task analysis allows the experimenter to examine joint angles occurring at specific time points during the task using specialized software. Although it may allow for a more detailed postural analysis of the task than time-sampling approaches, video-based task analysis is often limited by equipment location and work environment, making it difficult to capture motion in a single plane, thus reducing the accuracy of the analysis (Sutherland *et al*, 2007). Other data collection tools such as the Virtual Corset (Microstrain Inc, VT, USA) may be used to provide more accurate postural analyses of the trunk in a field setting. The Virtual Corset (VC) is an inclinometer with an integrated data logger that is worn on the sternum to keep track of trunk inclination (flexion and lateral bend) during work tasks. The VC has been used in field studies as a means of measuring low-back exposures and distinguishing exposure level in workers across different industries (Trask *et al*, 2007). The VC records a continuous data stream of trunk postures, however identifying task-specific events within the data stream may be challenging.

The objectives of this investigation were to (1) describe upper body postures during the tree-planting task in a field setting in Ontario and (2) compare trunk flexion data collected with an inclinometer (Virtual Corset) with trunk flexion data collected by digital video.

By defining the postures assumed by the workers at various points throughout the day, we will more fully understand the physical demands of this understudied occupation. It will also be possible to suggest postural modifications to reduce postural loading and decrease likelihood of sustaining musculoskeletal injuries, thereby decreasing lost time and increasing productivity. Comparison of digital video data with inclinometer data will provide valuable information on the usefulness of a non-visual technique for describing postural loading of the spine in a field setting.

2.0 Methods

2.1 Overview of Study

Workers started planting in early May and ended by late June. Planters typically arrived at the worksite at 0800 hrs and finished work by 1800 hrs. Work shifts were four days in length followed by a rest day and land conditions were typical of Ontario planting. Data were collected in June 2007 during three consecutive workdays, six weeks into the planting season. Two types of data were collected: (1) upper body posture (trunk flexion, shoulder flexion, shoulder abduction and elbow flexion) was recorded at the beginning and the end of the workday with a digital video camera, and (2) trunk flexion and lateral bending were recorded during a full workday using an inclinometer/datalogger device (Virtual Corset, Microstrain Inc, VT, USA).

Five events of interest were identified (from video) during the tree-planting task: (1) shovel at highest vertical position before entry into the ground, (2) shovel entry into the ground, (3) shovel at the furthest horizontal position from the trunk (opening of the hole), (4) shovel at the closest horizontal position to the trunk, and (5) tree insertion into the ground / shovel removal (Figure 3-1). The events were chosen because (a) they were thought to be the points during the task that put the most biomechanical stress on the body, (b) they define the task from start to finish, and (c) despite variations in planting style, these events are common to all workers. Upper body posture was determined for each of the above events.

Figure 3-1: Events defined during one full planting cycle.

Event 1: shovel at highest vertical point; Event 2: shovel entry into ground; Event 3: shovel at furthest horizontal point from trunk; Event 4: shovel at closest horizontal point to trunk; Event 5: tree insertion into ground / shovel removal.

2.2 Participants

Fourteen tree-planters from a Northern Ontario tree-planting camp (8 male, 6 female; age 21.8*(0.8)* yrs; height 1.75 *(0.09)* m; mass 75.7*(8.8)* kg) were recorded using digital video, and 6 of the 14 wore the inclinometer/datalogger. All subjects who participated in the study used D-handle shovels modified to suit the planter's preferences. The modifications included removing a kick plate or decreasing the length of the shovel shaft by up to 5 cm. Without modifications, the shovel typically has a steel blade (mass 0.86kg, length 22.5 cm) with a kick plate on either side of the blade, and a total length of 93.8 cm (Bushpro D-Handle Shovel www.Bushpro.ca, 2007). All subjects were right handed, but several planted ambidextrously, alternating between the left and right hand when using the shovel.

The study was approved by the Queen's University General Research Ethics Board, and participants gave written informed consent prior to participating in the study.

2.3 Data Collection and Analysis

2.3.1 Digital Video Data

Workers were recorded with a digital video camera (Sony HandyCam DCR-SR82) and were instructed to assume their normal postures while performing their typical planting activities. Experimenters followed the workers in the field with the camera and recorded postures from both the frontal and sagittal planes (from a distance of less than 5m) during a 15-minute session at both the beginning and the end of the workday in order to capture a minimum of 10 complete planting cycles from each of the two views. All possible efforts were made by the experimenters to capture motion in the planter's sagittal plane (planters filmed from the side) or frontal plane (planters filmed from the front).

One full planting cycle is defined as occurring from event 1 (shovel at highest vertical position) to event 5 (tree insertion into ground / shovel removal from ground) inclusive (Figure 3-1). Data were recorded directly onto the hard drive of the video camera, and later transferred to a laptop computer for analysis of the postures. Video data were digitized using video analysis software (DartFish, ProSuite 4.0, Lausanne, Switzerland). A digital protractor was aligned with the long axes of the proximal and distal segments of each joint in question and the angle between the segments was taken to be representative of the joint angle. Single frames in which the camera was positioned at the appropriate angle (90˚ with respect to the plane of motion) were chosen to be digitized in order to most accurately measure joint angles. Absolute trunk flexion (from the global vertical), and relative shoulder flexion, shoulder abduction and elbow flexion of the shovel arm were calculated by the DartFish ProSuite software at each of the defined events for 10 planting cycles at both the start and the end of the workday. Global vertical was estimated by using a vertical tree within the image as a reference point. Thus, accuracy and precision of measurements may have been influenced by vertical alignment of the global reference.

Body Segment and Joint Angle Definitions: Body segments were defined by digitizing approximate landmarks as follows: *trunk* – C7 to L5; *upper arm* – acromion to lateral epicondyle of the humerus; *forearm* – lateral epicondyle of the humerus to ulnar styloid at the wrist. Joint angles were defined as follows: *trunk flexion* - the angle between the trunk and the global vertical where the horizontal trunk was 90°; *shoulder flexion* - the angle between the trunk and the upper arm in the sagittal plane, where positive values represent flexion, and negative values represent extension; *shoulder* *abduction* - the angle between the trunk and upper arm in the frontal plane where 0° is neutral with the arm at the side of the body (positive = abduction, negative = adduction) ; *elbow flexion* - the angle between the upper arm and forearm, where 0° = full flexion, and 180° = full extension.

2.3.2 Inclinometer Data

Six of the 14 subjects wore an inclinometer to record trunk flexion and lateral bending during a full workday. Data were collected at 7.5 Hz and recorded directly to an on-board data logger. Each subject wore a harness that held the device in place at the sternum and was zeroed to upright standing posture at the start of the workday. No planting equipment was worn at the time of setup – addition of the tree-planting gear did not interfere with the device. At the end of the workday, data were downloaded to a laptop computer for analysis. Prior to analysis, inclinometer data were filtered using a low-pass Butterworth filter with a cutoff frequency of 2 Hz, determined by residual analysis.

Trunk flexion and lateral bending data were treated separately. For trunk flexion, an amplitude probability distribution function (APDF) analysis was performed to determine 10^{th}, 50^{th} and 90^{th} percentile trunk flexion angles for the three time periods. These periods were (1) 15 minutes at the start of the workday, (2) 15 minutes at the end of the workday (6 hours into the workday), and (3) over the entire workday. These time intervals were chosen so as to be similar to the time intervals recorded with the digital video data. The APDF quantified the percentage of time spent at the 10^{th}, 50^{th} and 90^{th} percentile angles. The number of trunk flexion occurrences in excess of 100° (deep trunk flexion) throughout the workday were determined using a Matlab-based program (The

MathWorks, Natick, USA). For lateral bending, frequency was also determined using a Matlab-based program and counting each time lateral bending exceeded 30 degrees to the left or the right. Mean maximum lateral bending was determined over 10 randomly chosen planting cycles in each participant.

2.4 Statistical Analysis

A repeated measures ANOVA with 2 factors (day and time) was performed on the upper body angles from the video data (trunk flexion, elbow flexion, shoulder flexion and shoulder abduction) to determine differences in posture between days and from start to end of a workday. Student's T-tests were used to determine postural differences in trunk flexion (from inclinometer data) from start of the workday to the end of the workday, and to determine differences in joint angles across postural events within the planting cycle. T-tests were also used to determine differences in maximal trunk flexion recorded by the inclinometer and video. Statistical significance was set to $p \leq 0.05$.

3.0 Results

3.1 Upper body postures

Mean upper body angles for each planting cycle event are presented in Table 3-1. Shoulder flexion was greatest when the shovel was farthest from the trunk (96.3 *(14.3)*°). At this point, the elbow was also nearly fully extended. Shoulder abduction was greatest both prior to shovel-ground contact (*event 1*, 60.6 *(10.0)*°) and during removal of the shovel (*event 5*, 64.7 *(23.5)*°). Elbow extension was smallest at shovel removal (*event 5*, 48.9 *(17.5)*°).

Joint angles were significantly different ($p < 0.05$) across all planting events with the following exceptions: elbow extension between event 1 and 5; shoulder flexion between events 1 and 2, 1 and 4; shoulder abduction between events 1 and 5, 2 and 3, 2 and 4, 3 and 4.

Table 3-1: Mean angles (SD) from video data for trunk flexion, shoulder flexion, shoulder abduction and elbow extension for events 1 – 5 of the planting cycle (n=14).

Event descriptions are as follows: Event 1: shovel at highest vertical position before entry into the ground, Event 2: shovel entry into the ground, Event 3: shovel at the furthest horizontal position from the trunk (opening of the hole), Event 4: shovel at the closest horizontal position to the trunk, and Event 5: tree insertion into the ground / shovel removal. The trunk is in full flexion approaching 180°, the shoulder is in full flexion at 180°, the upper arm is parallel to the ground when shoulder abduction reaches 90°, and the elbow is fully extended at 180°. Mean values for each subject were determined, then group means were compared across days and times; no significant differences were found between days or times ($p > 0.05$).

Event	**Trunk Flexion (sd) (degrees)**	**Shoulder Flexion (sd) (degrees)**	**Shoulder Abduction (sd) (degrees)**	**Elbow Extension (sd) (degrees)**
1	39.4 (11.6)	50.0 (24.9)	60.9 (10.0)	60.9 (16.0)
2	64.6 (12.9)	66.7 (11.0)	15.3 (5.4)	133.3 (17.5)
3	84.5 (12.0)	96.3 (14.3)	17.9 (2.3)	147.2 (20.0)
4	102.2 (10.7)	44.4 (13.2)	36.0 (10.4)	95.3 (20.0)
5	105.3 (8.2)	4.8 (24.5)	64.7 (23.5)	48.9 (17.5)

Table 3-2: Individual and mean lateral bend angles from the inclinometer over a full workday.

Lateral bend to the left is presented as the 10th percentile angle (negative angles); lateral bend to the right is presented as the 90th percentile angle (positive angles). Upright standing posture (no lateral bend) is 0 degrees.

	Trunk Lateral Bend (from Inclinometer in °)		
Worker	**10th Percentile Bend to Left**	**50th Percentile Median Bend**	**90th Percentile Bend to Right**
1	-21	-1	17
2	-23	-6	13
3	-38	-11	7
4	-13	5	24
5	-8	12	33
6	-20	2	20
Mean (sd)	-20.5 (10.3)	0.2 (8.1)	19.0 (9.0)

There were no significant postural differences in upper body angles from the start of the workday to the end of the workday, or between days in the work shift ($p > 0.05$).

3.2 Trunk postures

Mean trunk flexion angles recorded by digital video were largest when the tree was inserted into the ground (*event 5*, 105.3 *(8.2)*°), and smallest when the shovel was at the highest vertical point prior to penetrating the ground (*event 1*, 39.4 *(11.6)*°). Trunk flexion angles from the inclinometer from three representative planting cycles are presented in Figure 3-2. Lateral bending angles are presented in Table 3-2. Workers spent 10% of the time laterally bent to the left (20.5*(10.3)*˚) and 10% of the time laterally bent to the right (19.5*(9.0)*˚). An average of 2615 trunk flexion events and 4928 lateral bending events (both left and right) were recorded during the planting day.

APDF analysis of trunk flexion from inclinometer data for the start of the day, end of the day and the full workday are presented in Figure 3-3. Workers spent over half the day flexed past 45 degrees and 10% of the day in deep flexion (>130 degrees), while only 10% of the day was spent close to vertical (< 12.5˚) (Table 3-3). Inclinometer data show that mean 50^{th} and 90^{th} percentile trunk flexion were significantly less during the full day than at the beginning of the day ($p = 0.02$; $p = 0.01$ respectively) (Table 3-3). Video data revealed no significant postural differences in trunk angles from the start of the workday to the end of the workday, or between days in the work shift ($p > 0.05$).

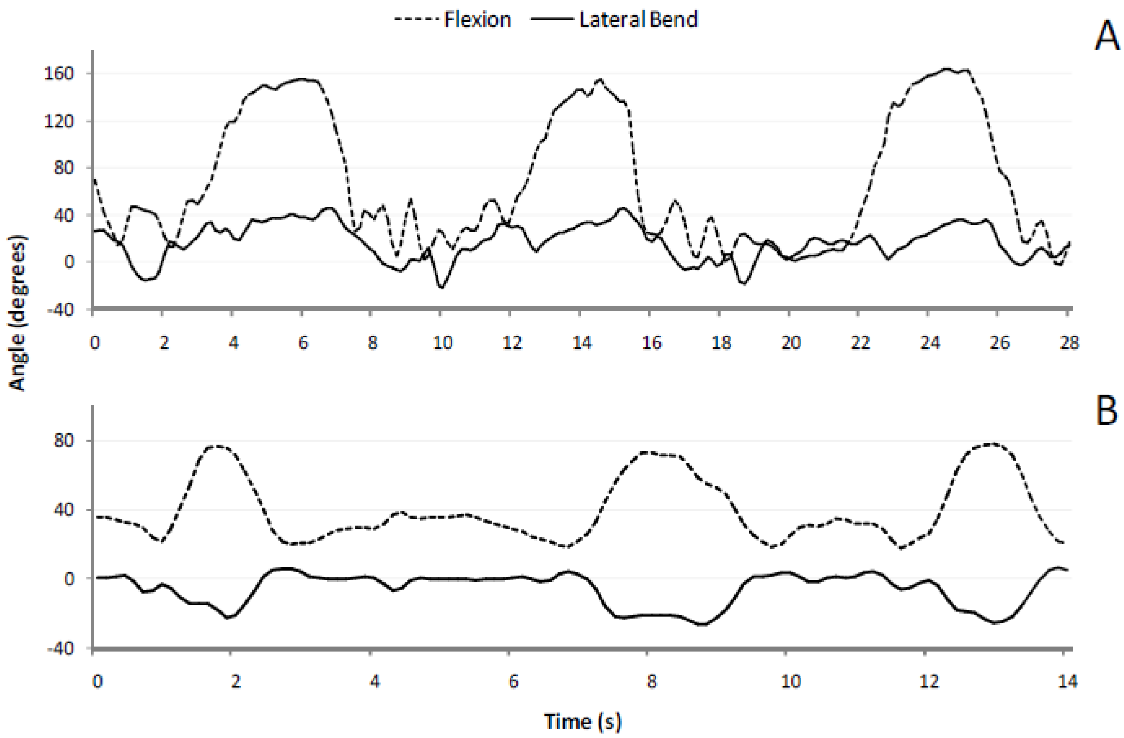

Figure 3-2: Trunk flexion and lateral bending measured by the inclinometer (Virtual Corset) in two workers during three planting cycles.

(A) A subject performing lateral bending to the right during the planting task (positive angles) (B) A second subject performing lateral bending to the left during the planting task (negative angles). Trunk flexion and lateral bending are concurrent and lateral bending occurs opposite to the shovel side of the body.

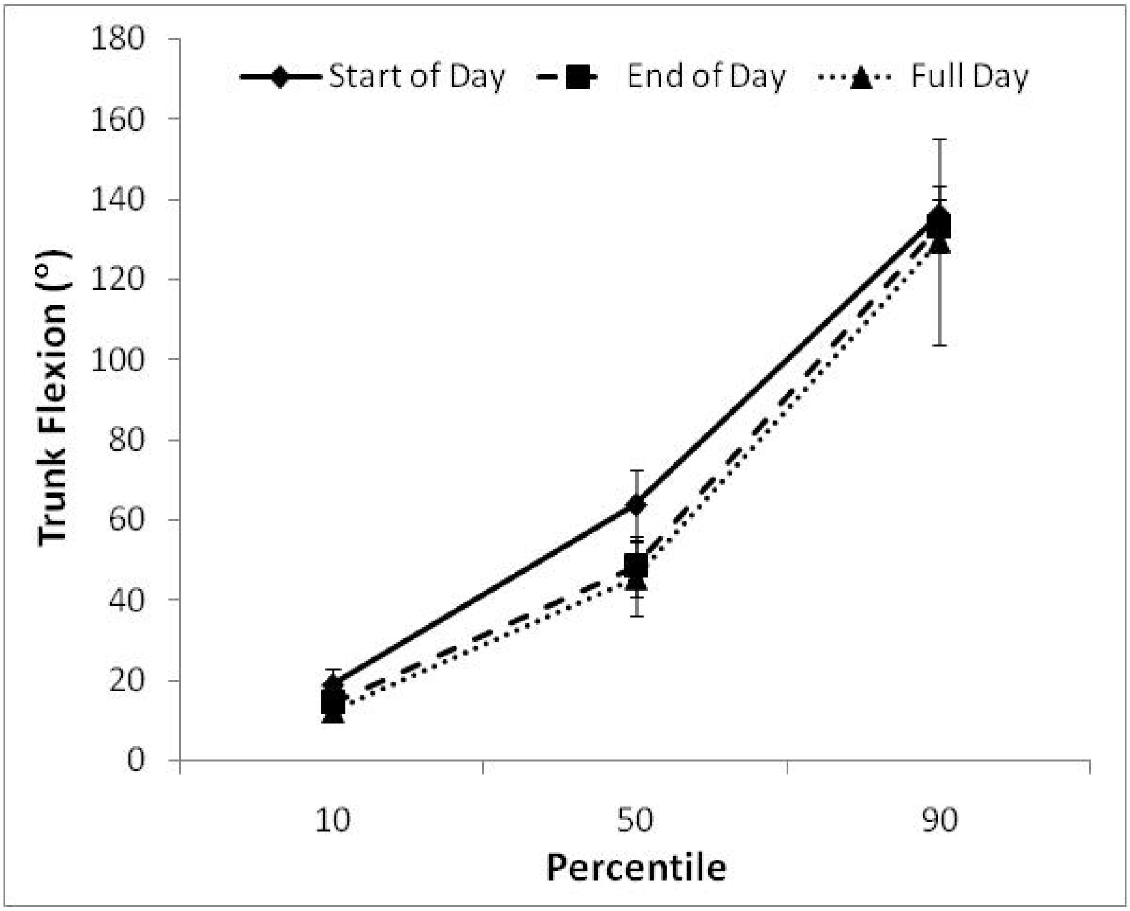

Figure 3-3: Mean APDF values for trunk flexion (Inclinometer/Virtual Corset data) 15 minutes at the start of the day, 15 minutes at the end of the day, and over a full workday(n = 6).

Error bars represent standard error of the mean. No significant differences were found from the start of the day to the end of the day ($p \geq 0.05$).

3.3 Comparison of Video and Inclinometer data

Comparisons of trunk flexion from inclinometer and digital video are presented in Table 3-3. There was large variability in inter-worker 10^{th}, 50^{th} and 90^{th} percentile angles recorded with the inclinometer, with the largest variability at the 90^{th} percentile (42˚, from 115° to 157° flexion). Large inter-worker variability in trunk flexion was also found across events in the video data. Inclinometer data show significantly greater maximal trunk flexion than video data at both the start of the day and end of the day ($p < 0.01$ in each case) (Table 3-3).

Table 3-3: Comparison of 10th, 50th and 90th percentile trunk flexion angles from inclinometer and mean trunk flexion angles from digital video (for Events 1 – 5).

Angles are presented for the start of a workday (a.m.), the end of a workday (p.m.), and the full workday (Full Day). • Inclinometer data show that mean 50th and 90th trunk flexion was significantly less during the full day than in the AM (p = 0.02; p = 0.01 respectively). No differences were found between PM and Full Day trunk angles in either inclinometer or video data. * Inclinometer data show significantly greater maximal trunk flexion than video data in both the AM and PM ($p < 0.01$ in each case). N = 6 for both inclinometer and video data

		Trunk flexion (from Inclinometer in °)			Trunk Flexion by event (from video in °)				
Worker	**Time**	**10th**	**50th**	**90th**	**1**	**2**	**3**	**4**	**5**
1	a.m	12	38	**140**	23	55	80	104	**113**
	p.m	18	35	**144**	20	44	74	101	**103**
	Full Day	6	31	137					
2	a.m	29	90	**152**	48	82	91	115	**112**
	p.m	12	28	**127**	55	83	95	121	**117**
	Full Day	12	57	137					
3	a.m	31	66	**115**	38	67	90	110	**104**
	p.m	26	69	**118**	33	63	98	114	**110**
	Full Day	28	56	110					
4	a.m	4	46	**155**	46	71	94	111	**106**
	p.m	18	62	**157**	57	83	107	119	**114**
	Full Day	14	47	148					
5	a.m	23	88	**140**	41	59	80	95	**104**
	p.m	11	64	**139**	37	64	84	98	**108**
	Full Day	10	48	136					
6	a.m	14	55	**115**	32	55	75	98	**112**
	p.m	2	33	**115**	40	64	77	101	**111**
	Full Day	5	35	109					
Mean (sd)	a.m	18.8 (10.6)	63.8 (21.6) •	**136.2 (17.5) •***	38.0(9.3)	64.8(10.6)	85.0(7.6)	105.5(7.9)	**108.5(4.3) ***
	p.m	14.5 (8.1)	48.5 (18.4)	**133.3 (16.2) ***	40.3(8.9)	66.8(14.7)	89.2(12.9)	109.0(10.2)	**110.5(4.8) ***
	Full Day	12.5 (4.1)	45.7 (21.4) •	129.5 (72.9) •					

4.0 Discussion

This is the first study to provide detailed postural analysis of tree-planting in a field-setting. The main findings were that (1) fifty percent of the workday (4.3 hours) was spent in trunk flexion greater than 45°, (2) trunk flexion, shoulder flexion, shoulder abduction and elbow flexion did not differ throughout the work shift, (3) there was a large inter-worker variability in upper body posture, especially in 90th percentile trunk flexion, suggesting discrepancies in planting technique among workers, and (4) maximal trunk flexion recorded by the inclinometer was significantly greater than maximal trunk flexion recorded by video, indicating that the video recordings may misrepresent the true postures of the job.

4.1 Upper body posture

Concurrent shoulder flexion and abduction were present through much of the planting cycle. This may be problematic for workers as the day progresses as it has been reported that as shoulder flexion increases during a work task so does localized muscle fatigue in the surrounding musculature (Herberts *et al*, 1980), which may in turn lead to injury. Although both shoulder flexion and abduction repeatedly exceed 50°, the cumulative time spent in this posture was generally between 2-5 seconds during each planting cycle, which may not be enough to cause muscle fatigue or injury. However, a combination of shoulder flexion and abduction is a mechanism for impinging the bursa. Shoulder loading may be greatest during opening of the hole, when the shovel is farthest away from the trunk. At this point shoulder flexion increases past 90°, the elbow is extended and a downward force is being exerted on the shovel, resulting in a large external flexion moment at the shoulder in response to the internal (muscle) extensor moment.

No significant differences were found in any joint angles in the upper body or trunk between morning and afternoon or between days (day 1 to day 3 during the work shift). These findings are contrary to what was expected; it was expected that posture would change both during the day and between days due to constant physical exertion and muscle fatigue.

However, a large inter-worker variability, evidenced by large standard deviations in the majority of upper body angles was found throughout the planting cycle (Table 3-1). This variability is likely due to differences in planting technique between workers and their specific shovel modifications. Tree-planting differs from other repetitive industry tasks because there are no time standards and very few constraints so that workers adopt their preferred posture during the task. Likewise, planting pace is self selected, and varies greatly, as is evident in Figure 3-2: Worker A completed three planting cycles in 28 seconds at the rate of 9.3 seconds/tree while worker B completed three cycles in only 14 seconds at the rate of 4.6 seconds/tree. While there are no set time standards, tree-planting is a piece-work occupation: the faster trees go in the ground, the more money is made by the worker. Therefore, pace tends to be motivated by monetary gain.

Tree-planting is largely unregulated in terms of ergonomic guidelines; very few industry standards have been established to instruct workers on best practices to reduce loads due to posture. Existing documents focus mainly on prevention of single incident injuries with relatively little emphasis on postural loading strategies and avoiding repetitive strain injuries (Work-Safe BC, 2006). An ergonomic study was recently conducted in British Columbia in which tree-planters were followed in the field and upper body postures were recorded with pen and paper based on visual observation. This study resulted in the publication of proposed ergonomic guidelines that are intended to reduce musculoskeletal injuries (MSIs) (Stjernberg & Kinney, 2007). These guidelines recommend that workers maintain neutral upper body postures throughout the planting cycle and a maximal range of motion (ROM) for each joint during each phase of the planting cycle is noted. In the present study, shoulder flexion and abduction of the shovel arm when preparing to penetrate the soil were at the upper limit of the recommended maximal ROM (50.0*(24.9)*° and 60.0 *(10.0)*° respectively). When penetrating the soil, shoulder flexion exceeded the maximal ROM (66.7 *(11.0)*°), while shoulder abduction was less than 20° (15.3 *(5.4)*°) and could be considered 'neutral'. During seedling insertion, shoulder flexion was relatively neutral (≤ 5° of flexion), while shoulder abduction exceeded the maximum ROM (> 60° of abduction). At this same time trunk flexion exceeded 110° in all participants and lateral bend exceeded 35° to both the right and left sides, surpassing maximum recommended ROM for the trunk.

These industry standards may be less applicable to tree-planters in Ontario due to differences in cycle frequency, terrain and joint loading. For example, cycle frequency in Ontario may be higher than in British Columbia due to planting of container stock vs. bare root. Terrain in Ontario is often swampier and less hilly than in BC. Soil density may also differ between provinces (Ontario soil may be either harder or softer than soil in BC depending on the type of soil – ie. swamp vs. clay). Nonetheless, worker postures recorded in this study exceed the maximal recommended joint angles detailed in the proposed guidelines, potentially increasing risk for MSIs (Stjernberg &Kinney, 2007).

4.2 Trunk postures

Sagittal trunk angle (trunk flexion) is one of five postural variables for predicting risk for developing low back disorders in industrial work (Marras *et al*, 1993). Postural assessment tools often assign a higher (risk) score to a task if the task involves trunk flexion greater than 20° from vertical and the score is higher still if the task involves trunk twist or lateral bending or repetitive motions (Hignett & McAtamney, 2000; McAtamney & Corlett, 1993). This study's video analysis revealed that the trunk was in a constantly changing posture throughout the planting cycle, with maximum flexion occurring when the tree was inserted into the ground. The highly repetitive combination of trunk flexion and lateral bending throughout the day likely results in cumulative loading of the spine, which is an independent risk factor for low back pain (Norman *et al*, 1998). In addition, in-vitro studies have shown that highly repetitive flexion/extension motions, with even modest flexion/extension moments, can result in disc failure (Adams & Hutton, 1985; Callaghan & McGill, 2001). These results suggest that tree-planters are at risk for developing low back disorders due to repetitive trunk flexion motions.

4.3 Comparison of Digital Video and Inclinometer trunk flexion data

Video has traditionally been used for postural analysis in the field due to the relative ease of collection and portability of equipment (Eger *et al*, 2008; Gregory *et al*, 2008; Spielholz *et al*, 2008) but it may not provide the most complete representation of posture throughout a given task or continuously throughout the workday. In this study, digital video allowed visual identification of trunk flexion at particular events of interest but unlike the inclinometer, did not allow continuous recording of trunk flexion angle throughout the workday due to the impossibility of keeping the camera in the planter's sagittal plane. The inclinometer recorded significantly higher maximum trunk flexion than the digital video by over 20˚ at both the start of the day and the end of the day. This could indicate that when used as an ergonomic tool in field studies, digital video may under-predict maximal postures and postural loading of the trunk during flexion tasks depending on the nature of the task. In addition to measuring continuous trunk flexion, the inclinometer records continuous lateral bend data that is difficult to capture with video. Lateral bending of the trunk has been identified as a risk factor for low back disorders, specifically scoliosis (Noone et al, 1993), and when combined with trunk flexion and axial rotation, increases the risk for low back pain (Fathallah, 1995; Haas and Nyiendo, 1992). Together, these measures give a more complete representation of posture in the spine than trunk flexion alone.

Inclinometers are becoming increasingly popular as a means of quantifying postural loading. In a recent study, inclinometers were used in a field study as a means of validating a back exposure sampling tool in heavy industries. When postural observations for trunk flexion were compared with direct inclinometer measures, there was moderate correlation for trunk flexion angles of 45°- 60°, and a high correlation for flexion angles greater than 60° (Village *et al*, 2008). The same group also used inclinometers as a means of predicting occupational exposure to risk factors for low back disorders in heavy industry (Trask *et al*, 2008). Inclinometer-based estimates of spinal compression were found to be comparable to EMG-based estimates and allow distinction between exposure groups in industry. These studies suggest that inclinometers may be a suitable tool for determining back exposure in field studies, and may be better suited to predict trunk flexion than direct postural observation or digital video analysis.

4.4 Study Limitations

Only upper body postures of the shovel arm and trunk posture were analyzed. The wrist joint was not included in the study as it is difficult to analyze wrist motion from video under the conditions examined, however, the wrist has been noted as being the body part that the tree-planting task is 'hardest on', and developing musculoskeletal pain over the course of a work season. (Upjohn *et al* 2009, Tree-planter.com, 2008). Therefore, wrist posture during the tree-planting task should be evaluated in future studies. There may be error associated with the viewing angle in the present study as Sutherland *et al* (2007) suggested that camera viewing angle may impact posture matching in tasks with a large range of motion. However, the current study used the actual postures and did not rely upon posture-matching schemes. Some error may also have been introduced with the task being analyzed in 2D without the use of reflective markers to identify joint centers. Finally, the subject number was relatively small (14 for video data and 6 for inclinometer data).

5.0 Conclusions and Recommendations

Results of the study indicate that workers spent fifty percent of the workday (4.3 hours) in trunk flexion greater than 45°. Trunk flexion, shoulder flexion, shoulder abduction and elbow flexion did not differ significantly from the start of the workday to the end of the workday or throughout the work shift. This lack of biomechanical change is likely due to the constraints of the job, whereby workers have to maintain certain postures in order to complete the task. This in itself may place workers at risk for the development of injuries. There was a large inter-worker variability in upper body posture, especially in 90^{th} percentile trunk flexion, suggesting differences in planting technique among workers. Maximal trunk flexion recorded by the inclinometer was significantly greater than maximal trunk flexion recorded by video, suggesting that when used as an ergonomic tool in field studies, digital video may under-predict maximal postures and postural loading of the trunk during flexion tasks. Cumulative time spent in non-neutral postures during the tree-planting task may put workers at a greater risk of developing musculoskeletal injuries. A more complete 3D kinematic and kinetic analysis of the task should be completed.

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Chapter 4 : Effect of Tree Unloading Condition on Upper limb and Trunk Posture

Abstract

Tree-planting is a physically demanding occupation requiring workers to engage in repetitive motions throughout the workday while carrying heavy loads of tree seedlings. Tree-planters use various strategies to unload the seedlings from their bags. This study examines differences in upper limb and trunk relative joint angles during three unloading conditions: (1) load evenly distributed to the right and left sides of the body – *evenly loaded* (2) load entirely on the right side – *right-loaded* and (3) load entirely on the left side – *left-loaded*. Twenty tree-planters; 14 male, 6 female, working at a reforestation camp in Northern Ontario volunteered to participate in the study. Inertial motion sensors were placed on the right hand, right and left forearms and upper arms, sacrum, and T1 vertebrae. Using relative sensor orientation, joint angles were determined for the right wrist, right and left elbow and trunk for the three unloading conditions while workers carried out normal planting tasks in the field. The main findings were as follows: 1) In the *left-loaded* condition, the right wrist was less extended, the right elbow was more flexed, the trunk experienced less right-rotation, and the right and left forearms were less pronated than in either the *evenly loaded* or *right-loaded* conditions. 2) In both the *left* and *right-loaded* conditions, the left forearm was less pronated, and the trunk was less flexed than in the *evenly loaded* condition. These postural differences may be caused by workers leaning on the shovel during the task to try to unload the joints and compensate for the asymmetric load. Using the shovel in this manner may be beneficial to

all workers to decrease joint loading during the planting task, thereby reducing the likelihood of musculoskeletal symptoms and repetitive strain injuries.

Keywords: Tree-planting, upper limb, trunk, kinematics, musculoskeletal symptoms

1.0 Introduction

Many tree-planters sustain musculoskeletal injuries during their short work season. Ninety percent of workers will suffer a work-related injury during their planting career, with a 75% chance of sustaining an injury each season (Smith, 1987). The most frequently occurring types of injury in Ontario reforestation workers are repetitive strain injuries (OFSWA, 2006). In a recent study musculoskeletal symptoms were found to be significantly greater at the end of the season than at the beginning of the season with the highest reported pain in the feet, wrists and back (Upjohn *et al*, 2009).

These musculoskeletal symptoms may be caused by repetitive non-neutral postures. Tree-planters spend over 50% of the workday in trunk flexion of 45 degrees or greater with respect to standing and in fact, workers bend over more than 2600 times per day (Upjohn *et al*, 2008). This large amount of trunk flexion is of concern, as intervertebral disc herniation has been linked to repeated flexion/extension motions even more so than applied joint compression (Callaghan & McGill, 2001). In addition to substantial amounts of trunk flexion, tree-planters may engage in trunk twisting motions depending on the type of planting tool used. When analyzing body position during the insertion of tree seedlings into the ground during the tree-planting task, Giguere *et al* (1993) observed a more twisted trunk posture when using a 'D' handle shovel with a shorter shaft as compared to a shovel with a straight shaft. Frequent twisting and bending in occupational tasks has been linked to increased risk of low back pain (Punnett *et al*, 1991), and higher torso velocities have been linked to increased risk of low back disorders (Marras *et al*, 1993). Asymmetric bending and axial torque have also been linked (in vitro) to increased risk of disc rupture when combined with flexion motions (Drake *et al*, 2005).

Tree-planters use various strategies to unload tree seedlings from their planting bags, resulting in either symmetric or asymmetric load distribution to the body. The goal of this study was to examine differences in upper limb and trunk joint angles during three common tree-unloading conditions: (1) load evenly distributed to the right and left sides of the body – *evenly loaded;* (2) load distributed entirely to the right side of the body – *right-loaded* and (3) load distributed entirely to the left side of the body - *left-loaded*. In all conditions the planter begins by loading tree seedlings (~15kg) evenly in the right and left planting bags, creating an even load distribution to the body. The method by which the seedlings are unloaded then results in either symmetric or asymmetric load distribution. In the *evenly loaded* condition, the planter draws trees from only the left side bag, but transfers trees from the right side to the left side at 10 minute time intervals in order to maintain a symmetrically distributed load to both the left and right side of the body until all trees are planted. Some planters prefer to completely unload their left bag first, leading to asymmetric loads. In the *right-loaded* condition, the planter has planted half of the load of trees, drawing only from the left side bag. The remaining load is now distributed asymmetrically to the right side of the body. In the *left-loaded* condition, the planter has again planted half of the tree-load and has placed the remaining half entirely in the left-side bag.

It was hypothesized that the *evenly loaded* condition (1) would result in more neutral upper body and trunk postures than in the asymmetrical *right-loaded and left-loaded* conditions thereby decreasing the likelihood of sustaining musculoskeletal disorders. Results will serve to guide future research on joint loading, postural modifications and equipment redesign in order to decrease future incidences of musculoskeletal injury.

2.0 Methods

2.1 Definition of terms

Planting bags:	Set of three bags (right-side, back, left-side) worn around the waist with shoulder straps, similar to backpack straps. Tree seedlings are carried in both the right and left side bag, and are removed from either side bag to be planted in the soil (Figure 4-1). The back bag is generally used to carry water, extra clothes, or sunscreen.
Bag-up:	Workers load tree seedlings (450 on average) in their planting bags to plant in the soil. When all the trees have been unloaded and planted, the worker has finished his or her 'bag up'. The term 'bag up' may also be used to refer to the actual act of placing trees into the planting bags before heading out to plant them.
Side bag:	Side bags are on the left and right sides of the body and are used to carry trees. Trees may be unloaded from either the right or left side bag. When the shovel is operated solely with the right hand, the trees are unloaded from the left side bag (Figure 4-1).
Grab bag:	The side bag from which the worker 'grabs' the seedlings (unloads the trees) to plant in the soil. The grab bag is opposite to the shovel hand (Figure 4-1).

2.2 Overview of Study

Data were collected in a field setting (north of Armstrong, Ontario) in June 2008 during the final three weeks of a 9-week work season. Inertial motion sensors (MTx, XSens Technologies, The Netherlands) were used to record upper limb and trunk kinematics during normal work activities under three tree-unloading conditions: (1) trees *evenly loaded*; (2) trees *right-loaded*; and (3) trees *left-loaded*. Participants completed each of the three conditions in random order. Worker anthropometrics and planting preferences were recorded and equipment measurements were taken (bag weight, shovel weight/length).

2.3 Participants

Twenty tree-planters (14 male, 6 female) with an average of two seasons of tree-planting experience participated in the study (Table 4-1). Ethics approval was obtained from the Queen's University Health Sciences Research Ethics Board, and participants gave written informed consent prior to participating in the study.

Figure 4-1: Typical shovel and planting bags with shoulder straps (Bushpro Inc).

Bags are fastened securely around the waist and shoulder straps are worn to redistribute some of the load from the hips to the shoulders. The grab bag is opposite to the shovel hand. *Figure is not to scale.

2.4 Data Collection

2.4.2 Participant Characteristics and planting preferences

Participants were asked a series of questions regarding planting preferences (Table 4-1). Shovel and bag mass were measured with a fish-hook spring gauge, and the number of trees loaded into the planting bags was recorded. Upper body anthropometrics and whole body height were measured with a 2 m measuring tape (Table 4-1).

2.4.3 Musculoskeletal symptoms

Participants were asked to complete a modified version of the Corlett Body Map (Corlett & Bishop, 1976) rating their level of musculoskeletal pain on a scale of 0 to 10 (0 indicating no pain and 10 indicating severe pain). The questionnaire was completed on the same day that upper body motion was recorded and participants were asked to rate their mean pain scores for the present work shift. Pain scores were reported in boxes throughout the body with both frontal and posterior views. Pain was defined as any numbness, stiffness, tingling, pulling, burning, or aching.

Specific areas of the body indicated on the body map diagram were as follows: on the front of the body, both left and right: *neck*, *deltoid*, *forearm, wrist, hip, thigh, knee, ankle,* and *toes*; on the back of the body, both left and right: *deltoid, forearm, wrist, fingers, thigh*, *calf,* and *feet*, and *upper*, *middle* and *lower back*.

2.4.4 Upper Limb and Trunk Angles

Upper limb and trunk kinematics were recorded with inertial motion sensors (XSens Technologies, The Netherlands). Participants stood in a reference posture (anatomical position) and sensors were placed on the shovel hand, right and left forearm and posterior upper arm, sacrum, T1 vertebrae, and shovel. In the reference posture, the positive x-axis of the sensor was aligned with the long-axis of the segment, pointing downwards. The sensor y-axis was oriented to the right, and the z-axis was oriented posteriorly (Figure 4-2). No dynamic calibration was performed. Sensors were linked together with serial cables in two chains; each chain was connected to a battery-operated, wireless data logger (XBus, XSens Technologies). Data were collected at 50Hz using a custom made C++ program, and data were sent to a tablet PC (Panasonic Toughbook) using Bluetooth technology and stored as .txt files.

Data collection was initiated by a button push after participants loaded the tree seedlings into their planting bags and began planting. The beginning of each planting cycle (shovel at highest vertical point before entry into soil) and end of each planting cycle (shovel removal from ground/tree insertion) were recorded by a button push. All adverse events that occurred during data collection (participant fall, unusual posture, incomplete planting cycle), and the beginning of the *right-loaded* and *left-loaded* conditions were also recorded by a button push. Data were recorded continuously until all trees in the planting bags were unloaded and planted (an average of 2 hours per condition). A typical planting cycle is depicted in Figure 4-3.

Figure 4-2: Instrumented participant indicating inertial motion sensor placement

Instrumented participant in reference posture with inertial motion sensors on T1, the sacrum, and the left and right upper and lower arms. Sensors were attached with mefix medical tape and secured with duct tape to avoid sensor movement during the task. The positive x-axis of the sensor was aligned with the long-axis of the segment, pointing downwards.

Figure 4-3: Typical postures assumed at five representative events during the planting cycle.

Events are as follows: Event 1: shovel at highest vertical point; Event 2: shovel entry into ground; Event 3: shovel at furthest horizontal point from trunk; Event 4: shovel at closest horizontal point to trunk; Event 5: tree insertion to ground / shovel removal.

2.5 Data Processing

Data from inertial motion sensors were output as quaternions and saved as .txt files. Data were stored in a database (MySQL) and processed using a custom-written Matlab program. All walking that took place between planting cycles, as well as those planting cycles marked as incomplete or unusual were removed from the database. Data were processed separately for each joint and were filtered using a Butterworth filter with a cutoff frequency of 3Hz as determined by residual analysis. Quaternions for each sensor were read in Matlab from MySQL. The distal sensor was rotated into the coordinate system of the proximal sensor, and a rotation matrix was created from the quaternions. Abduction and flexion angles were calculated using a spherical coordinate system while joint rotation was determined using the polar coordinate system. A custom amplitude probability distribution function (APDF) written in Matlab was performed on the data and 10^{th}, 50^{th} and 90^{th} percentile angles were output and stored in Excel.

2.6 Statistical Analyses

Statistical analyses were run on the full data set for the *evenly loaded* condition (1), and for the first 20 planting cycles of the *right-loaded* (2) and *left-loaded* (3) conditions. In conditions (2) and (3), only the first 20 cycles were included in the analyses as they were the most representative of the asymmetrical loading of these conditions. This resulted in a load difference between condition (1) and conditions (2) and (3): the load in condition (1) was approximately twice that of conditions (2) and (3). In order to determine whether this would affect the outcome of the statistical comparisons of joint angles, paired t-tests were run on the first 20 cycles (time point 1), middle 20 cycles (time point 2) and last 20 cycles (time point 3) within condition (1). No significant differences existed between time points.

Significant differences at the 10^{th}, 50^{th} and 90^{th} percentile angles in the right wrist, right and left elbows, and trunk were determined using paired t-tests for each joint between condition 1 and condition 2; condition 1 and condition 3; condition 2 and condition 3. Significance was set at $p \leq 0.05$.

Significant differences in pain scores between participants who reported asymmetric tree-unloading as their preferred method and participants who reported symmetrical tree-unloading as their preferred method were determined by t-test.

3.0 Results

3.1 Participant characteristics and planting preferences

Participant characteristics, planting preferences and anthropometric measurements are presented in Table 4-1. Seventy percent of participants were male, while 30% were female. The majority were right handed (95%) and 75% operated their shovel with their right hand on a regular basis. On average, workers loaded 449*(52.5)* trees in their bags, resulting in a load of 14.8*(1.5)* kg. Workers unloaded and planted the trees in an average of 85 minutes.

Table 4-1: Participant characteristics, planting preferences and anthropometric measurements (sd). (n = 20)

Participant Characteristics	
Gender	
Male (%)	70
Female (%)	30
Age (yrs)	22.1 (2.8)
Height (cm)	172.5 (9.7)
Mass (kg)	66.2 (17.7)
Experience (seasons)	2.2 (1.3)
Handedness	
Right (%)	95
Left (%)	5
Ambidex (%)	0
Shovel Hand	
Right (%)	75
Left (%)	10
Ambidex (%)	15
Equipment Preferences	
Shovel Length (cm)	71.8 (4.6)
Shovel Mass (kg)	1.3 (0.3)
Trees Bagged (#)	449 (52.5)
Bag Mass (kg)	14.8 (1.5)
Length of 1st Bag-up (min)	86.4 (25.4)
Length of 2nd Bag-up (min)	82.3 (23.7)

3.2 Musculoskeletal symptoms

Musculoskeletal pain was reported on a scale of 0 – 10. Areas with the highest reported musculoskeletal pain were the right hip (4.0 (*1.9)*), and left hip (4.3(*2.0)*) (Table 4-2). Areas with the highest frequency of pain reporting were the low back (80%), left and right feet (75%), and mid back (65%). Over 50% of participants reported pain in the knees, toes, neck, left shoulder, right wrist and fingers. Musculoskeletal symptoms were significantly greater in the left side of the neck ($p = 0.02$), mid back ($p = 0.02$) and left arm ($p = 0.01$) in participants who reported symmetric unloading as their preferred method of tree-unloading throughout the season (n = 10) when compared to participants who reported asymmetric unloading as their preferred method (n = 10).

3.3 Upper Limb and Trunk Kinematics

3.3.1 Wrist

The right wrist was extended throughout the planting cycle with a maximum extension of over 40 degrees (Figure 4-4). Right wrist extension was significantly less in the *left-loaded* condition (3) than the *right-loaded* condition (2) at the 50th and 90th percentile angles ($p = 0.03$ and $p = 0.01$). Right wrist extension was also less in the *left-loaded* condition (3) than in the *evenly loaded* condition (1) at the 90th percentile angle ($p = 0.03$). Ulnar deviation exceeded 25 degrees, while radial deviation exceeded 15 degrees. Ulnar deviation was significantly greater in the *left-loaded* condition (3) than in the *evenly loaded* condition (1) at both the 10th percentile (maximum ulnar deviation) and 50th percentile ($p = 0.02$ and $p = 0.03$). No significant differences in wrist rotation were found between conditions.

Table 4-2: Mean pain scores and frequency of reporting (n = 20).

Scores over 4.0 were considered to be 'high' (bolded in table). Frequency of reporting was considered to be 'high' if over 50% of the participants reported musculoskeletal symptoms (bolded in table).

Mean non-zero pain scores (0-10)					
		Right		**Left**	
		Score *(sd)*	Freq (%)	Score *(sd)*	Freq (%)
Front of Body	Neck	2.4 *(1.4)*	**50**	2.4 *(1.4)*	**50**
	Deltoid	1.7 *(0.8)*	25	1.0 *(0.4)*	**50**
	Forearm	2.3 *(1.2)*	20	1.0 *(0.3)*	5
	Wrist	2.4 *(1.8)*	45	2.0 *(1.0)*	25
	Hip	**4.0** *(1.9)*	25	**4.3** *(2.0)*	25
	Thigh	3.8 *(1.8)*	35	3.8 *(1.8)*	35
	Knee	3.3 *(1.9)*	**60**	3.1 *(2.1)*	**55**
	Ankle	2.4 *(1.6)*	40	3.0 *(1.7)*	40
	Toes	3.1 *(2.1)*	**55**	2.9 *(2.1)*	**55**
Rear of Body	Deltoid	3.8 *(2.2)*	40	3.0 *(1.9)*	**50**
	Forearm	1.0 *(0.3)*	15	3.3 *(1.6)*	25
	Wrist	2.0 *(1.0)*	30	2.3 *(1.9)*	**50**
	Finger	3.4 *(2.4)*	40	3.3 *(2.0)*	**50**
	Thigh	3.2 *(1.9)*	45	3.3 *(2.0)*	45
	Calf	3.4 *(2.2)*	45	3.8 *(2.2)*	45
	Foot	3.5 *(2.3)*	**75**	3.5 *(2.3)*	**75**

		Score	**Frequency**
Back	Upper	3.0 (1.7)	40
	Middle	3.3 (2.0)	**65**
	Lower	3.3 (1.9)	**80**

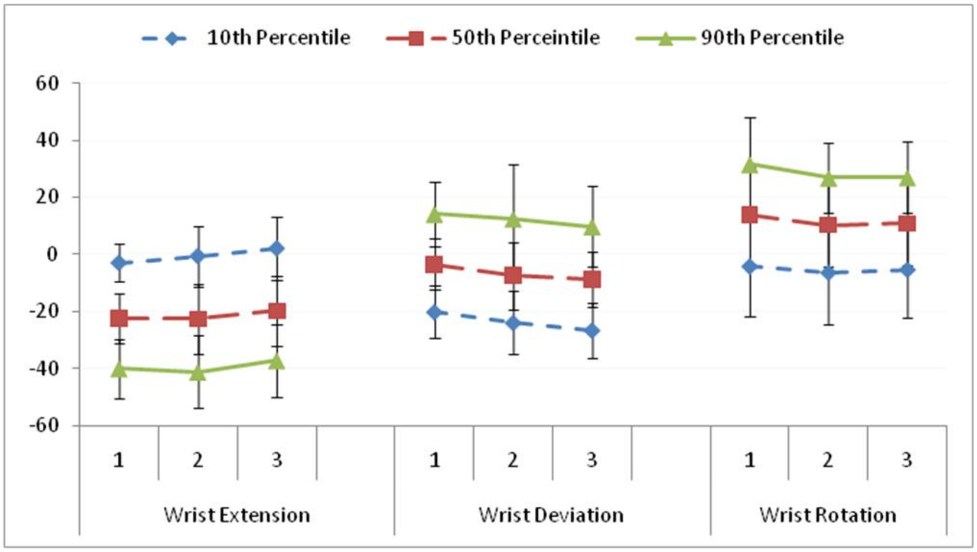

Figure 4-4: Mean 10th, 50th and 90th percentile right wrist angles for unloading conditions (1) *evenly loaded*, (2) *right-loaded*, and (3) *left-loaded*.

Wrist extension, ulnar deviation and rotation to the left are reported as negative angles. Wrist extension was less in the *left-loaded* condition than the *right-loaded* condition at both 50th and 90th percentile angles (p = 0.03 and p = 0.01 respectively). Ulnar deviation was greater in the *left-loaded* condition as compared to the *evenly loaded* condition ($p \leq 0.03$) at the 10th and 50th percentile angles (n = 10). Error bars represent standard deviation.

3.3.2 Right and Left Elbows

Fiftieth percentile right elbow flexion was 50 degrees across all conditions, increasing to just less than 70 degrees (Figure 4-5). Elbow flexion was significantly greater in the *left-loaded* condition than the *right-loaded* condition at the 10^{th}, 50^{th} and 90^{th} percentiles ($p = 0.01$, $p < 0.01$, $p = 0.03$ respectively). 50^{th} percentile pronation in the right forearm was close to neutral. Pronation was significantly less in the *left-loaded* condition (3) than in the *right-loaded* condition (2) at the 10^{th} and 50^{th} percentile angles ($p < 0.01$ and $p = 0.01$ respectively).

The left elbow was in 36 degrees of flexion across loading conditions at the 50^{th} percentile, increasing up to 62 degrees (90^{th} percentile; Figure 4-6). There were no significant differences in left elbow flexion between conditions. Mean left forearm pronation was 105 degrees. Left elbow pronation was significantly less in the *left-loaded* condition (3) than in the *right-loaded* condition (2) at the 10^{th} percentile ($p < 0.01$). Decreases in 50^{th} percentile pronation between the *evenly loaded* condition (1) and the *right-loaded* condition (2) approached significance ($p = 0.06$).

3.3.3 Trunk

During the planting task the trunk was predominantly flexed; however 10% of the time, the trunk was extended greater than 20 degrees with respect to global vertical (Figure 4-7). Mean 90^{th} percentile trunk flexion exceeded 48 degrees. Trunk flexion was significantly less in the *left-loaded* condition (3) than in the *evenly loaded* condition (1) at the 90^{th} percentile ($p = 0.03$). Trunk rotation to the right exceeded 42 degrees, while rotation to the left exceeded 53 degrees. Trunk rotation to the right was significantly less in the *left-loaded* condition (3) than the *right-loaded* condition (2) ($p = 0.05$) (Figure 7).

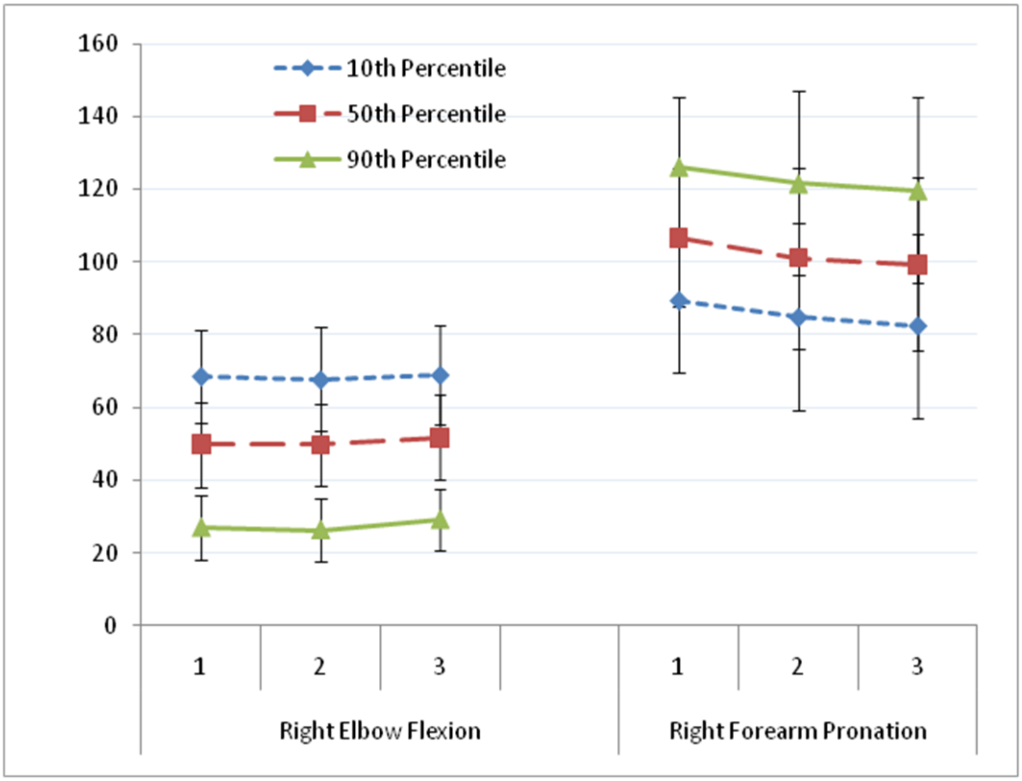

Figure 4-5: Mean 10th, 50th and 90th percentile angles in the right elbow and forearm for unloading conditions (1) *evenly loaded*, (2) *right-loaded*, and (3) *left-loaded*.

Elbow flexion and forearm pronation are depicted as positive angles. Elbow flexion was greater in condition (3) than condition (2) at the 10th (p = 0.01), 50th (p < 0.01), and 90th (p = 0.03) percentiles. Right forearm pronation was less in condition (3) than in condition (2) at both 10th and 50th percentile angles ($p \leq 0.01$), (n = 15). Error bars represent standard deviation.

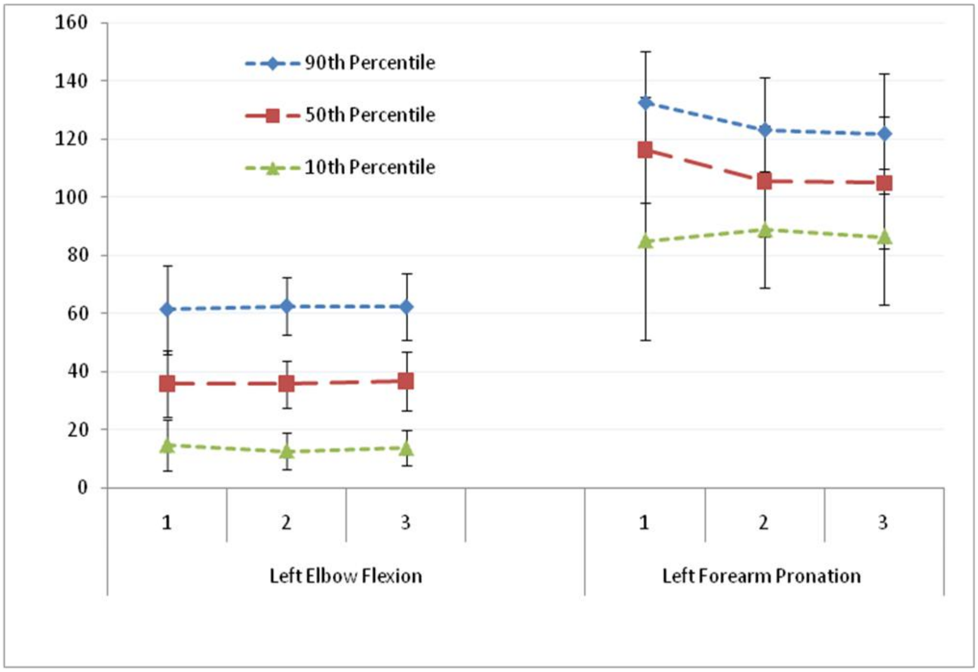

Figure 4-6: Mean 10th, 50th and 90th percentile angles in the left elbow and forearm for unloading conditions (1) *evenly loaded*, (2) *right-loaded*, and (3) *left-loaded*.

Elbow flexion and forearm pronation are depicted as positive angles. Left forearm pronation was less in condition (3) than in condition (2) at the 10th percentile angle ($p \leq 0.01$), ($n = 12$). Error bars represent standard deviation.

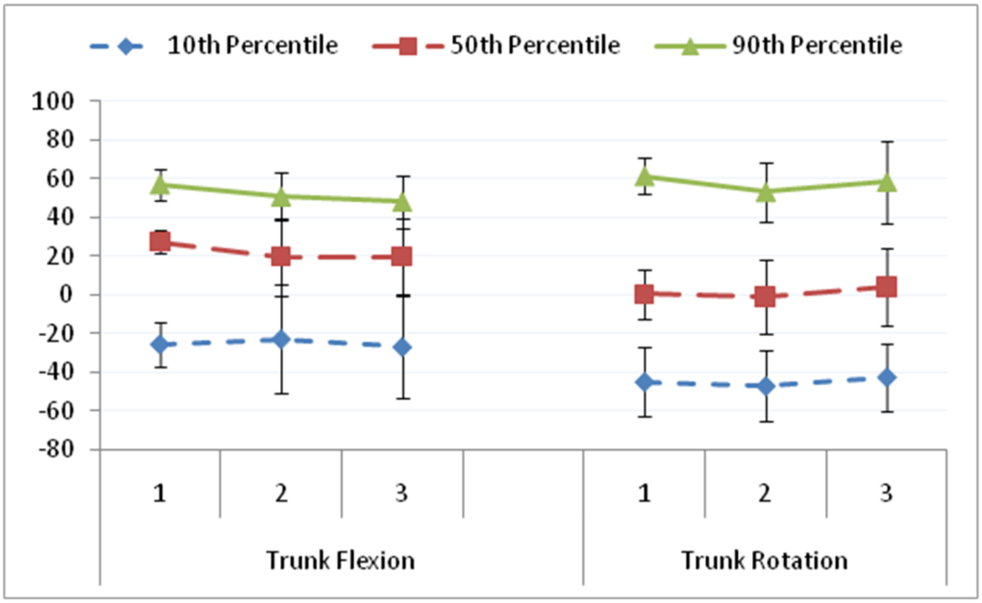

Figure 4-7: Mean 10th, 50th and 90th percentile trunk angles for unloading conditions (1) *evenly loaded*, (2) *right-loaded*, and (3) *left-loaded*.

Trunk flexion angles are reported as positive; trunk extension angles are reported as negative. Trunk rotation to the left is positive and is depicted on the figure as the 90th percentile angle; trunk rotation to the right is negative and is depicted as the 10th percentile angle (n = 14). Trunk flexion at the 90th percentile was significantly less in the *left-loaded* condition (3) than in the *evenly loaded* condition (1) (p = 0.03), Trunk rotation to the right (10th percentile) was significantly less in the *left-loaded* condition (3) than in the *right-loaded* condition (2) (p = 0.05) (n = 14). Error bars represent standard deviation.

4.0 Discussion

The primary goal of this study was to examine differences in upper limb and trunk relative joint angles during three commonly used tree-unloading conditions: (1) load evenly distributed to the right and left sides of the body – *evenly loaded;* (2) load distributed entirely to the right side of the body – *right-loaded* and (3) load distributed entirely to the left side of the body - *left-loaded*. The main findings were as follows: (1) loading on the left side of the body resulted in less wrist extension, greater right elbow flexion, less pronation of the right and left forearm, and less trunk rotation to the right than asymmetrical loading on the right side or symmetrical loading and (2) asymmetrical loading (either on the left or right side of the body) resulted in less left forearm pronation, and less trunk flexion than symmetrical loading.

4.1 Upper Limb and Trunk Angles

4.1.1 Wrist

There was a significant decrease in wrist extension when the load was located to the left side of the body, as compared to the right side of the body. All participants included in the data set were right handed and planted with the shovel in their right hand. A decrease in wrist extension could be explained by an increased tendency to lean on the shovel, especially as an aid while they were returning to standing, in an attempt to compensate for the uneven, heavy load on the left side of the body.

4.1.2 Right Elbow/Forearm

The right elbow showed a significant increase in flexion and the forearm showed a significant decrease in pronation when the load in the planting bags was switched from the right side of the body to the left side of the body. Decreases in forearm pronation and increases in elbow flexion could be due to an increased usage of the shovel for support during the planting cycle, similar to the above explanation for decreased wrist extension. This would be especially true during bending down to insert the seedling, and rising to a standing position once the seedling is planted. Using the shovel as support would alleviate some of the heavy load on the opposite side of the body. In this study, neutral forearm posture is defined as 90 degrees, or halfway between fully supinated (0 degrees) and fully pronated (180 degrees). Given the above qualification of 'neutral', the right forearm could be considered to be in a neutral posture only at the 10^{th} percentile angle. The forearm is considerably more pronated at the 50^{th} and 90^{th} percentile angles, which may result in decreased grip force on the shovel, and increased susceptibility to musculoskeletal disorders, especially when combined with increased wrist flexion (Mogk & Keir, 2003).

4.1.3 Left Elbow/Forearm

The left forearm showed a significant decrease in pronation when the load in the planting bags was switched from the right side of the body to the left side of the body. The volume of the left-side planting bag was greatly increased when the load was transferred, thereby possibly impeding pronation of the left forearm when the arm was at or moved to the side of the body. This decrease in forearm pronation may reduce the likelihood of developing musculoskeletal symptoms, as maximal pronation is now closer to what would be considered a 'neutral' posture. However, given the negligible load carried in the left hand, the risk for injury in the left wrist/forearm is much less than would be expected in the right arm, which is subjected to larger load/force combinations.

It was expected that elbow flexion would increase when the load was shifted from the right to the left side of the body because the bags were full to the top on the left side, which would decrease the distance that workers would have to reach to grab the tree seedlings, thus increasing the amount of elbow flexion. However, no such increase in flexion was found. This is likely because workers had retrieved the seedling from their bags while walking between micro-sites, and no walking was included in data analysis.

4.1.4 Trunk

When compared to even loading, left-side loading resulted in a significantly lower maximal trunk flexion. Although this was the only significant finding in trunk flexion, it is interesting to note that trunk flexion was generally less in asymmetric loading conditions than in the even-loaded condition at both the 50th and 90th percentiles. A lack of significant results may be due to large standard deviations in the angles in the asymmetric conditions. Standard deviations were larger in the asymmetric conditions than in the symmetric conditions at the 10th, 50th and 90th percentile angles. This could be due to large inter-participant variation. Some participants likely used their legs during bending more than others, which would have a large impact on maximum trunk flexion reached during the planting task.

Decreases in trunk flexion during asymmetric unloading may again be due to using the shovel for support during bending. These findings are supported by the significantly lower pain scores reported by participants who use asymmetric unloading as their preferred technique throughout the planting season. If this hypothesis is verified, a practical application of these results would be for workers to use the shovel for support during bending and standing up as a means of unloading the back thereby decreasing risk for sustaining musculoskeletal symptoms. Similarly, when analyzing body position during the insertion of tree seedlings into the ground, Giguere *et al* (1993) found that posture is related to the length and the handle type of the planting tool. Therefore, tree-planters might want to consider choosing a shovel (or modifying their existing shovel) to a length that is suitable to be used for support. A recent ergonomic report on tree-planting suggests that such a length is between fingertips and wrists when standing upright (Stjernberg & Kinney, 2008).

Greater trunk flexion angles during the symmetric unloading technique may be problematic for tree-planters, as frequent twisting and bending in occupational tasks have been linked to increased risk of low back pain (Xu *et al*, 1997). During asymmetric planting when the load in the planting bags was switched from the right side of the body to the left side of the body, rotation to the right decreased significantly. A heavy load on the left side of the body would impede rotation to the right, as the trunk muscles would have to work harder to overcome the external moment in the opposite direction created by the load of the trees.

4.2 Asymmetric unloading vs. Symmetric Unloading

Throughout the season, 55 percent of participants regularly unloaded their trees asymmetrically while 30 percent unloaded their trees symmetrically, and 15 percent unloaded their trees in some combination of the two. Asymmetric unloading is often chosen as the preferred method because it is less time consuming than symmetric unloading due to less transferring of trees. When asked to unload their planting bags asymmetrically, those participants who regularly unloaded their bags symmetrically verbally reported increased discomfort in their back and legs.

4.3 Study limitations and Future Directions

Although 20 workers participated in the study, there were many environmental and logistical challenges that resulted in the collection of partial data-sets (either symmetrical only, or asymmetrical only) for some participants. An increased number of participants and/or data sets may have reduced the standard deviations and increased the number of significant findings.

Although both upper arm and trunk movement were recorded with inertial motion sensors, we were unable to report joint angles at the shoulder. A recent study validating static, quasi-static and dynamic root mean square (RMS) error in orientation with the same inertial motion sensors used in the present study reported that during dynamic complex human motion (table washing task), mean RMS error in the upper arms approached 15˚, 13˚ and 27˚ in the x, y and z axes respectively (Godwin, 2009). Maximum RMS error for the task exceeded 45˚ (x-axis), 39˚(y axis) and 64˚ (z-axis). Upper arm orientation was reported to have the highest mean RMS error, followed by the forearm (8.6˚ (x-axis), 2.2˚ (y-axis) and 5.6˚(z-axis)) and the thorax (2.3˚ (x-axis), 1.5˚ (y-axis) and 3.8˚(z-axis)) segments (Godwin, 2009). Given the complex dynamic nature of the tree-planting, inertial motion sensors may not be the ideal tool for capturing the full range of motion during this task in a field setting.

A field setting was chosen due to the many environmental challenges encountered by workers that are not easily replicable in a lab setting. Since no other similar study exists to describe three dimensional joint angles of the tree-planting task in a field setting, these results undoubtedly provide novel information about this understudied occupation. However, given the possibility of the above error in the device during such dynamic motions, results should be interpreted with care and it is suggested that the task be replicated in a lab setting to confirm results of this study. A laboratory study would also be beneficial to describe joint forces in both the upper and lower body during the task in the three unloading conditions reported here. Description of joint forces at the wrist would also serve to verify our expectation that the shovel is used for support more during asymmetric tree unloading than symmetric tree unloading.

5.0 Conclusions

This study examined joint angles in the upper limbs and trunk during symmetrical and asymmetrical unloading strategies. Findings suggest that asymmetrical tree unloading results in more neutral postures than symmetrical tree unloading. These results are supported by significantly lower pain scores reported by participants who use asymmetric tree unloading as their preferred technique throughout the planting season. More neutral angles during asymmetric tree unloading may be a result of increased use of the shovel for support while bending and standing up to help balance the uneven load. Use of the shovel in this manner may result in less cumulative loading of the spine throughout the workday. However, this could not be verified and a more comprehensive look at joint loading during the tree-planting task is required.

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Chapter 5 : Posture and Joint Reaction Forces and Moments in a Simulated Tree-planting Task

Abstract

During tree-planting, several strategies are commonly used to unload trees from the planting bags, resulting in either symmetric or asymmetric load distribution to the body. The objectives of the study were to (1) describe posture and joint reaction forces and moments in the trunk and lower body during a simulated tree-planting task and (2) examine the effects of symmetric and asymmetric tree-unloading strategies on posture and joint reaction forces and moments in the lower limbs and trunk.

Twenty experienced tree-planters performed a simulated tree-planting task 10 times under each of the following loading conditions: (1) load evenly distributed to the right and left sides of the body – *evenly loaded,* (2) load distributed entirely to the right side of the body – *right-loaded,* and (3) load distributed entirely to the left side of the body - *left-loaded*. Lower body and trunk joint reaction forces and momments and postures were recorded using two force plates and an optoelectric system.

Greatest joint forces and moments and non-neutral postures occurred when the tree was inserted in the ground; therefore this posture should be assumed for as little time as possible during the task. Right-loaded planting bags seemed to produce the most differences in posture and joint reaction forces, suggesting that it is worse to carry the load on the right side of the body than the left side of the body or evenly across the body. Axial forces were greater in the right leg than the left leg throughout the planting cycle regardless of loading condition.

1.0 Introduction

Tree-planting is an integral part of the forestry industry in Canada and a primary contributor to the nation's gross domestic product (NFDP, 2008). It is a physically demanding seasonal occupation where workers are exposed daily to repetitive motions and heavy loads (Giguere *et al*, 1993; Upjohn *et al*, 2008; Upjohn *et al*, 2009b). Repeated biomechanical stress to the lower body joints, spine and wrist joints is likely a primary contributor to musculoskeletal injuries reported by workers. Workers carry an average of 16kg of trees and plant an average of over 1200 tree seedlings per day (Giguere *et al*, 1993). The most commonly reported musculoskeletal pain in tree-planters occurs in the feet, wrists and back and is significantly higher at the end of the work season than at the beginning of the work season (Upjohn *et al*, 2009a), suggesting that cumulative biomechanical loading contributes to reported pain.

In an attempt to more fully understand the physical demands of this challenging task, upper body postures have been recorded in the field using various methods of instrumentation such as digital video, inclinometers (Upjohn *et al*, 2008), and inertial motion sensors (Upjohn *et al*, 2009b). These studies indicate that workers spend 50% of the workday in trunk flexion greater than 45 degrees, with an average maximal trunk flexion over 130 degrees with respect to vertical (Upjohn *et al*, 2009b). Although results of these studies have provided valuable insight into the postural demands of the task and have resulted in suggestions for postural and equipment modifications to reduce musculoskeletal strain – such as tailoring the length of the shovel to the height of the planter, joint reaction forces in the areas most susceptible to injury has not been reported.

Tree-planters use various strategies to unload tree seedlings from their planting bags, resulting in either symmetric or asymmetric load distribution to the body. Studies suggest that asymmetric bending and lifting puts the spine at greater risk for injury than symmetric bending (Drake *et al*, 2005). When combined with deep trunk flexion and simultaneous lateral bending, it seems likely that asymmetrically distributed load would further increase forces and moments acting not only on the trunk but on the lower body, resulting in an increased risk of injury.

The objectives of this study were to (1) describe posture and joint reaction forces and moments in the lower body and trunk during a simulated tree-planting task and (2) examine the effects of symmetric and asymmetric tree-unloading strategies on posture and joint reaction forces and moments in the lower limbs and trunk. Three commonly used tree unloading strategies were used as being representative of asymmetric and symmetric unloading: (1) load evenly distributed to the right and left sides of the body – *evenly loaded*, (2) load distributed entirely to the right side of the body – *right-loaded*, and (3) load distributed entirely to the left side of the body - *left-loaded*.

Due to the complex nature of the task, a field setting would be preferable to obtain these data; however, it is difficult to use portable force measurement devices in such a harsh environment. Therefore, the task was simulated in a lab environment. It was hypothesized that the evenly loaded condition would produce more evenly distributed forces to the lower body joints and would therefore be less likely to contribute to musculoskeletal injury to workers.

2.0 Methods

2.1 Overview of Study

A repeated measures design was used to study the effect of three unloading conditions on posture and joint reaction forces and moments in the lower body and trunk during the tree-planting task. The tree-planting task was simulated in the lab using a sandbox filled with dense sand and rocks, representative of soil found in parts of Northern Ontario. The sand box was located at the end of an elevated walkway. Participants performed the planting task 10 times under each of three loading conditions in randomized order: (1) *evenly loaded*, (2) *right-loaded*, and (3) *left-loaded*. Joint reaction forces and moments during the task was recorded by two force plates (AMTI) located just proximal to the sandbox and posture was captured by two Optotrak® bars located to the front-right, and back-right of the calibrated task area. Data were synchronized using an Optotrak data acquisition unit (ODAU), and digital video was collected as a visual representation of the task.

2.2 Participants

Twenty participants (12 female, 8 male; age 21.4*(2.0)* yrs, height 175.3 *(8.2)* cm, weight 72.0 *(10.0)* kg) from the Queen’s community volunteered to participate in the study. Participants were right handed, had a minimum of one season’s tree-planting experience and had no musculoskeletal disorders or pain at the time of testing. Ethics approval was obtained from the Queen’s University Health Sciences Research Ethics Board, and participants gave written informed consent prior to participation.

2.3 Data Collection

Data were collected in the Motor Performance Laboratory in the School of Rehabilitation Therapy at Queen's University in Kingston, Canada.

2.3.1 Posture

Lower body and trunk postures were measured using an optoelectric system (Optotrak®, Northern Digital Inc., Waterloo) with two bars located midway between the frontal and sagittal planes to the front and to the rear of the participant. The task area was calibrated statically and dynamically using the Optotrak® Cube® prior to data collection. The origin of the laboratory space was designated as the front right hand corner of the left force plate. A one-second static data file was collected with the cube placed on the second force plate to indicate its relative position. Rigid clusters containing three infrared emitting diodes (IREDs) were custom made using rapid prototyping and were placed on the participants' C7 vertebra, sacrum, right and left posterior thigh, shank and heel. A rigid cluster was also placed on the shaft of the shovel just distal to the handle (Figure 5-1). Anatomical landmarks were digitized on each segment with the Optotrak® probe to relate the position of the clusters to the bones. These landmarks included the 1st and 5th metatarsals, medial and lateral malleoli, medial and lateral femoral condyles, greater trochanter, anterior superior iliac spine, and acromion process on the left and right side of the body. The shovel was landmarked at the right and left kick plate and handle. The participants' right and left hip joint centres were determined dynamically by recording relative positions of the pelvis and thigh for 15 seconds while the participant moved the leg (with motion originating from the hip) through a full range of motion. Landmarks were digitized prior to the planting tasks.

The positions of the rigid clusters were recorded using ToolBench software (Northern Digital Inc., Waterloo) at a rate of 50Hz for 10 seconds per planting task trial. A total of 30 trials were recorded for each participant with 10 trials per condition.

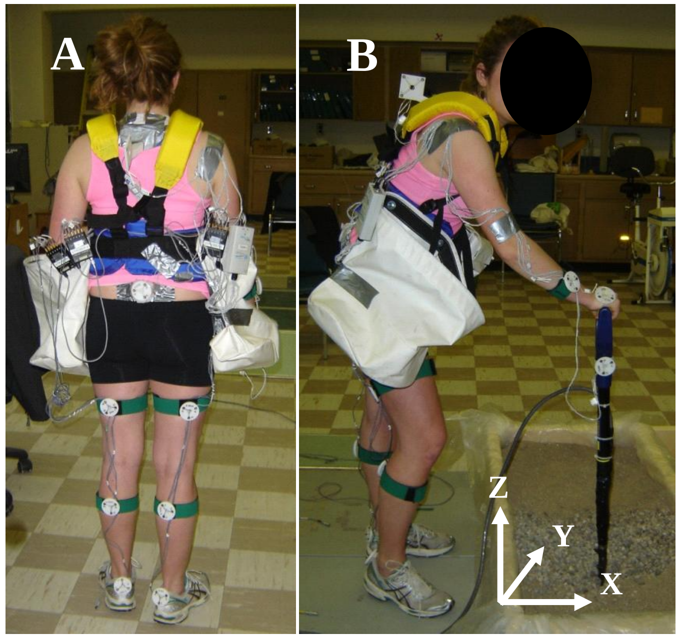

Figure 5-1: (A) Posterior and (B) Sagittal plane views of an instrumented participant.

Clusters of three infrared emitting diodes were placed with a neoprene band or self-adhesive Velcro on the heels, back of the calves, back of the thighs, sacrum, C7, and the shovel. In Figure 5-1 B, the subject is standing on the force plates with the shovel in the sandbox. The lab coordinate system is depicted in Figure 5-1 B.

2.3.2 Joint Reaction Forces

Two force plates (AMTI) were positioned flush with a raised walkway just proximal to the sand box (Figure 5-1B). The left and right force plates recorded the ground reaction forces and moments for the left and right sides of the body during the planting task. Force plates were zeroed prior to data collection and in between unloading conditions. Participants were instructed to ensure that their left foot made contact with only the left force plate, and their right foot made contact with only the right force plate. Data were recorded using ToolBench software (Northern Digital Inc., Waterloo) at 50Hz for 10 seconds per planting task trial and were synchronized with optoelectric data using the ODAU.

2.4 Data Processing

Data were processed using Visual3D Software for 3D motion analysis (C-Motion, Kingston, Canada). Data were interpolated and filtered using a low-pass Butterworth filter with a cut-off frequency of 2.8 Hz determined by a residual analysis. Angles and forces were exported from Visual3D to Excel at the following events for each trial: (1) shovel at highest vertical position – denoting the start of the planting cycle, (2) shovel contact with ground, (3) maximum trunk flexion – also representative of planting of the tree, and (4) return to standing position (Figure 5-2). The angles of interest were ankle flexion, inversion and rotation, knee flexion, hip flexion, abduction and rotation, and trunk flexion, lateral bend and rotation.

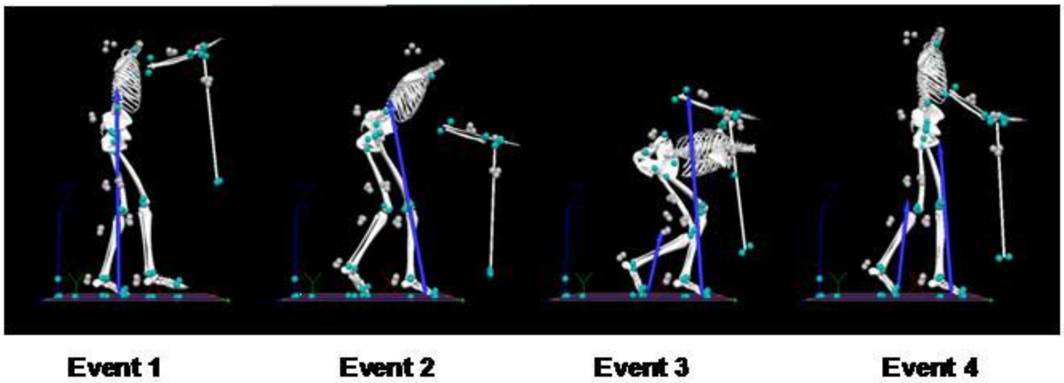

Figure 5-2: Representative planting cycle events in Visual 3D.

Event 1: Start of planting cycle (shovel at highest vertical point); Event 2: Shovel impact with ground; Event 3: Maximal trunk flexion; Event 4: End of planting cycle (return to upright posture).

2.5 Statistical Analyses

A one-way repeated measures ANOVA was used to determine significant differences in angles, forces and moments in the X Y and Z directions between unloading conditions for each joint. Data analyses were performed using SPSS 15.0 (Chicago, USA) and statistical significance was set to $p \leq 0.05$.

3.0 Results

3.1 Posture

Joint angles for the trunk, hips, knees and ankles at shovel insertion and maximum trunk flexion in the three loading conditions are presented in Tables 5-1 through 5-7. Due to the large number of data, values for the beginning of the planting cycle (shovel at highest vertical point) and end of planting cycle (return to upright standing position) are not reported in the tables. Significant differences between loading conditions exist primarily during shovel insertion and maximum trunk flexion across all joint angles. Data not found within the tables are reported within the body of the manuscript.

3.1.1 Trunk

Figure 5-3 depicts representative angles, forces and moments in the trunk during one full planting cycle. Trunk angles are described with respect to the global (lab) coordinate system for better comparison to previously collected field data (Inclinometer and Video data from Chapter 3). At the beginning of the planting cycle (when the shovel is at its highest vertical position) the trunk was bent slightly to the left across conditions with significantly more bending in the

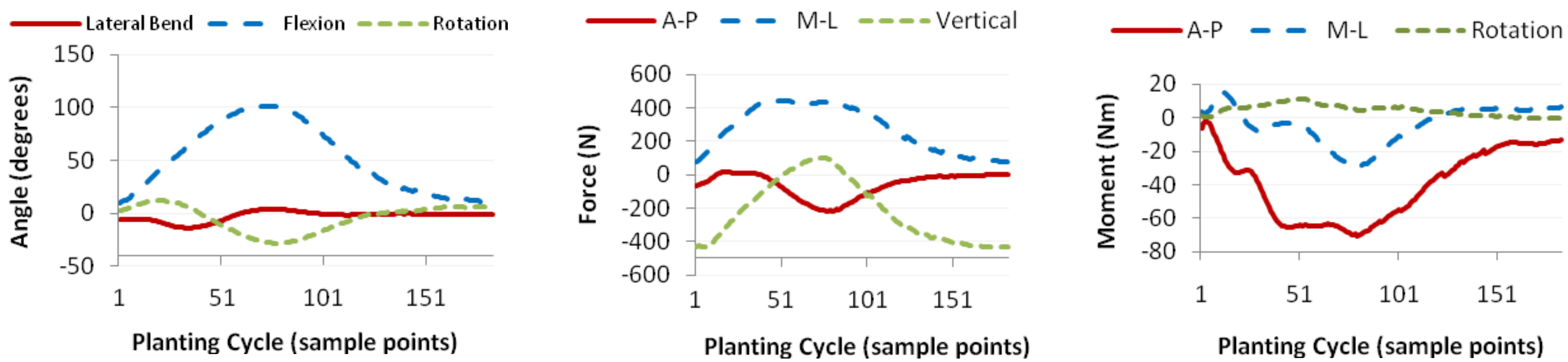

Figure 5-3: Representative trunk angles, forces and moments in the Antero-Posterior (lateral bending), Medial-Lateral (flexion) and Vertical (rotation) axes during the planting cycle averaged across 10 trials in the evenly loaded condition.

Right bending, flexion and left rotation are positive. Anterior shear, left shear and upwards force are positive. Planting cycle begins when the shovel is at the highest vertical position and ends at upright standing posture after the 'tree' has been planted. Data were collected at 50 Hz and the planting cycle is approximately 200 Hz or 4 seconds long. Trunk angles are with respect to the lab coordinate system, trunk forces and moments are in the sacral coordinate system. N = 1.

Table 5-1: Trunk angles, forces and moments in the X, Y and Z axes for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Angles are with respect to the global coordinate system, while forces and moments are in the sacral coordinate system. Right lateral bend angle (X-axis), flexion angle (Y-axis) and left rotation angle (Z-axis) are positive. Posterior shear forces (Y-axis), left shear forces (X-axis) and downwards forces (Z-axis) are positive. Left rotation moments (Z-axis), right lateral bending moments (Y-axis) and extension moments (X-axis) are positive.

[1] indicates a significant difference between even- and right-loaded conditions; [2] indicates a significant difference between even- and left-loaded conditions, and [3] indicates a significant difference between right- and left-loaded conditions.

		ANGLES (degrees) n=18			FORCES (N) n=16			MOMENTS (Nm) n=16		
	E	Even	Right	Left	Even	Right	Left	Even	Right	Left
X	2	-4.68 (4.89)	-8.89 (5.05)	-3.05 (3.88) [1,3]	14.38 (48.33)	-33.86 (48.21)	13.62 (66.4) [1,3]	-58.62 (14.77)	-58.39 (10.41)	-62.65 (18.59)
	3	0.62 (6.52)	-3.08 (6.85)	2.45 (7.29) [1,3]	-227.45 (115.09)	-262.67 (83.75)	-221.95 (83.35)	-91.92 (30.73)	-79.73 (23.33)	-93.39 (27.6)
Y	2	46.14 (11.60)	46.18 (13.84)	48.28 (13.69)	313.78 (56.83)	327.07 (54.12)	317.73 (79.43)	2.37 (7.80)	9.10 (11.99)	-8.33 (11.17) [1,2,3]
	3	90.35 (6.24)	90.83 (5.98)	88.70 (6.29)	429.26 (98.88)	398.84 (66.15)	440.19 (101.40)	-45.06 (30.29)	-47.24 (19.90)	-37.15 (22.83)
Z	2	5.77 (8.79)	0.19 (7.30)	5.51 (10.8) [1]	-288.20 (99.47)	-264.27 (112.20)	-252.45 (112.26) [1,3]	1.04 (6.95)	19.61 (9.58)	-12.06 (11.47) [1,2,3]
	3	-30.10 (8.22)	-34.96 (5.64)	-28.20 (9.3) [1,3]	-2.54 (59.47)	15.52 (50.56)	--0.23(59.95)	0.72 (16.22)	27.79 (12.69)	-17.33 (25.61) [1,3]

right-loaded condition (-8.61 degrees) than the even (-3.94 degrees) or left-loaded (-1.62 degrees) conditions (p = < 0.01 in each case). There was little difference in trunk flexion across conditions at the beginning of the planting cycle (9.27 degrees (even), 10.92 degrees (right) and 9.86 degrees (left)). The trunk was rotated slightly to the right in the left-loaded condition (2.96 degrees) and slightly to the left in the right-loaded condition (-2.11 degrees) ($p = 0.01$).

At shovel impact mean lateral bending to the left was greatest in the right-loaded condition (-8.89 degrees), and was significantly greater than in the even-loaded and left-loaded conditions (p = < 0.01 in both cases) (Table 5-1). Mean trunk flexion at shovel impact was similar across conditions (46-48 degrees of flexion with respect to vertical), and increased to 90 degrees at maximum flexion. There were no significant differences across conditions. The trunk was rotated slightly to the left across conditions with significantly greater left-rotation in the evenly loaded condition than the right-loaded condition ($p = 0.02$).

At maximum trunk flexion, there was almost no lateral bending in the even-loaded condition (0.62 degrees), whereas there was slight bending to the left in the right-loaded condition (-3.08 degrees) and slight bending to the right in the left-loaded condition (2.45 degrees). Subjects engaged in significantly more lateral bend to the left in the right-loaded condition as compared to the even-loaded and left-loaded conditions ($p = 0.02$ and < 0.01 respectively). At maximum trunk flexion, mean rotation was to the right in all loading conditions with significantly greater right-rotation in the right-loaded condition (-34.96 degrees) than the even-loaded condition (-30.10 degrees) and left-loaded conditions (-28.20 degrees) (p <0.01 and 0.03 respectively).

At the end of the planting cycle (return to upright standing) the trunk was bent to the right in the even-loaded (1.57 degrees) and left loaded (2.7 degrees) conditions and slightly to the left in the right-loaded condition (-2.15 degrees) ($p < 0.01$). The trunk was slightly flexed upon return to standing across conditions, with greater flexion in the right-loaded condition (5.11 degrees) than the even-loaded condition (2.32 degrees) ($p = 0.01$). There was some rotation the right (< 5 degrees) across conditions, but no significant differences between conditions.

3.1.2 Lower Body

Hips - Figure 5-4 depicts representative angles, forces and moments in the hips during one full planting cycle. At the beginning of the planting cycle, both the right and left hips were flexed (24 and 15 degrees respectively) and no significant differences were observed across condition in either leg. Both hips were slightly abducted (< 5 degrees) with no significant differences across conditions. The right hip was in neutral rotation (< 1 degree of rotation across conditions), whereas the left hip was inwardly rotated (< 5 degrees across conditions) with no significant differences across conditions in either leg. At shovel impact, hip flexion increased to over 50 degrees in the right hip and over 40 degrees in the left hip (Table 5-2 and 5-3). No significant differences were found across conditions. The left hip was slightly abducted, whereas the right hip remained in a mainly neutral position with abduction angles ≤ 3 degrees across conditions. No significant differences were found across conditions in either hip. Both the right and left hips were internally rotated at shovel impact. In the right hip, inward rotation was greater in the left-loaded condition (8.19 degrees) than the right-loaded condition (3.23 degrees) ($p < 0.01$).

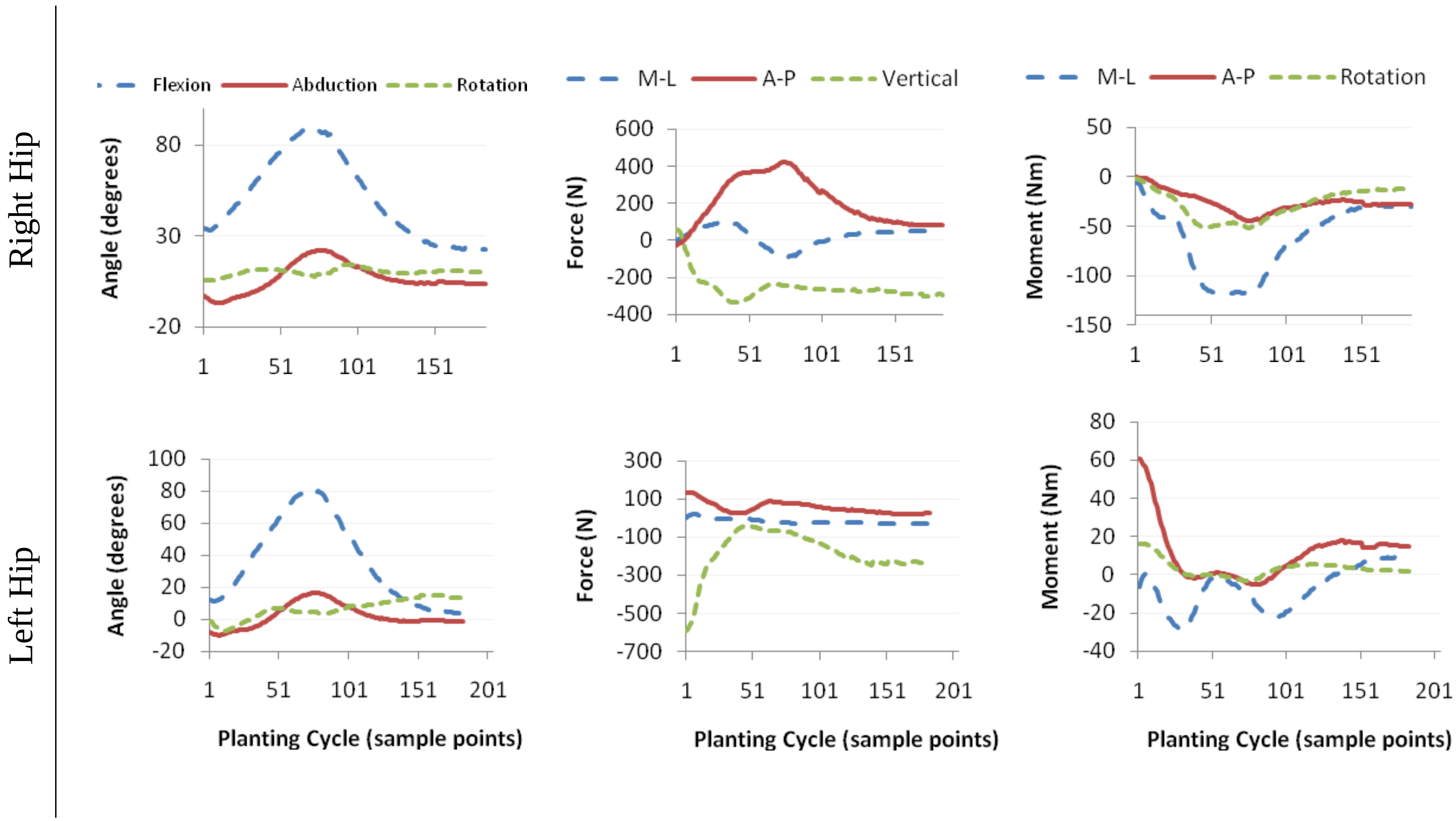

Figure 5-4: Representative right and left hip angles, forces and moments during the planting cycle averaged across 10 trials in the evenly loaded condition.

Data were collected at 50 Hz; N = 1. *For right hip angles*, flexion, adduction and internal rotation are positive; *for right hip forces*, anterior, lateral ad upwards forces are positive; *for right hip moments*, extension, abduction and external rotation are positive. *For left hip angles*, flexion, abduction and external rotation are positive; *for left hip forces*, anterior, medial and upwards forces are positive; *for left hip moments*, extension, adduction and internal rotation are positive.

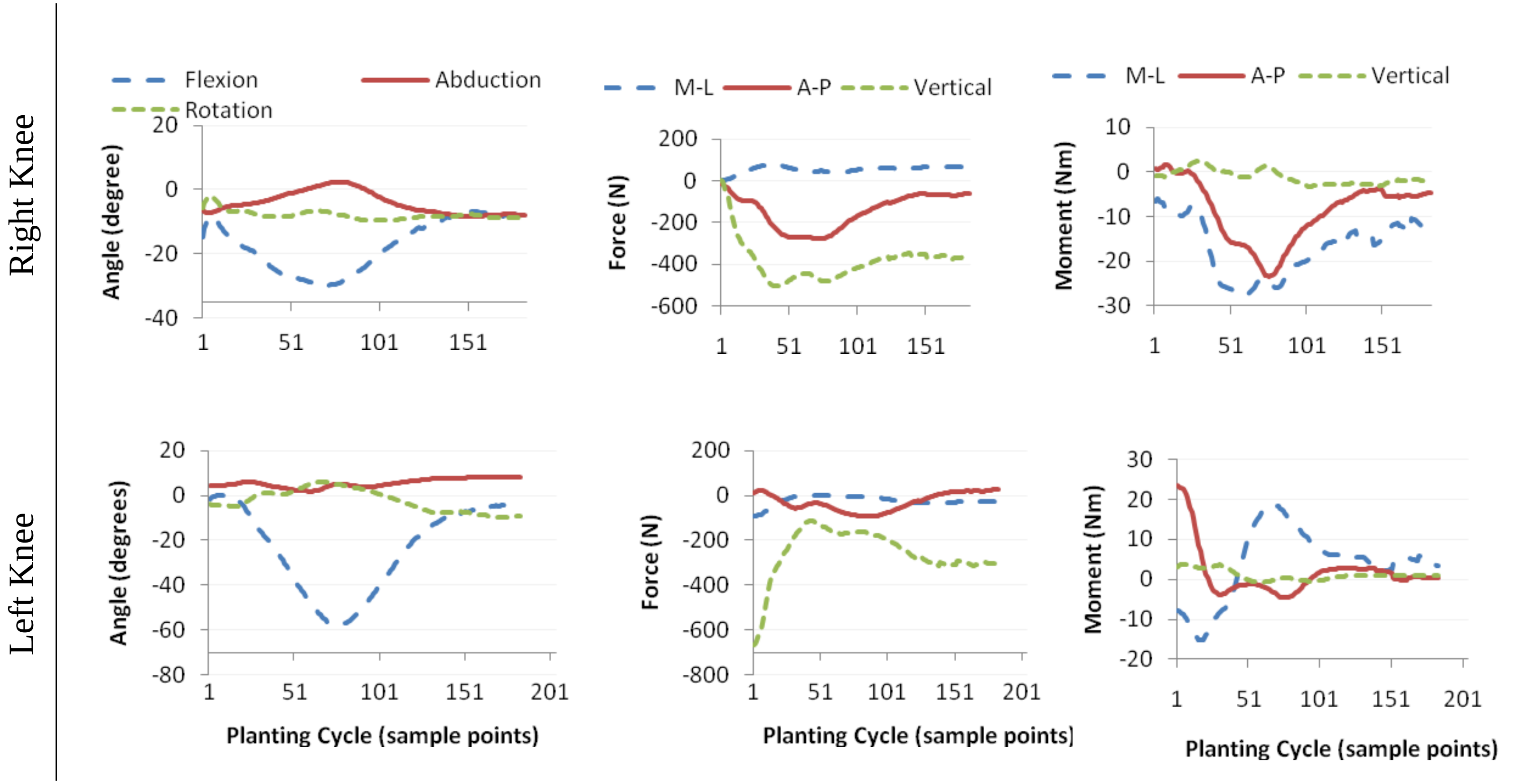

Figure 5-5: Representative right and left knee angles, forces and moments during the planting cycle averaged across 10 trials in the evenly loaded condition.

Data were collected at 50 Hz; n = 1. *For right knee angles*, flexion, adduction and internal rotation are positive; *for right knee forces*, anterior, lateral and upwards forces are positive; *for right knee moments*, extension, abduction and external rotation are positive. *For left knee angles*, flexion, abduction and external rotation are positive; *for left knee forces*, anterior, medial and upwards forces are positive; *for left knee moments*, extension, adduction and internal rotation are positive.

At maximum trunk flexion, flexion of the right hip approached 100 degrees across conditions, while flexion in the left hip was just over 80 degrees with no significant differences across conditions in either hip. The right hip was in ~15 degrees of adduction across conditions while the left leg was in ~20 degrees of abduction with significantly greater abduction in the right-loaded condition (20.90 degrees) than the even-loaded condition (16.79 degrees) ($p = 0.02$) (Tables 5-2 and 5-3). At maximum trunk flexion, the right hip was slightly internally rotated in the even-loaded (2.21 degrees) and left-loaded (5.69) conditions while slightly externally rotated in the right-loaded condition (-1.99 degrees), with significant differences between right and left-loaded conditions ($p = 0.03$). Mean left hip rotation was 15 degrees with no significant differences across conditions.

At the end of the planting cycle (upright standing), the right hip was in slight flexion while the left hip was in slight extension (< 5 degrees). The right hip was in < 1 degree of adduction while the left hip was in slight abduction (< 8 degrees across conditions). Mean rotation in the right hip was slightly internal with significantly greater internal rotation in the right-loaded condition (7.19 degrees) than in the left-loaded condition (2.90 degrees) ($p = 0.02$).

Knees - Figure 5-5 depicts representative angles, forces and moments in the knees during one full planting cycle. Right and left knee angles for shovel impact and maximum trunk flexion across loading conditions are presented in Tables 5-4 and 5-5. At the beginning of the planting cycle mean knee flexion in the right and left knees across conditions was 27 and 30 degrees respectively with no significant differences across conditions. Both the right and left knees were slightly abducted (< 3 degrees) and externally rotated (<7 degrees) across conditions.

At shovel impact, knee flexion remained similar to the beginning of the planting cycle in the right knee, while flexion in the left knee increased to 40 degrees (Table 5-5). In the right knee, mean adduction in the left-loaded condition (4.60 degrees) was significantly greater than in the right-loaded condition (0.62 degrees) ($p = 0.02$), while left knee adduction in the right-loaded condition (-5.05 degrees) was significantly greater than in both the even-loaded condition (-2.19 degrees) and left-loaded condition (-1.77 degrees) ($p < 0.01$ and 0.02; Table 5-5). Both the right and left shank were externally rotated with respect to the thigh. The right-loaded condition produced a significantly greater rotation in the shank than the even-loaded condition in the left leg (Table 5-5).

At maximum trunk flexion, mean flexion in the right knee approached 50 degrees, while mean flexion in the left knee approached 70 degrees with no significant differences across loading conditions in either knee (Tables 5-4 and 5-5). Both the right and left shank were abducted with respect to the thigh across conditions with the left shank significantly more abducted in the right-loaded condition (-5.39 degrees) than the even-loaded condition (-1.28 degrees) ($p = 0.01$). Both knees were in external rotation at maximum trunk flexion with no significant differences across loading conditions (Tables 5-4 and 5-5).

At the end of the planting cycle (upright standing), both the right and left shank were slightly flexed, abducted and internally rotated with respect to the thigh. No significant differences across loading conditions.

Ankles - Figure 5-6 depicts representative angles, forces and moments in the ankles during one full planting cycle. Mean left and right ankle angles in a neutral standing posture were 62 degrees and 60 degrees respectively.

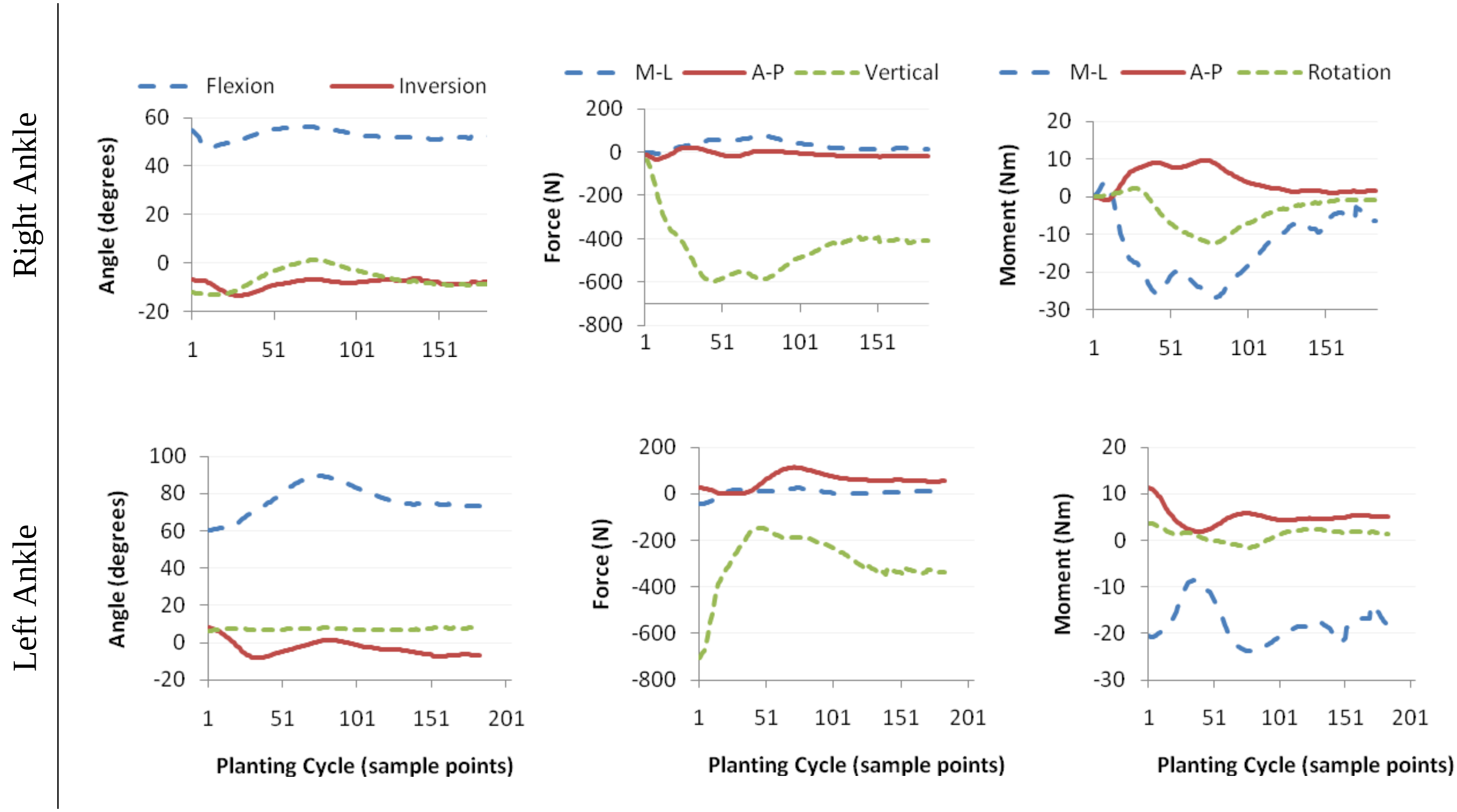

Figure 5-6: Representative right and left ankle angles, forces and moments during the planting cycle averaged across 10 trials in the evenly loaded condition.

Data were collected at 50 Hz; n = 1. *For right ankle angles*, plantar flexion, inversion and internal rotation are positive; *for right ankle forces*, anterior, lateral and upwards forces are positive; *for right ankle moments*, dorsi flexion, eversion and external rotation are positive. *For left ankle angles*, plantar flexion, eversion and external rotation are positive; *for left ankle forces*, anterior, medial and upwards forces are positive; *for left ankle moments*, dorsi flexion, inversion and internal rotation are positive.

The right ankle remained in a fairly neutral posture with respect to standing at both shovel contact and at maximum trunk flexion when the tree was inserted, whereas the left ankle was in approximately 15 degrees of plantar flexion at maximum trunk flexion. Both the right and left ankles were everted throughout the planting cycle. Right ankle eversion was significantly greater in the even and left-loaded conditions than in the right-loaded condition at max trunk flexion, while left ankle eversion was significantly greater in the right-loaded condition than the left-loaded condition at shovel contact. The left ankle exceeded 10 degrees of external rotation throughout the planting cycle, while the right ankle was externally rotated only at shovel contact, with a more neutral posture (< 1 degree internal rotation) at maximum trunk flexion.

3.2 Joint Reaction Forces and Moments

Joint forces and moments in the trunk, ankles, knees, and hips during shovel insertion and maximum trunk flexion are presented in Tables 5-1 to 5-7. Forces and moments are described in (N) and (Nm) respectively and are not normalized to body weight. The mass of the planting bags (10 kg) was applied above the level of the superior iliac spine of the pelvis (approximately the level of the L3 vertebra (Chakraverty et al, 2007)) therefore there was no interference with the inverse dynamics model used to calculate forces and moments in the joints of the lower body and the trunk at the sacrum. Forces and moments are in the coordinate system of the proximal segment.

Table 5-2: Right hip angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where hip flexion, adduction and internal rotation angles are positive; lateral, anterior and downwards vertical force are positive; and internal rotation, flexion and adduction moments are positive. Angles, forces and moments are reported in the proximal joint coordinate system.[1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=16			FORCES (N) n=16			MOMENTS (Nm) n=16		
	E	Even	Right	Left	Even	Right	Left	Even	Right	Left
X-Flexion	2	53.05 (17.88)	51.88 (18.29)	57.38 (23.00)	41.85 (37.03)	21.43 (37.75)	43.97 (36.56)	-67.47 (23.81)	-66.61 (27.61)	-72.14 (31.71)
	3	99.21 (15.24)	97.46 (18.36)	97.71 (21.70)	-85.72 (74.81)	-123.49 (67.06)	-77.71 (79.95) [1,3]	-132.44 (52.53)	-133.18 (42.76)	-128.12 (49.44)
Y-Adduction	2	0.21 (7.58)	3.08 (8.38)	-0.19 (8.36)	213.55 (132.04)	237.64 (144.66)	216.34 (138.50)	-15.27 (15.06)	-14.70 (17.41)	-17.40 (20.03)
	3	15.12 (8.84)	16.28 (7.62)	14.40 (8.23)	418.74 (135.50)	450.59 (136.67)	404.23 (114.53)	-35.58 (18.81)	-40.20 (18.11)	-38.64 (23.44)
Z-Internal Rotation	2	5.59 (6.85)	3.23 (7.20	8.19 (8.46) [3]	-299.59 (91.23	-318.66 (120.35)	-272.23 (105.15)	-21.34 (15.83	-18.80 (15.61)	-27.02 (19.92)
	3	2.21 (7.94)	-1.99 (8.18	5.69 (11.64) [3]	-229.55 (126.37	-240.77 (118.48)	-238.61 (115.26)	-32.36 (28.80	-26.65 (24.29)	-42.01 (31.39) [3]

Table 5-3: Left hip angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where hip flexion, abduction and external rotation angles are positive; medial, anterior and downwards vertical force are positive; and external rotation, flexion and abduction moments are positive. Angles, forces and moments are reported in the proximal joint coordinate system.[1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=19			**FORCES (N) n = 18**			**MOMENTS (Nm) n=18**		
	E	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**
X-Flexion	2	44.42 (16.85)	44.07 (16.37)	46.07 (20.60)	-24.33 (19.41)	-23.08 (25.03)	-23.59 (26.97)	-21.10 (19.10)	-19.75 (20.57)	-20.16 (15.60)
	3	82.95 (23.07)	83.76 (19.56)	81.91 (22.20)	-34.18 (33.09)	-11.97 (29.44)	-29.99 (18.55)	-15.07 (28.94)	-7.26 (18.25)	-11.99 (24.82)
Y-Abduction	2	7.22 (5.74)	9.15 (6.28)	7.80 (6.48)	32.26 (60.09)	13.87 (67.05)	38.57 (80.87)	4.58(10.91)	9.63 (11.33)	2.26 (10.39) [3]
	3	16.79 (7.39)	20.90 (6.92)	18.23 (9.41) [1]	42.68 (63.17)	-2.07 (58.03)	63.14 (57.25) [1,3]	-7.65 (12.69)	-4.44 (8.34)	-9.60 (7.08) [3]
Z-External Rotation	2	-7.05 (8.80)	-7.65 (10.87)	-5.64 (9.59)	-125.58 (142.01)	-102.85 (142.89)	-146.48 (152.74)	6.49 (6.19)	8.53 (8.14)	5.14 (6.91)
	3	-15.55 (10.15)	-15.99 (8.87)	-15.11 (11.41)	-59.00 (46.46)	-25.66 (43.76)	-66.47 (37.16) [1,3]	-1.43 (9.16)	-0.06 (7.39)	-6.01 (11.08) [2,3]

Table 5-4: Right knee angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where knee flexion, abduction and external rotation angles are negative; lateral, anterior and downwards vertical force are positive; and external rotation, flexion and abduction moments are negative. Angles, forces and moments are reported in the proximal joint coordinate system. [1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=16			FORCES (N) n=16			MOMENTS (Nm) n=16		
	E	Even	Right	Left	Even	Right	Left	Even	Right	Left
X-Extension	2	-26.98 (10.84)	-26.03 (9.86)	-29.60 (13.86)	26.18 (28.67)	33.04 (41.81)	16.95 (53.50)	-1.67 (14.38)	-0.64 (16.41)	-1.46 (14.38)
	3	-48.67 (15.56)	-46.51 (14.56)	-50.57 (19.15)	-9.90 (64.39)	-0.88 (71.26)	-6.35 (85.01)	-0.62 (34.09)	4.63 (34.24)	2.29 (36.06)
Y-Adduction	2	2.45 (4.25)	0.62 (5.20)	4.60 (6.74) [3]	-176.16 (75.32)	-165.14 (75.35)	-192.45 (102.22)	-13.01 (9.17)	-11.10 (9.78)	-15.19 (11.72)
	3	10.10 (8.19)	9.13 (7.74)	10.21 (10.03)	-329.18 (114.40)	-333.14 (115.92)	-335.69 (141.86)	-28.88 (15.76)	-30.44 (11.02)	-30.71 (18.18)
Z-Internal Rotation	2	-9.44 (6.17)	-8.14 (6.28)	-9.62 (6.43)	-421.58 (113.51)	-456.00 (145.18)	-384.56 (126.75)	5.77 (5.31)	2.58 (5.50)	7.27 (7.79) [1,3]
	3	-7.94 (7.45)	-8.58 (6.07)	-6.44 (8.32)	-433.27 (147.34)	-465.60 (137.27)	-411.65 (128.71) [3]	10.93 (11.81)	9.29 (6.97)	11.25 (16.76)

Table 5-5: Left knee angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where knee flexion, adduction and internal rotation angles are negative; medial, anterior and downwards vertical force are positive; and internal rotation, flexion and adduction moments are negative. Angles, forces and moments are reported in the proximal joint coordinate system. [1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=18			FORCES (N) n=18				MOMENTS (Nm) n=18		
	E	**Even**	**Right**	**Left**	**Even**	**Right**		**Left**	**Even**	**Right**	**Left**
X-Extension	2	-38.76 (14.76)	-41.16 (12.85)	-40.08 (14.68)	-0.52 (10.84)	-4.77 (23.03)	X-flexion	1.60 (17.94)	2.68 (7.84)	1.75 (6.97)	5.95 (10.66)
	3	-67.96 (21.88)	-71.86 (14.33)	-68.04 (22.98)	-3.09 (27.37)	2.46 (13.09)		13.66 (21.01)	20.27 (15.82)	13.64 (10.14)	20.89 (15.61)
Y-Abduction	2	-2.19 (6.32)	-5.05 (6.42)	-1.77 (6.71) [1,3]	-67.21 (50.10)	-64.97 (56.36)	Y-Abduct	-73.09 (48.32)	4.57 (10.65)	6.82 (8.58)	4.05 (10.81)
	3	-1.28 (8.89)	-5.39 (8.09)	-3.16 (10.30) [1]	-106.11 (91.88)	-79.76 (81.02)		-105.47 (80.48)	-2.75 (8.09)	0.01 (4.70)	-2.71 (11.68)
Z-External Rotation	2	2.96 (7.57)	6.03 (6.92)	4.38 (6.97) [1]	-189.86 (156.01)	-161.80 (153.65)	Z-Rotation	-210.93 (169.99)	0.26 (2.74)	-1.44 (2.63)	0.74 (3.34) [1,3]
	3	9.57 (6.05)	8.43 (6.94)	10.01 (8.33)	-134.12 (63.07)	-90.26 (72.17)		-149.49 (70.63) [1,3]	0.19 (3.09)	-0.43 (2.62)	-0.20 (4.68)

Table 5-6: Right ankle angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where upright standing is 60 degrees of flexion, (plantar flexion >60 degrees; dorsiflexion <60 degrees), inversion and internal rotation are positive. Lateral, anterior and upwards vertical force are positive, and plantar flexion, inversion and internal rotation moments are positive. Angles, forces and moments are reported in the proximal joint coordinate system. [1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=18			FORCES (N) n=18			MOMENTS (Nm) n=18		
	E	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**
X-Flexion	2	57.71 (*8.55*)	57.41 (*7.20*)	58.93 (*6.56*)	42.17 (*26.46*)	34.92 (*25.10*)	42.95 (*29.70*)	-22.02 (*12.58*)	-24.60 (*11.39*)	-23.02 (*14.22*)
	3	68.86 (*7.46*)	67.68 (*7.72*)	68.30 (*7.42*)	93.02 (*62.18*)	81.87 (*41.07*)	95.19 (*52.11*)	-47.53 (*19.15*)	-45.82 (*14.68*)	-47.75 (*18.55*)
Y-Inversion	2	-9.28 (*10.03*)	-6.06 (*10.07*)	-9.71 (*9.07*)[1]	48.64 (*52.60*)	54.27 (*53.03*)	56.99 (*63.00*)	3.44 (*5.66*)	4.17 (*5.23*)	3.90 (*6.09*)
	3	-7.83 (*10.55*)	-3.88 (*10.39*)	-8.27 (*8.62*)[1,3]	113.99 (*84.88*)	119.45 (*84.94*)	122.84 (*95.77*)	12.02 (*12.46*)	11.26 (*10.90*)	12.01 (*11.14*)
Z-Internal Rotation	2	-9.07 (*7.29*)	-8.99 (*6.51*)	-7.44 (*9.37*)	-513.62 (*120.97*)	-554.28 (*141.20*)	-472.52 (*153.62*)[1]	-2.07 (*3.25*)	-2.78 (*3.35*)	-2.96 (*4.11*)
	3	0.36 (*3.93*)	0.02 (*5.11*)	0.90 (*9.24*)	-562.57 (*148.93*)	-586.36 (*145.07*)	-543.92 (*133.91*)	-15.47 (*8.19*)	-14.11 (*5.29*)	-15.35 (*6.98*)

Table 5-7: Left ankle angles, forces and moments in the X (flexion), Y (lateral bending) and Z (rotation) directions for shovel contact and maximum trunk flexion (Events 2 and 3 respectively).

Where upright standing is 62 degrees of flexion, (plantar flexion > 62 degrees; dorsiflexion < 62 degrees), eversion and external rotation are positive. Medial, anterior and upwards vertical force are positive, and plantar flexion, eversion and external rotation moments are positive. Angles, forces and moments are reported in the proximal joint coordinate system. [1] indicates a significant difference between even and right-loaded conditions; [2] indicates a significant difference between even and left-loaded conditions, and [3] indicates a difference between right and left-loaded conditions.

		ANGLES (degrees) n=19			**FORCES (N) n=19**			**MOMENTS (Nm) n=19**		
	E	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**	**Even**	**Right**	**Left**
X-Flexion	2	73.18 (*6.71*)	74.96 (*7.40*)	73.00 (*7.53*)	-8.42 (*25.06*)	-14.91 (*19.39*)	-3.46 (*23.36*) [3]	-21.64 (*15.10*)	-17.04 (*11.54*)	-24.29 (*16.11*) [3]
	3	85.41 (*5.74*)	85.63 (*5.42*)	84.62 (*5.47*)	13.62 (*19.20*)	6.94 (*14.62*)	18.04 (*24.41*) [3]	-23.47 (*10.76*)	-20.33 (*11.86*)	-27.00 (*12.67*) [3]
Y-Inversion	2	3.03 (*9.17*)	4.22 (*8.29*)	1.21 (*8.77*) [3]	66.60 (*53.56*)	56.89 (*41.82*)	82.99 (*55.70*) [2,3]	1.14 (*3.37*)	1.04 (*3.19*)	2.19 (*4.73*)
	3	4.99 (*9.95*)	5.20 (*10.37*)	4.08 (*10.78*)	113.85 (*53.53*)	95.02 (*52.32*)	127.96 (*61.98*) [3]	1.64 (*3.44*)	1.37 (*2.82*)	2.86 (*4.44*) [3]
Z-External Rotation	2	10.87 (*5.90*)	10.84 (*5.99*)	11.09 (*6.58*)	-232.77 (*161.58*)	-201.81 (*157.01*)	-264.27 (*179.21*) [3]	2.58 (*4.75*)	3.08 (*3.89*)	2.75 (*4.86*)
	3	12.99 (*5.89*)	12.73 (*6.43*)	13.56 (*7.20*)	-168.62 (*96.65*)	-138.98 (*91.59*)	-199.23 (*111.39*) [3]	-1.23 (*3.44*)	-0.18 (*3.32*)	-1.45 (*5.58*)

3.2.1 Trunk

At shovel impact, medial-lateral shear force was towards the left in the right-loaded condition and towards the right in the even-loaded and left-loaded conditions (-33.86 N and 14.38 N respectively) ($p \leq 0.01$ between right and even/left conditions). Axial force was significantly greater in the even-loaded condition (-288.2 N) than in the right or left-loaded conditions (-264.27 N and -252.45 N respectively). Lateral-bending moments were significantly different between all three conditions ($p \leq 0.01$). The right-loaded condition produced a right-bending moment (9.10 Nm), whereas the left-loaded condition produced a left-bending moment (-8.33 Nm). Similarly there were significant differences between all rotation moments ($p \leq 0.01$) where right loading resulted in a left-rotation moment (19.61 Nm) and left loading resulted in a right-rotation moment (-12.06 Nm) (Table 5-1).

At maximum trunk flexion, forces in the Z-direction are indicative of shear forces acting on the spine and are almost nonexistent - there were no significant differences between loading conditions. Similar to shovel impact, the right-loaded condition resulted in a left-rotation moment (27.79 Nm) and the left-loaded condition resulted in a right-rotation moment (-17.33 Nm). Mean rotation moment for the even-loaded condition was negligible at 0.72 Nm (Table 5-1).

3.2.2 Lower Body

Hips - In both the right and left hips there was a lateral force at shovel contact across loading conditions; however, at maximum trunk flexion in the right hip, this lateral force became a medial force which was significantly greater in the right-loaded condition (-123.49 N) than in the even- and left-loaded conditions (-85.72 N and -77.71 N respectively). The large anterior forces in the right hip at shovel contact and maximum trunk flexion (>200 N and >400 N respectively) were balanced by smaller anterior forces in the left hip (< 50 N) at both shovel contact and maximum trunk flexion. Axial forces were also greater in the right hip at shovel contact and maximum trunk flexion than in the left hip (Tables 5-2 and 5-3). In both hips, shovel contact resulted in extension, abduction and external rotation moments in all three loading conditions (Tables 5-2 and 5-3). At maximum trunk flexion, right hip moments remained similar but increased in magnitude, whereas in the left hip, maximum trunk flexion resulted in smaller extension, adduction and internal rotation moments.

Knees - Forces in the knees followed the same general pattern as forces in the hips with lateral shear forces at shovel contact in both the right and left knees, and medial shear forces at maximum trunk flexion in both knees. Large posterior forces were present in the right knee at shovel contact (~170N), almost doubling at maximum trunk flexion (~330N). Posterior forces were also present in the left knee but were considerably smaller at both events across conditions (< 100N at shovel contact). Axial forces were nearly twice as large in the right knee as the left knee at shovel contact, and almost three times as large at maximum trunk flexion (Tables 5-4 and 5-5). Axial force was significantly smaller in the right-loaded condition than in the left-loaded condition in both the right and left knees (p = 0.01 and 0.02 respectively). There were no significant differences in moments between conditions in either knee with the exception of rotation moments at shovel contact for both knees. In both knees, internal rotation moments at shovel contact were significantly greater in the even and left-loaded conditions than the right-loaded condition. Rotation moments in the left knee were fairly small across conditions at both shovel impact and maximum trunk flexion (≤ 1 Nm).

Ankles - There were more significant differences across conditions in the left ankle than in the right ankle. Similar to the knees, forces in the right ankle were much greater than in the left ankle, specifically in the vertical direction at maximum trunk flexion (Tables 5-6 and 5-7). Anterior shear forces of approximately the same magnitude were present in both ankles at shovel contact and maximum trunk flexion. In the left ankle, anterior shear was significantly greater in the left-loaded condition (82.99 N) than both the right-loaded and even-loaded conditions (56.89 N and 66.60 N respectively) (p = 0.01, $p \leq 0.01$). Anterior shear was also greater in the left-loaded condition than in the right-loaded condition at maximum trunk flexion. Extension moments were present in both ankles at both shovel contact and maximum trunk flexion. The right ankle was subjected to inversion moments while the left was subjected to eversion moments. Both ankles had external rotation moments in the magnitude of 3 Nm at shovel contact. Right ankle external rotation moments increased to 15 Nm at maximum trunk flexion whereas there was a slight internal rotation moment in the left ankle (< 2 Nm across conditions).

4.0 Discussion

The objectives of the study were: (1) to describe posture and joint reaction forces in the trunk and lower body during a simulated tree-planting task and (2) to examine the effects of symmetric and asymmetric tree-unloading strategies on posture and joint reaction forces in the lower limbs and trunk. The main findings were as follows: (1) during the planting cycle, maximum trunk flexion (representative of the posture assumed when the tree is planted in the ground) resulted in greater joint reaction forces and greater deviation from neutral posture across all joints than during any other part of the planting cycle, (2) right-loaded planting bags seemed to produce the most differences in posture and joint reaction forces, and (3) axial forces were greater in the right leg than in the left leg throughout the planting cycle regardless of loading condition .

4.1 Trunk

Lateral bending angles and rotation moments seem to be in the opposite direction of the loaded side of the body. This suggests that workers compensate for external loads by making postural adjustments in the opposite direction as the applied load. At maximum trunk flexion, the trunk was rotated to the right in all loading conditions. This could perhaps be due to postural constraints imposed by the shovel at maximal trunk flexion. The trunk must rotate to the right to compensate for the length of the shovel held in the right hand; therefore, a shorter shovel may result in less trunk rotation.

Although flexion moments in the trunk were much lower than values reported in the literature during lifting tasks (Hooper *et al*, 1998), rotation moments at maximum trunk flexion in the asymmetrically loaded conditions are similar to those reported during asymmetrical lifting tasks (45 and 90 degrees with 10 kg load), and lateral bending moments are larger than the same lifting task (93.39 Nm/kg vs 83 Nm/kg) (Hooper *et al*, 1998). These fairly large external moments are applied when the trunk is at a postural disadvantage to withstand them (flexed and rotated). In addition to lateral bending moments at maximum trunk flexion, the forward swing movement of the planting bags creates large anterior shear forces to the spine.

In-vitro studies suggest that the maximum compressive strength values for some vertebral segments may be even lower; less than 2500 N (Brinckmann et al, 1988; Jager and Luttman, 1989). Compression forces in the spine were estimated at both shovel insertion and maximum trunk flexion using a polynomial prediction equation designed to predict low-back compression during complex 3-D tasks (McGill et al, 1996). The third-order polynomial equation predicts compression based on flexion/extension, lateral bending and axial twisting moments as follows:

$$C = 1067.6 + 1.219F + 0.083F^2 – 0.0001F^3 + 3.229B + 0.119B^2 – 0.0001B^3 + 0.862T + 0.393T^2 – 0.0001T^3$$

Where C = Compression (N)
F = flexion-extension moment where negative values correspond to flexion (Nm)
B = lateral bending moment where bending to the right is positive (Nm)
T = axial twisting moment where CCW twist is positive (Nm)

Compression values were calculated for each subject at both shovel contact and maximum trunk flexion. Maximum flexion produced the highest mean compression values as follows in the *even-loaded*, *right-loaded* and *left-loaded* conditions respectively: 1936 N, 2092 N, and 2109 N suggesting that workers are approaching the biomechanical limit to failure and may be subject to disc herniation or vertebral fracture. .

Maximal trunk flexion during the tree-planting task has previously been recorded in the field using three different techniques – inclinometer, digital video, and inertial motion sensors. Each method produced slightly different results, with mean inclinometer and video data being the most similar (130 and 110 degrees with respect to global vertical respectively) (Upjohn *et al*, 2008). Mean maximum trunk flexion recorded by the inertial motion sensors was much smaller, at 50 degrees with respect to the global vertical (Upjohn *et al*, 2009b). Mean trunk flexion values recorded in this simulated planting task in a laboratory setting are fairly similar to those recorded by the inclinometer and digital video. Smaller values are likely due to laboratory constraints (camera placement, simulated terrain conditions). In a field setting, workers sometimes plant in lower ground than that on which they are standing, which would result in greater trunk flexion. In the lab, the simulated terrain was at or slightly above the platform on which the subjects were standing, perhaps decreasing the amount of trunk flexion required to plant the tree.

To decrease compressive loading of the spine and reduce risk of injury, workers (especially new planters) should be encouraged to spend as little cumulative time in trunk flexion as possible. The worker should aim to engage in only one flexion/extension cycle per seedling, and should return to an upright posture once the seedling is planted in the ground. Best practices may therefore include choosing the appropriate micro-site while in an upright posture, and clearing the micro-site of debris with the foot while remaining in an upright posture and using the shovel for support (Foot Screef), as opposed to clearing the micro-site with the hands while in a flexed or bent posture (Hand Screef).

4.2 Lower Body

Axial forces were greater in the right leg than in the left leg throughout the planting cycle regardless of loading condition. This suggests that the primary function of the right leg is to support the majority of the body weight and the load from the planting bags, while the left leg functions more as a stabilizer. During the task, subjects adopted a stance where the right leg was positioned in front of the body closest to the planting micro-site while the left leg was behind. It is possible that under different conditions in a field setting, this stance could have been reversed (due to environmental constraints, or depending on which hand the shovel is held in), in which case it is likely that the left leg would support the majority of the load. This stance also explains the greater hip flexion and anterior shear in the right hip than in the left at maximum trunk flexion. Left hip moments changed at maximum trunk flexion and ended up in extension, adduction and internal rotation moments, possibly to balance external rotation of hip at maximum trunk flexion and to stabilize the body as the trunk descends towards max trunk flexion to plant the tree. Although this study did not examine the walking in between the planting cycles, it has been suggested that asymmetric load carriage during gait increases abduction moment in the contra lateral hip (Matsuo *et al*, 2008), which, if sustained over time such as would be the case over the course of a workday, may increase lower limb joint stress and affect dynamic balance during gait (Matsuo *et al*, 2008).

Contrary to walking where the largest moment is the plantar flexor moment in the ankle at push off – about 2 Nm/kg of body weight (Winter, 2005), the largest moment in the planting cycle was the extensor moment in the right hip which was roughly twice as great as normative gait values. Conversely, plantar flexion angles in the ankle were about 1/3 to 1/4 of the normative values for gait. Abductor moments in the hip during the planting cycle were roughly half as large as during normal gait, while external rotation moments were more than twice as large (0.53 Nm/kg at max trunk flexion vs 0.2 Nm/Kg at toe off in gait).

4.3 Limitations and future studies

Tree-planting is a complex dynamic task that takes place in ever-changing environmental and terrain conditions. A simulated lab environment tends to oversimplify the task and perhaps underestimate the forces and postures required in tougher, outdoor terrain. Due to the nature of the task, it is challenging to obtain joint reaction forces data in the field; therefore simulating the task in the lab seems to be a suitable alternative. This study recorded a relatively small number of planting cycles (30) as compared with up to 3000 planting cycles over the course of a workday in the field, thus cumulative loading due to bending motions are likely to be much greater than what was captured in this study. In order to more accurately record cumulative loading in the spine, future studies could use an EMG assisted model to track muscle activity and fatigue over the course of a full work shift. Due to technical constraints, this study focused primarily on joint reaction forces in the lower body and trunk. Ideally, whole body posture and joint reaction forces should be considered to best understand body mechanics during this challenging task. It would also be beneficial to quantify loading in-between the planting cycles while walking from one micro-site to the next over rough terrain. This element of the job may be just as biomechanically challenging as the planting cycle itself, substantially contributing to risk of musculoskeletal injury. Although significant differences in angles, forces and moments were found between loading conditions, many are relatively small and may not be biologically significant. The body is under a lot of biomechanical strain during tree-planting, which is fairly difficult to quantify and compare to existing literature because of the complexity of the task and the differences in the way the body is loaded compared to lifting and bending tasks. We feel that the best comparisons are most likely those noted in the above discussion in asymmetrical bending and lifting tasks.

4.4 Relevance to Industry

The point at which the tree is inserted into the ground produced greater joint reaction forces and non-neutral postures than at any other point in the planting cycle, suggesting that it is at this point in the cycle that workers are at most risk for injury. Therefore, to decrease risk of injury workers should avoid assuming this posture for any prolonged period of time. Workers' best practices would therefore include clearing the micro-site of debris with the foot in an upright standing posture while using the shovel for support (Foot Screef), as opposed to clearing the micro-site with the hands while in a flexed or bent posture (Hand Screef). Other techniques to minimize the degree of trunk flexion include adopting a combination stoop-squat posture when planting the tree instead of a stoop-only posture.

5.0 Conclusions

Trunk and lower limb posture and joint reaction forces were quantified during three loading conditions in a simulated tree-planting task. Greatest joint reaction forces and non-neutral postures occur when the tree is inserted in the ground, therefore this posture should be assumed for as little time as possible during the task. Right-loaded planting bags seemed to produce the most differences in posture and joint reaction forces, suggesting that it may be worse to carry the load on the right side of the body than the left side of the body or evenly across the body. Axial forces were greater in the right lower limb than the left lower limb throughout the planting cycle regardless of loading condition, suggesting that the right leg functions primarily as the load-bearing limb while the left leg functions primarily as a stabilizer.

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Chapter 6 : Wrist Postures in Tree-planters during Three Tree-Unloading Conditions

Abstract

Wrist pain is one of the primary musculoskeletal complaints in tree-planters. The principal contributors to musculoskeletal pain are known to be force, repetitive movement and awkward postures. The aims of this study were: (1) to investigate postures in the wrist while operating the shovel during the tree-planting task and (2) to determine if different tree unloading techniques result in variations in wrist postures at specific events during the tree-planting task. Experienced tree-planters performed the tree-planting task in a simulated laboratory environment 10 times for each of three loading conditions (even-loaded planting bags, right-loaded planting bags and, left-loaded planting bags). Wrist posture was captured by an optotelectric system. The wrist was nearly fully pronated and in ulnar deviation of up to 40 degrees throughout the planting cycle with varying degrees of flexion and extension. Combinations of ulnar deviation and forearm pronation may be a primary risk factor for the musculoskeletal pain experienced by workers as the work season progresses. No differences in wrist posture existed between loading conditions suggesting that the wrist is not affected differently by either symmetric or asymmetric unloading strategies commonly used by workers.

1.0 Introduction

Work related musculoskeletal disorders of the upper extremities are common in industrial workers and are known to be caused primarily by some combination of force, posture and level of repetitiveness of job tasks (Putz-Anderson, 1988 – from Cary and Gallwey, 2002). Silviculture workers in the forestry industry - more commonly known as tree-planters, are likely to experience a combination of force, awkward postures of the upper body and repetitiveness in their job tasks. Thus it is not surprising that wrist pain is one of the primary musculoskeletal symptoms among workers (Lyons, 2001; Tree-planter.com, 2008; Upjohn et al, 2009a), being significantly worse at the end of the season then the beginning of the season (Upjohn et al, 2009a).

Many diseases and disorders of the wrists and hands are associated with repetitive manual work (Muggleton et al, 1999) and anecdotal evidence suggests that the most common tendon disorder among tree-planters is what is often referred to by workers as 'the claw' or 'claw hand'. Many workers believe that this particular disorder is due to the repetitive trauma to the palmer side of the hand when the shovel contacts the ground with over 500 N of force thousands of times per day (Dumas, 2009). However, 'claw hand' can also be caused by pinching of the ulnar nerve just distal to the elbow, perhaps caused by repeated flexion/extension movements combined with pronation and supination of the forearm (Upjohn et al, 2008). High angular velocity and range of motion in the elbow during planting (Upjohn et al 2009b) could also cause the numbness in the wrist and hand due to ulnar neuropathy or nerve entrapment at the elbow (Dawson, 1993).

Externally applied forces to the palm such as are common in the tree-planting task can also increase carpal tunnel pressure, potentially leading to carpal tunnel syndrome (Cobb et al, 1995).

Notwithstanding the force at which the ground is impacted with the shovel, the repetitiveness of the task may be an even greater risk factor for wrist injury (Silverstein et al, 1986). High angular velocity of the wrist in combination with repetitiveness of the task likely contributes to the high prevalence of injury among some industrial workers (Arvidsson et al, 2003). Tree-planters plant an average of 9 trees per minute or 450 trees every 50 minutes, followed by a 10-15 minute break to re-load their planting bags before beginning the cycle again. This pattern continues for a 9-10 hour workday, resulting in upwards of 3000 trees planted per workday for an experienced planter (Upjohn et al, 2009b).

One aim of this study is to investigate postures in the wrist during operation of the shovel during the tree-planting task in an attempt to determine whether there are extreme postures or postural combinations that may contribute to the pain and discomfort in planters that occurs as the work season progresses. The second aim of the study is to determine if different tree unloading techniques result in variations in wrist postures at specific events during the tree-planting task.

2.0 Methods

2.1 Overview of Study

A repeated measures design was used to study the effect of three tree unloading conditions on wrist posture during the tree-planting task. The tree-planting task was simulated in a lab setting using a sand box filled with dense sand and rocks, representative of soil found in parts of Northern Ontario. The sand box was located at the end of an elevated walkway. Participants performed the planting task 10 times under each of following three loading conditions, in randomized order: (1) planting bags loaded evenly to the left and right sides – *even-loaded*, (2) planting bags loaded only on the right side – *right-loaded*, and (3) planting bags loaded only on the left side – *left-loaded*. Wrist posture was captured by two Optotrak® bars located to the front-right, and back-right of the calibrated task area and digital video was collected as a visual representation of the task.

2.2 Participants

Twenty participants (12 female, 8 male; age 21.4 ± 2.0 yrs, height 175.3 ± 8.2 cm, weight 72.0 ± 10.0 kg) from the Queen's University student community volunteered to participate in the study. Participants were right handed, had a minimum of one season's tree-planting experience and had no musculoskeletal disorders or pain at the time of testing. Ethics approval was obtained from the Queen's University Health Sciences Research Ethics Board, and participants gave written informed consent prior to participation.

2.3 Data Collection

Data were collected in the Motor Performance Laboratory in the School of Rehabilitation Therapy at Queen's University in Kingston, Canada. Right wrist posture was measured using an optoelectric system (Optotrak®, Northern Digital Inc., Waterloo) with two bars located midway between the frontal and sagittal planes to the front and to the rear of the participant. The task area was calibrated statically and dynamically using the Optotrak® Cube® prior to data collection. Rigid clusters containing three infrared emitting diodes (IREDs) were custom made using rapid prototyping and were placed on the participants' right forearm, right hand, and shaft of the shovel just distal to the handle (Figure 6-1). Anatomical landmarks were digitized on each segment with the Optotrak® probe to relate the position of the clusters to the bones. These landmarks included the medial and lateral elbow and wrist, the distal end of the 2^{nd} and 4^{th} metacarpals, and the shovel, which was landmarked at the right and left kick plate and handle. Landmarks were digitized prior to the planting tasks. The positions of the rigid clusters were recorded using ToolBench software (Northern Digital Inc., Waterloo) at a rate of 50Hz for 10 seconds per planting task trial. A total of 30 trials were recorded for each participant with 10 trials per condition. All participants used the same unmodified D-Handle tree-planting shovel to perform the task (*Highballer Stainless Steel Shovel* from Bushpro Supplies Inc. blade weight - 1.89 lbs , blade length 9" x 4 1/2" wide, shovel length from tip to top of handle - 37.5").

Figure 6-1: Clusters of Infrared Emitting Diodes (IRED) on the right forearm, dorsal surface of the hand, and shovel.

2.4 Data Processing

Data were processed using Visual3D Software for 3D motion analysis (C-Motion, Kingston, Canada). Data were interpolated and filtered using a low-pass Butterworth filter with a cut-off frequency of 2.8 Hz determined by residual analysis. Angles were exported from Visual3D to Excel at the following events for each trial: (1) shovel at highest vertical position, denoting the start of the planting cycle, (2) shovel contact with 'ground', (3) maximum trunk flexion, also representative of planting of the tree, and (4) return to standing position (Figure 6-2). As in Chapters 3-5, events were chosen because they were thought to be the points during the task that put the most biomechanical stress on the body, and they define the planting cycle from start to finish.

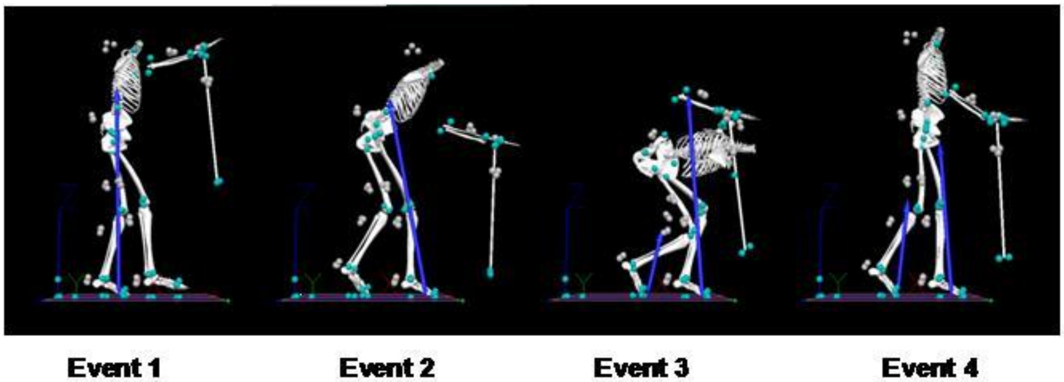

Figure 6-2: Representative planting cycle events in Visual 3D.

Event 1: Start of planting cycle (shovel at highest vertical point); Event 2: Shovel impact with ground; Event 3: Maximal trunk flexion; Event 4: End of planting cycle (return to upright posture).

2.5 Statistical Analyses

A one-way repeated measures ANOVA was used to determine significant differences in flexion, deviation and forearm pronation angles between unloading conditions for the right wrist. Data analyses were performed using SPSS 15.0 (Chicago, USA) and statistical significance was set to $p \leq 0.05$.

3.0 Results

Right wrist flexion, deviation and rotation angles were fairly consistent across conditions with no significant differences between conditions at any event during the planting cycle. Representative wrist flexion, deviation and forearm pronation are presented in Figure 6-3.

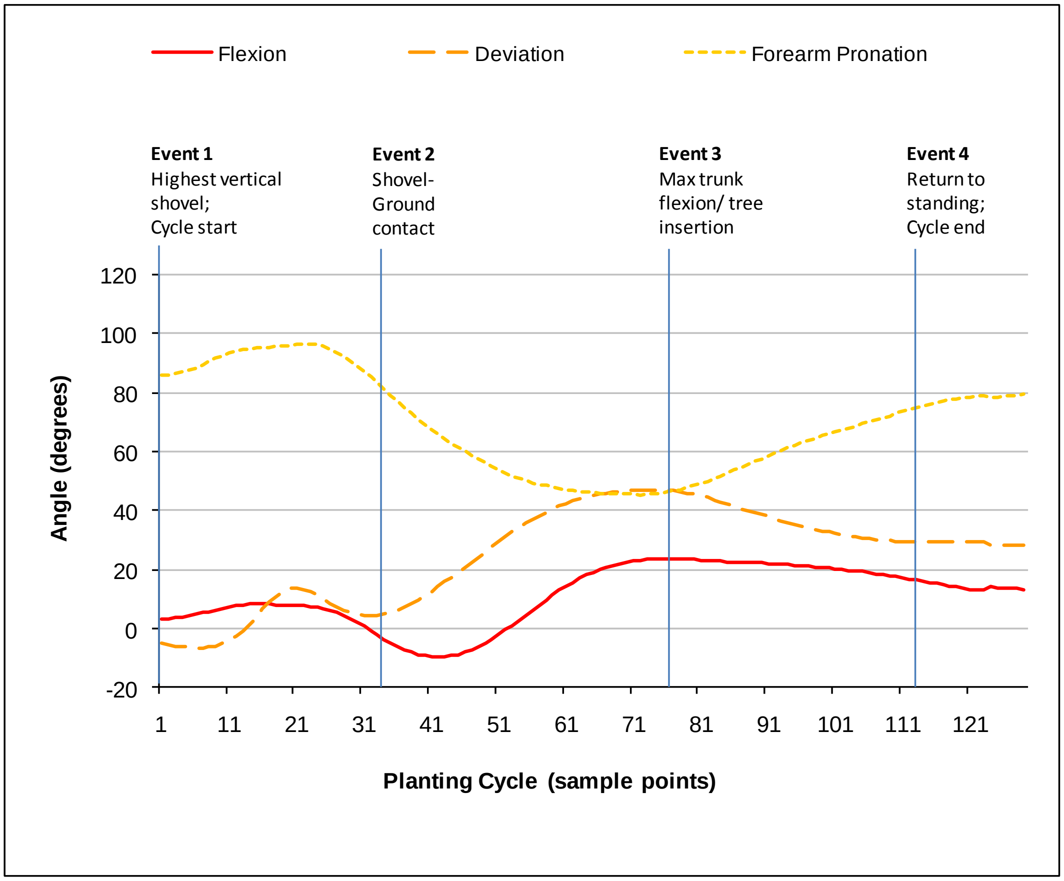

Figure 6-3: Representative right wrist flexion, deviation and rotation for one full planting cycle.

Data are from a single subject averaged over 10 planting cycles in the evenly loaded condition. Where wrist extension, ulnar deviation and forearm pronation are positive angles. Sample frequency was 50 Hz.

When the shovel was at the highest point before ground contact, the right wrist was in slight flexion (< 5 degrees) with almost no deviation (≤ 1 degree). Forearm pronation exceeded 90 degrees across conditions (Table 6-1).

At shovel contact, flexion increased slightly to just less than 10 degrees across conditions and the right wrist was deviated less than 5 degrees to the left. Forearm pronation remained constant at just less than 90 degrees (Table 6-1).

At maximum trunk flexion, when the tree was inserted into the ground, the wrist was somewhat extended (< 5 degrees of extension), in 15 degrees of ulnar deviation, and in 90 degrees of pronation.

Upon return to standing, the wrist was extended between 5 and 10 degrees (slight variation between loading conditions but no significant differences) (Table 6-1), in 45 degrees of ulnar deviation, and 78 degrees of pronation.

Representative wrist flexion, deviation and rotation across conditions (even, right and left-loaded) are presented in Figures 6-4, 6-5 and 6-6 respectively.

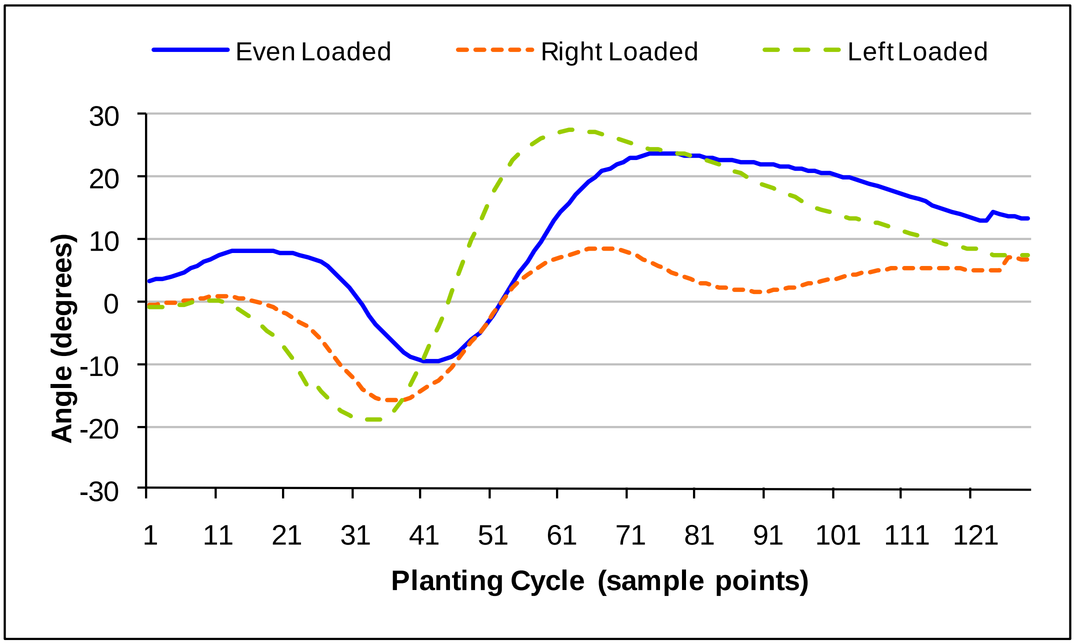

Figure 6-4: **Representative right wrist flexion in one subject across conditions for a full planting cycle.**

Where extension is positive and flexion is negative. No significant differences were found between conditions. Sample frequency was 50Hz.

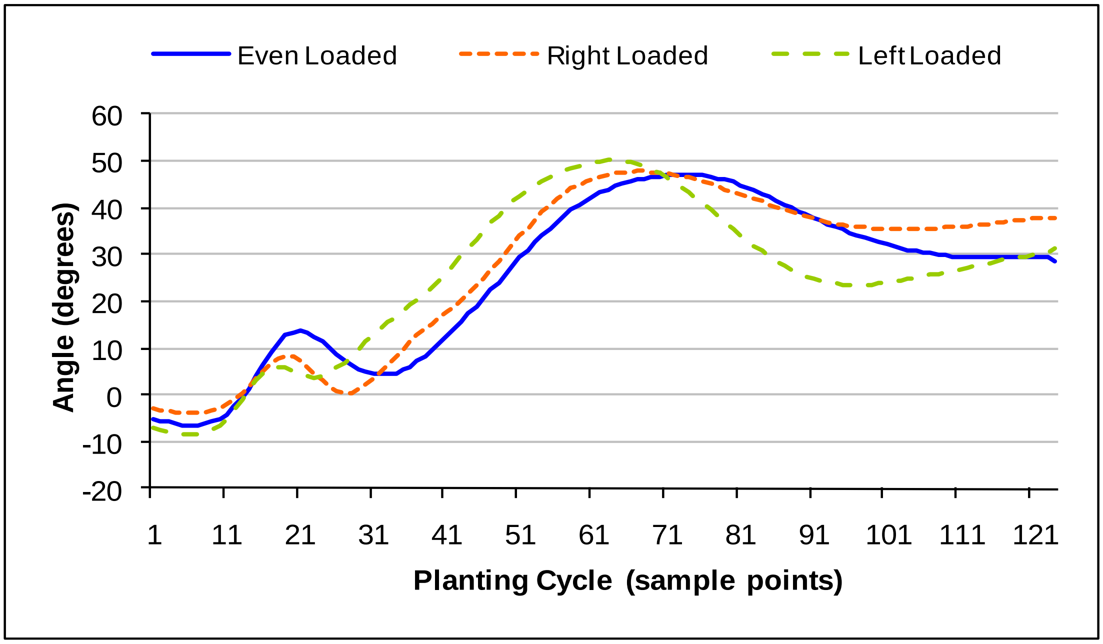

Figure 6-5: Representative right wrist deviation in one subject across conditions for a full planting cycle.

Where ulnar deviation is positive. No significant differences were found between conditions. Sample frequency was 50Hz.

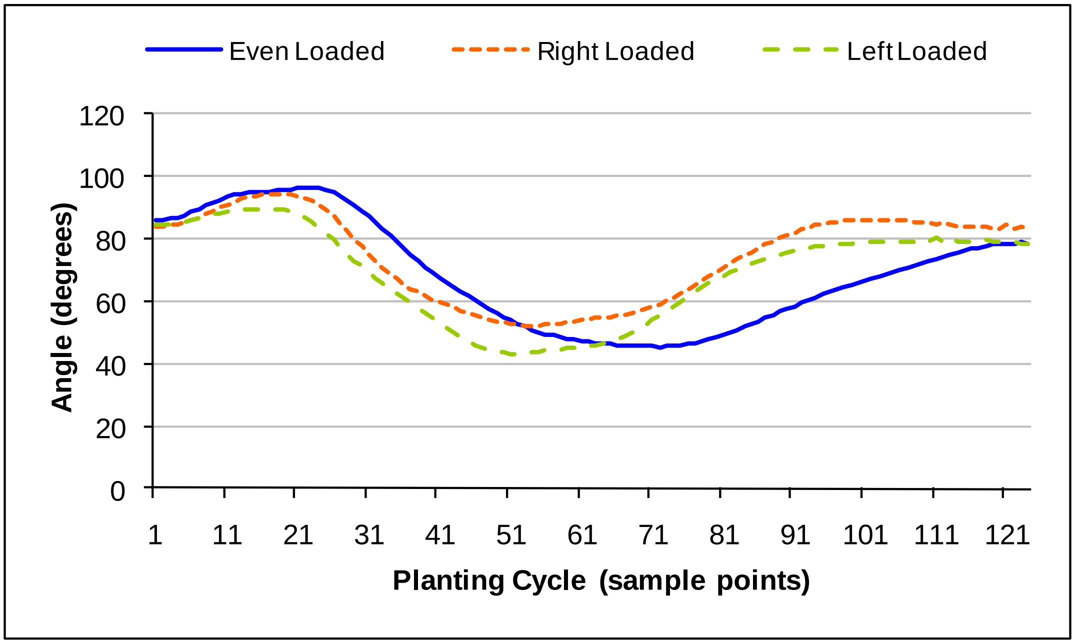

Figure 6-6: Representative right forearm rotation with respect to the hand in one subject across conditions for a full planting cycle.

Where 0 degrees is fully supinated and pronation is positive. No significant differences were found between conditions. Sample frequency was 50Hz.

Table 6-1 Right wrist angles in the X, Y and Z directions for events 1 through 4 of the planting cycle in the *even, right and left-loaded* conditions.

X is the medial-lateral axis (flexion angle), Y is the antero-posterior axis (deviation angle), and z is the longitudinal axis (rotation angle). Joint angles are relative (hand with respect to forearm). No significant differences existed between loading conditions. Event 1- beginning of the planting cycle (shovel at highest vertical point); Event 2-shovel impact with ground; Event 3-maximal trunk flexion (representative of tree insertion); Event 4-end of planting cycle (return to upright standing position).

		ANGLES (sd)(degrees) n=18		
	Event	**Even**	**Right**	**Left**
X-Flexion	1	2.37 (12.47)	4.16 (9.17)	3.46 (11.45)
	2	6.53 (12.57)	7.89 (8.60)	6.67 (11.18)
	3	-2.24 (9.55)	-0.53 (8.04)	-2.17 (9.60)
	4	-8.60 (23.34)	-4.29 (22.53)	-6.86 (22.60)
Y-Deviation	1	0.07 (12.23)	1.05 (11.68)	0.85 (14.42)
	2	-2.06 (16.10)	-2.24 (12.53)	-5.15 (15.38)
	3	13.99 (11.95)	15.50 (12.27)	14.78 (13.61)
	4	42.04 (20.57)	46.03 (14.64)	45.73 (18.63)
Z-Pronation	1	93.44 (21.40)	92.78 (19.70)	95.36 (21.10)
	2	89.86 (20.97)	88.51 (20.25)	90.32 (20.14)
	3	94.47 (23.50)	90.74 (26.75)	90.75 (24.17)
	4	79.61 (35.22)	78.78 (27.34)	77.55 (33.03)

4.0 Discussion

The goals of the study were first to examine wrist postures during the planting task and determine if extreme wrist postures or some postural combinations may contribute to wrist pain and discomfort, and second to determine if the way planters unload their trees from their planting bags affects wrist posture.

The right wrist was in varying degrees of ulnar deviation throughout the planting cycle, always combined with either wrist flexion or extension up to 20 degrees as well as full pronation of the forearm. Wrist deviation exceeded 40 degrees in parts of the planting cycle, which may be a risk factor for the musculoskeletal pain that develops as the work season progresses (Upjohn et al, 2008). Deviation of over 25% of maximum range of motion has been shown to significantly increase wrist discomfort during repetitive exertions (Carey and Gallwey, 2000; Carey and Gallwey, 2002) and discomfort may increase significantly when wrist deviation increases from 35% range of motion to 50% range of motion (Carey and Gallwey, 2000).

In addition to increasing discomfort, deviated wrist postures may decrease grip strength. Changes of only a few degrees from self-selected wrist deviation may result in decreased grip strength (O'Driscoll *et al*, 1992). Wrist extension of only 15 degrees may also result in a substantial decrease in grip strength (2/3 of normal grip strength) (O'Driscoll *et al*, 1992). It is therefore possible that given the combination of wrist deviation and extension during the planting cycle, the strength at which planters are able to grip their shovel may be substantially less than if the shovel were gripped with a neutral wrist posture.

Many of the wrist postures during the task may be due to a motion referred to as a 'c-cut' to open a hole in the ground to plant the tree. In this motion, the shovel arm is fully extended forward after ground contact (defined as event 2 here), then brought back around to the core of the body in a sweeping side arc. This motion creates a pie-shaped hole where the tree is inserted at the apex of the pie (defined as event 3 here). When the hole is closed, a tight seal is formed around the tree so as not to create an air pocket. This kind of hole is encouraged to increase the tree's survival chances. A back and forth movement can also be used to create a hole, but this is often discouraged as it creates an air pocket at the bottom of the hole and decreases the tree's chances of survival. From an ergonomic standpoint, the wrist postures used during the back and forth motion likely place less strain on the wrist than those used during a typical c-cut. Future studies would be wise to investigate differences in wrist postures during different hole opening techniques.

The shovel used in this study was the Highballer Stainless Steel D-Handle by Bushpro. Many variations in shovels exist but this particular shovel was selected for the study because it has a D-Handle which is the most common handle type used by tree-planters. Ergonomic shovel handles have been developed by various companies in an attempt to place the wrist in a more neutral posture during the planting task (for example the *Ergo D Handle* by Bushpro). These handles are similar to the classic D-Handle shape, but with a sloped top handle designed to decrease forearm pronation and put the wrist in a more neutral posture. Anecdotal evidence reports that this shovel has been met by mixed reviews by the tree-planting community. Some planters feel that when the shovel contacts the ground, the sloped handle causes the majority of the force to be transferred solely to the ulnar side of the palm, increasing discomfort and potential for injury. Some of these handles are also mounted on the shaft at a slight angle to the blade to encourage less twisting of the wrist while opening the hole in the ground. These shovel handles may not decrease ulnar deviation, which may be one of the primary contributing factors to pain and discomfort of the wrist. The staff shovel is used to a lesser extent than the D-handle shovel. To grip the staff shovel, the worker simply grips the longer shaft with a power grip at a height that is comfortable for them. The staff shovel promotes a more neutral wrist posture, putting the wrist mid-way between pronation and supination. It may also result in less ulnar deviation than the D-handle shovel; it also allows the worker to control his or her grip on the shovel when it enters the ground, likely decreasing the impact force to the wrist. Future studies may wish to investigate differences in planters'wrist postures while using a variety of shovel handles.

When compared with wrist data collected during the same task and loading conditions in a field study (Upjohn et al, 2009b), data collected in the laboratory showed similar postural patterns but also some notable differences. During the lab task, the wrist was primarily in ulnar deviation, which is consistent with field data that reported maximum ulnar deviation values in excess of 25 degrees, while radial deviation was reported to be fairly small, between 10 and 15 degrees. These values are smaller than those found in the current study. Wrist flexion/extension showed some notable differences between field and lab data. Field data showed wrist extension throughout the cycle, at times in excess of 40 degrees (Upjohn et al, 2009b). These values are 20 degrees larger than those reported in the lab data. This discrepancy may be due to different instrumentation used. In the field study inertial motion sensors were placed oriented along the long-axis of the hand and forearm and values reported were representative of the angular difference between the two sensors. Although care was taken to place the sensors as accurately as possible on the subject segments, there could have been an offset due to skin movement or a slight shift in sensor position. In the present study, reported values have been corrected to represent the differences between the bones themselves.

Significant differences in wrist postures found between loading conditions in the field study were not reproduced in the current lab study. Rationale for the differences between conditions in the field study was that workers may lean on the shovel in the un-evenly loaded conditions to help balance the load. Due to the small number of samples collected (trees planted) in the lab study, planters may not have been sufficiently fatigued to have needed to lean on the shovel for either support or balance at the time of the study. If a larger number of samples had been collected in the lab, similar postural differences between loading conditions may have been reproduced.

4.1 Limitations

In this study, the effect of fatigue was not accounted for: subjects only planted 10 trees in each condition for a total of 30 trees during the data collection session. On the other hand, over the course of a workday tree-planters may plant up to 3000 trees, at which point wrist posture may change due to forearm muscle and wrist joint fatigue caused by repetitive wrist motions and repeated force to the palmer aspect of the hand.

The study did not look at joint reaction forces in the wrist, a key contributing factor to the development of MSIs. This will be the subject of future work.

5.0 Conclusions

The right wrist (used to operate the shovel) was in ulnar deviation and nearly full forearm pronation throughout the tree-planting task. These postural combinations in conjunction with fluctuating wrist flexion and extension may be a primary contributor to the development of musculoskeletal pain and discomfort that occurs as the work season progresses. Wrist posture may be due in part to the type of shovel used, and/or upper body motion during a c-cut. In this study, tree unloading conditions produced no significant differences in wrist postures. Future research is needed to quantify wrist postures and forces while using different varieties of shovels and hole-opening techniques.

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Chapter 7 General Discussion

The focus of this dissertation has been to identify the biomechanical mechanisms that contribute to the musculoskeletal injuries sustained by tree-planters over the course of the work season. Due to its focus on occupational biomechanics, this research has resulted in some key ergonomic implications for industry – these are considered and discussed below. Limitations of the research are discussed as well as possible directions for future studies.

1.0 The culture of Tree-planting

I've spent many summers in Northern Ontario and Manitoba as a tree planter and it is both the most challenging and most rewarding occupation that I've ever worked. When I describe the work to friends and colleagues, the most prominent reaction is 'why would you ever go back'? And yet I did. Each summer through my undergraduate and master's degrees I went back. I struggle a little to try to explain why and it usually comes down to the culture. It's the culture of tree-planting that I love. I have formed countless friendships – many lifelong friendships – that are simply invaluable to me. A tree-planting camp is a tight knit group of people of the same age working and living together. While values, interests and political views differ within each camp, each worker is performing the same job tasks and working towards the same end goal – to plant all the tree seedlings awarded to their contract. Bonds are formed quickly and easily within a camp and tree-planters from across the province and across the country will always find common ground to walk on. Tree-planters have a strong work ethic; without a strong work ethic, you will not succeed. Tree-planters learn and retain information quickly and can work with anyone. Tree-planters take a team approach to work and camp life, are able to adapt to changing work environments and working conditions and have learned to deal with the physical discomfort associated with the job.

The second component of the Tree-planting culture is driven by competition and monetary gain. A superior tree planter can earn up to $10 000 in just a couple of months working for a good reforestation company on a good contract. That money goes a long way towards paying for university tuition or travel abroad. Given that there are a finite number of trees awarded in a contract, the competitive worker strives to take the biggest piece of the pie possible – to plant the most trees possible and earn the greatest reward. Thus, there is usually competition among the 'hiballers' in the camp. For these workers, the occupation could be likened to Sport. Sport is commonly defined as "an organized, competitive, and skillful physical activity requiring commitment and fair play. It is governed by a set of rules or customs. In a sport the key factors are the physical capabilities and skills of the competitor when determining the outcome". (Wikipedia, 2010) Good workers are extremely competitive, if not with others, then at least with themselves. They enjoy a challenge on a daily or even hourly basis. "Most hiballers will tell you that the single most driving force behind their success is the drive to beat either their own daily record or that of their colleagues" (Tree-Planter.com, 2010). It is this competitive drive that may contribute to musculoskeletal injuries in workers from a psychosocial perspective.

2.0 Linking Research to Reality: Etiology for Injuries and Suggestions for Change

This research has provided a good biomechanical description of the tree-planting task. But what implications do the occupational biomechanics of tree-planting have on the development of injuries? Unfortunately, although injury data from the Ontario Forestry Safe Workplace Association and the WSIB confirm that the majority of injuries are musculoskeletal injuries, no specific injury data are reported or documented. We don't know whether a reported injury was a vertebral fracture, disc injury (bulging disc, herniation, protrusion, extrusion or sequestration), wrist fracture, carpal tunnel syndrome or DeQuervain's syndrome, or any number of other musculoskeletal injuries. However, given epidemiological and biomechanical evidence for injury, we can reasonably conclude that tree-planters are likely to experience certain injuries based on their biomechanics during the work cycle.

2.1 Back Injuries

Back injuries are common among industrial workers. The most common back injuries are vertebral fractures, and disc injuries (herniation, protrusion, bulging disc etc) though chronic overuse or trauma to the low back may also inflame pre-existing or genetic conditions in young athletic populations that may otherwise remain asymptomatic (ie spondylolysis and spondylolisthesis) (Whiting and Zernicke, 2008). Disc herniations are the most commonly studied injury from a biomechanical perspective, so this discussion will focus mainly on these injury types. However, radiographic evidence suggests that 6% of the population suffers from some form of disc slippage, or spondylolisthesis which is aggravated by the type of repeated loading experienced by tree-planters, and thus will be discussed in short here. Spondylolisthesis is of particular interest to me. My brother, who worked as a tree planter for several seasons can directly attribute his pain and discomfort to the biomechanics of the job. Spondylolisthesis is caused or aggravated by repeated loading of the pars region, causing micro-fractures and eventual bone failure. Specific mechanisms responsible for this failure or defect are repetitive spinal flexion, combined flexion and extension, forcible hyperextension and lumbar spine rotation (Whiting and Zernicke, 2008). In addition, disc slippage between adjacent vertebrae is greatest with combined lateral bending and torsion moments. From inclinometer data (Chapter 3) we know that deep trunk flexion (over 100 degrees) and lateral bending in excess of 30 degrees to both the left and right occur simultaneously over 2600 times per day. Data also showed that 90^{th} percentile trunk rotation to both the left and right exceeded 50 degrees. This spinal rotation, combined with repeated flexion/extension put the worker at risk for development or aggravation of pre-existing spondylolisthesis.

Intervertebral disc pathologies are generally caused by one or any combination of the following mechanisms: spinal compression, torsional loading, and tensile stresses. Herniations of the intervertebral discs often occur in the posterolateral direction (Adams and Hutton, 1982; Callaghan and McGill, 2001), resulting in impingement of a nerve root and consequential pain in the back, buttocks, thigh, lower leg and possibly foot (Whiting and Zernicke, 2008). This pain is often referred to as low back pain.

Flexion and Disc Injury

The point at which the tree is inserted into the ground seemed to produce greater joint reaction forces and non-neutral postures than any other point in the planting cycle. Video data indicated that at this point, trunk flexion with respect to the global vertical exceeded 100 degrees, while inclinometer data indicated that 90^{th} percentile trunk flexion exceeded 130 degrees. Estimated compressive forces in the spine at tree insertion averaged over 2000 N. In-vitro studies suggest that the maximum compressive strength values for some vertebral segments may be less than 2500 N (Brinckmann et al, 1988; Jager and Luttman, 1989), suggesting that compressive spine forces during tree planting put the worker at risk for disc or intervertebral segment failure.

These data may be of particular interest to the new planter or 'Greener'. The Greener is less adept than the experienced planter at finding a suitable micro-site to plant the seedling. It will often take the Greener several attempts to find an appropriate spot, resulting in either several flexion/extension cycles to plant a single seedling, or an extended period of time may be spent in trunk flexion poking around for the right spot. This is both inefficient and biomechanically stressful. Both compressive loading of the spine and cumulative time spent in trunk flexion during the workday are increased.

To decrease compressive loading of the spine and reduce risk of injury, workers (especially new planters) should be encouraged to spend as little cumulative time in trunk flexion as possible. The worker should aim to engage in only one flexion/extension cycle per seedling, and should return to an upright posture once the seedling is planted in the ground. Best practices may therefore include choosing the appropriate micro-site while in an upright posture, and clearing the micro-site of debris with the foot while remaining in an upright posture and using the shovel for support (Foot Screef), as opposed to clearing the micro-site with the hands while in a flexed or bent posture (Hand Screef).

I have often heard that the best 'hiballers' plant by running between micro-sites while bent, or stooped. While this posture may be time efficient in the interim, I don't believe the permanent consequences to spine health are worth the monetary gain. This posture can only be maintained for so long before low back pain and muscle soreness and stiffness begin to develop. In fact, what I've often experienced are those planters who go hard one day to plant 4500 trees, and the next day are so sore and tired that they plant only 1500 trees. In my experience it is better to take the approach of the proverbial Turtle – slow and steady wins the race; both in numbers and in long term health.

Other techniques to minimize trunk flexion include adopting a combination stoop-squat posture when planting the tree instead of a stoop-only posture.

Axial Rotation/Torsion and Disc/Facet Injury

Axial rotation or *torsion* has been identified as an indicator of low back pain and development of low back injuries in epidemiological studies (Marras et al 1993). When combined with flexion/extension cycles, torsion significantly increases risk for injury. When tested in-vivo (porcine model) repetitive flexion extension motions combined with moderate compressive force (1472N) and 5Nm of axial torque produced significantly greater numbers of facet fractures than flexion/extension motions combined only with compression (Drake et al, 2005). It is also interesting to note that repetitive in-vitro loading of the spine when in flexion may increase inter facet angles and twist angle, allowing for a greater degree of torsion when the trunk is in a flexed posture than when in an upright posture (Drake et al, 2008). When measured in-vivo, lumbar spine stiffness and rotational range of motion were modified by the degree of flexion and extension. Similar to in-vitro measurements, when measured in-vivo, lumbar spine range of motion in the rotation axis is significantly greater in maximum trunk flexion than in trunk extension (Drake and Callaghan, 2008). The magnitude of flexion or extension and lateral bend angle adopted influenced torsion stiffness (Drake and Callaghan, 2008).

Maximum axial rotation in the trunk during the planting task was approximately 50 degrees to both the left and the right when recorded with the inertial motion sensors in the field (Chapter 4), while lab data showed rotation angles of approximately 30 degrees to the right when the trunk was at maximum trunk flexion (tree insertion) (Chapter 5). Axial rotation was combined with up to 50 degrees of relative trunk flexion (Chapter 4) and some lateral bending (relative lateral bend angles of approximately 3 degrees while flexed and rotated – Chapter 5). Given these postural combinations, the dynamic nature of the job and the epidemiological evidence linking axial torsion to low back pain, it is fair to say that tree-planters are at risk for developing low back disorders. Because of the torsional component of the tree-planting motions and the orientation of the facet joints, facet fractures may occur, in addition to intervertebral disc injuries, commonly caused by repeated flexion/extension motions and compressive loading.

Lateral Bending and Disc Injury

Lateral bending has been identified as a risk factor for low back disorders. Specifically, lateral spine loading increases the risk of scoliosis (Noone et al, 1993) and when coupled with trunk flexion and axial rotation, lateral bending increases the risk of low back pain (Fathallah, 1995; Haas and Nyiendo, 1992). Lateral bending requires both agonist and antagonist muscle co-contraction in the trunk to balance bending moments. This co-contraction results in significant compressive penalty to the spine, adding to overall compressive loads due to flexion/extension and axial rotation motions. Inclinometer data (Chapter 3) suggest that during the tree-planting task, lateral bending upwards of 30 degrees happened concurrently with trunk flexion (up to 130 degrees) as the planter bends down to insert the seedling into the ground. These postures, in combination with the axial rotation and flexion described above, increase risk of disc herniation and similar low back disorders.

2.2 Wrist Injuries

Carpal tunnel syndrome is a condition characterized by swelling within the carpal tunnel that creates a compressive neuropathy affecting the median nerve (Whiting and Zernicke, 2008). Inflammation and edema due to repetitive loading lead to compression of the median nerve, resulting in numbness, tingling, burning and pain in the wrist and radial fingers. Symptoms of carpal tunnel syndrome are associated with specific movement patterns and tasks – for example repeated flexion and extension of the wrist (Whiting and Zernicke, 2008). Epidemiological literature provides evidence for a relationship between exposure to combinations of force and repetition, or force and posture and the development of carpal tunnel syndrome and other work related musculoskeletal disorders of the wrist, such as wrist tendinitis, or DeQuervain's tenosynovitis (Barr et al, 2004).

Inclinometer data from chapter 3 show that tree-planters plant over 2600 trees per day and each planting cycle can take as little as 4.6 seconds to complete. In the span of 4.6 seconds the wrist goes through a series of motions including movement through over 40 degrees of deviation (from a neutral position to 46 degrees of ulnar deviation), and approximately 40 degrees of flexion/extension. Deviation of over 25% of maximum range of motion has been shown to significantly increase wrist discomfort during repetitive exertions (Carey and Gallwey, 2000; Carey and Gallwey, 2002) and discomfort may increase significantly when wrist deviation increases from 35% range of motion to 50% range of motion (Carey and Gallwey, 2000). Normal range of motion for radial and ulnar deviation is approximately 20 and 35 degrees, respectively (e-hand.com, 2010) whereas normal wrist extension/flexion range of motion is 70 and 75 degrees respectively. While the wrist moves through a relatively small range of motion in the flexion/extension plane, wrist deviation in the ulnar direction exceeded the normal maximal range of motion, likely significantly increasing discomfort. Given the repetitive work, short work cycles (~ 4.6 seconds), and combinations of wrist flexion and ulnar deviation, it is reasonable to expect that tree-planters will develop carpal tunnel syndrome or other compressive neuropathies of the wrist. In fact, many of my tree-planting colleagues, not to mention myself have indeed experienced numbness, tingling, burning and pain in the wrist and fingers, typical of compression of the median nerve, indicative of carpal tunnel syndrome.

In more recent years it has become common practice for new planters to learn how to use the shovel with both hands. Though this practice may slow the planter down in the beginning, ambidextrous planting should decrease strain on the dominant wrist and therefore decrease the chance of developing wrist pathologies such as carpal tunnel syndrome.

In Chapter 4 it was suggested that perhaps planters use the shovel as an assistive aid when standing up from the bent position after planting a tree. One of the bases for this postulation is that of personal experience. I have found that especially as the day progresses, I became increasingly tired and though my biomechanics may not have changed, the way in which I performed the task and loaded/unloaded my joints seemed to change. For example, near the end of the day, I relied more and more on my shovel as a means for support, both while planting and while walking between micro sites to steady myself over uneven terrain. This has yet to be verified, but if this is indeed the case, the shovel provides a similar service as a cane in assisted ambulation and thus should be treated as such and tailored to the individual's height to provide maximal support. Ideal length of a cane should produce an elbow flexion angle between 20 and 30 degrees for optimal force transmission through the cane during normal gait. To achieve such an angle, the length of the cane should be measured from the floor to the distal wrist crease, or by the following formula: $L = H \times 0.45 + 0.87$ meters or $L = A \times 0.76 + 0.19$ meters, where H is the height of the individual and A is the arm length measured in meters (Kumar et al, 1995). Therefore, when a planter purchases a shovel, it should be tailored to his or her specific height (distal crease of the wrist) prior to use to provide maximal support during the task.

2.3 Summary of Suggestions for Reducing Injuries

As noted in 'The Culture of Tree-Planting', many workers are driven largely by monetary gain and they will choose to use whichever work strategy allows them to plant the most trees in the least amount of time. Thus, the best way to reduce injuries may be an improvement in equipment, not a change in working style. As long as the workers remain compensated on a piece rate basis, it may be difficult to convince them of the long-term implications of work practices, when they are weighing their short term monetary gain.

That being said, should a worker choose to make postural adaptations or changes in work practice to avoid injury, the following strategies are suggested:

(1) Spend as little time in a bent posture as possible (decrease cumulative trunk flexion). Choose your micro-site in an upright standing position, choose a foot

screef over a hand screef, bend over only once to plant a seedling, and choose a combination of stoop and squat when bending down to plant a tree.

(2) Avoid combinations of forward and lateral bending and twist. Approach your micro-site head on and bend/squat straight down to plant your tree.

(3) Use a staff shovel instead of a D-handle to reduce wrist pronation and put your wrist in a more neutral posture. If you do choose to use a D-handle, consider tailoring your shovel to standing wrist height so that it can support your upper body when you are standing up after planting a tree, and when walking from one micro-site to the next (similar to the use of a cane in assisted ambulation). If you are finding that you are having increased wrist pain and discomfort when inserting the shovel, consider kicking the shovel into the ground using the kick-plate. This will decrease wrist joint loading and compression to the palm. Finally, learn to plant ambidextrously; give your dominant arm a break once in a while.

3.0 Discussion of Limitations

3.1 Validity and reliability of inertial motion sensors

In Chapter 4, Inertial Motion Sensors (IMS) (XSens, Enchede, Netherlands) were used to capture motion of the upper body and trunk during the planting task. Each MTx inertial motion unit uses a tri-axial accelerometer, magnetometer and rate gyroscope to track 3D movement. The manufacturer claims that the system uses a real-time algorithm to fuse the sensor information to calculate accurate 3D orientation. At the time this research study began, there was very little published work on use of inertial motion sensors for the capture of complex dynamic human movement. Manufacturers' specifications report static accuracy of < 1 degree, and dynamic accuracy of 2 degrees root mean square (RMS) error, dependent on the type of motion captured. There is some debate regarding the accuracy of the sensors among independent researchers. In simple pendulum motion tests, Godwin *et al* (2009) confirm static and dynamic accuracy as reported by the manufacturer, while Brodie *et al* (2008) report errors up to 30 degrees in dynamic motion. In one study, use of IMS to record upper arm and forearm orientation during activities of daily living resulted in errors approaching 20 degrees RMS, even when data were corrected using a constraint approach (Luinge *et al*, 2007). The same study reports a drift in elbow orientation over time when the adduction axis (perpendicular to the upper arm x-axis and forearm y-axis) is nearly vertical – such as when brushing teeth. The authors suggest that this drift is due to a heading error, which can be corrected. As soon as the arm was lowered during the task in the study, the heading angle was adjusted. This reported heading error could help explain some of the challenges we faced in calculating shoulder motion during the tree-planting task. In a dynamic test of complex human motion (sweeping arm motions and trunk flexion as would be performed during table washing), mean RMS error of the inertial motion sensors exceeded 25 degrees in the sensor z-axis (Godwin *et al*, 2009). Given the complex dynamic nature of tree-planting task, it is not unreasonable then to suggest that the inertial motion sensors may have been challenged beyond their capabilities, resulting in less than ideal data.

Due to dependence on magnetometer readings for accuracy, inertial motion sensor measurement errors may be induced by a distorted earth magnetic field. deVries *et al* (2009) suggest mapping the testing environment prior to data collection to determine its characteristics and to test at a minimum distance of 1 m from suspect materials. They found that when testing in a distorted magnetic field, orientation estimation deteriorated after 20-30 seconds (deVries et al, 2009). Our testing setting was outdoors in ever-changing environmental conditions where ferromagnetic characteristics of the area could not be accounted for. No known magnetic materials existed during testing, apart from the small blade of the shovel. However, the environment was unstable and it is reasonable to suspect that these conditions may have had some effect on the data set.

No sensor to segment dynamic calibration was performed to align the sensor coordinate system with the anatomical coordinate system. Angular data are representative only of differences in angle between sensors, not between bones. Thus, substantial error could exist if sensors were ill-aligned with the anatomical coordinate system. In future studies, dynamic calibration of the sensors such as is reported by Luinge *et al* (2007) should be performed for a true representation of joint angles.

3.2 Advantages and Limitations of Laboratory and Field Data

This dissertation presents data collected in both field and laboratory settings. Much of the research for this dissertation was conducted in the field. A field setting was preferred over a lab setting due to the complexity of the interaction between the worker and their environment. This interaction is not easily replicable in a lab setting, although a lab setting was preferred to examine joint reaction forces during the task due to challenges in collection of kinetic data in the field.

3.3 Differences in Postural Data across Studies

For many reasons, joint postures during the planting task were not consistent across studies.

Trunk Data

In Chapter 3 trunk flexion was recorded using an inclinometer and average 90^{th} percentile flexion was found to exceed 130 degrees with respect to upright standing. In Chapter 4, trunk flexion was recorded with inertial motion sensors and was found to be just less than 50 degrees with respect to the global vertical, whereas in Chapter 5, maximum trunk flexion was found to be 90 degrees with respect to global vertical when recorded during a simulated tree-planting task in the lab.

There are many reasons why we could expect to see such differences. Instrumentation used and the resulting data were not the same across studies. In Chapter 3, continuous data were collected with accelerometers at a frequency of 7.5 Hz, whereas in Chapters 4 and 5, although data were also collected continuously (at 50 Hz), only four specific events during the task were considered when describing trunk postures. These events – maximum vertical shovel height, shovel-ground impact, tree insertion to ground and return to upright standing – were chosen because (a) they were thought to be the points during the task that put the most biomechanical stress on the body, (b) they define the planting task from start to finish, and (c) despite variations in planting style these events are common to all workers.

Placement of the instrumentation on the body was not consistent across studies. In the first field study (Chapter 3) the Virtual Corset - used to represent trunk flexion - was placed on the front of the body at the sternum and was tared to the subject's upright standing posture prior to data collection. In the second field study (Chapter 4) and the lab study (Chapter 5), both the IMS unit and the IRED cluster were placed on the back of the body at the level of the T1 vertebra. Neither the IMS units nor the rigid clusters were tared to upright standing. The placement of the sensor/cluster with respect to the natural curvature of the spine may have resulted in some reported extension with respect to global vertical during upright standing. Thus, maximum trunk flexion may have been somewhat underreported in Chapters 4 and 5.

Environmental conditions likely contributed to inconsistencies in trunk postures between field studies. In Chapter 3, the terrain being planted was flat and swampy, whereas in Chapter 4, the terrain was often quite hilly. When planting a hill, the worker will always face uphill, therefore requiring less trunk flexion than when planting flat ground. In Chapter 3 the terrain was not site prepped, requiring a greater amount of manual micro-site preparation by the worker – often using the hands to clear debris before planting the tree. This might have resulted in a greater degree of trunk flexion, and for more prolonged periods of time than would be needed in site prepped land. In Chapter 4 there was a combination of site-prepped and non-site-prepped land.

Finally, as with any research involving human beings, inter-subject variability was high. No constraints were placed on the planters in the field studies – planters used their own equipment and their own preferred planting technique, and the work environment varied within and between subjects. For each tree planted, the subject likely assumed a slightly different posture than when planting the previous tree.

In the lab study, the environmental conditions were identical between subjects. The micro site was fabricated and contained no obstacles that might require a change in posture to manoeuvre around. Each subject used the same planting shovel and the planting bags were loaded with an identical weight each time the task was performed. Intra-subject variability was therefore much smaller than would be found in the field. Although the laboratory environment provides ideal measurement conditions, it is not necessarily representative of the true postures or forces that would be assumed by the worker in the field.

Wrist Data

As discussed in Chapter 6, wrist postures between studies showed similar postural patterns but also some notable differences. During the lab task, the wrist was primarily in ulnar deviation, which is consistent with field data. However, wrist flexion/extension were notably different between field and lab studies. Wrist extension data from the field study were 20 degrees greater than extension data from the lab study. This discrepancy may be due to different instrumentation used. In the field study inertial motion sensors were oriented along the long-axis of the hand and forearm and values reported were representative of the angular difference between the two sensors. Although care was taken to place the sensors as accurately as possible on the subject segments, there could have been an offset due to skin movement. In the lab study, clusters were also placed on the forearm, but values were corrected to represent angular differences between the bones themselves.

Significant differences in wrist postures found between loading conditions in the field study were not reproduced in the lab study. Rationale for the differences between conditions in the field study was that workers may have leaned on the shovel in the un-evenly loaded conditions to help balance the load. Due to the small number of samples collected (trees planted) in the lab study, planters may not have been sufficiently fatigued to have needed to lean on the shovel for either support or balance at the time of the study. If a larger number of samples had been collected in the lab, perhaps similar postural differences would have been reproduced.

3.4 Challenges in Load Modelling

The tree-planting task presents several challenges to load modelling. In Chapter 5, external forces and moments acting on the lower body and trunk were reported during the tree-planting task. Most biomechanical models were developed for relatively simple lifting or bending tasks in which the external load is applied to/at the hands continuously for the duration of the task (McGill and Norman, 1987; McGill and Norman 1987; Desjardins *et al*, 1998; Kingma *et al*, 1996; Winter, 2005). However, in the tree-planting task, the properties of the external load and the location on the body at which the load is being applied are somewhat undetermined. The external load (planting bags filled with seedlings) sits just above the lumbo-sacral region (approximately L3 level) and is supported on the body by both a waist strap and shoulder straps. Use of shoulder straps is particularly problematic when modelling the load because they change the point at which the load is being applied as the planting cycle progresses by transferring part of the load from the waist/hips to the shoulders as the planter bends over to plant the tree. Because the load is not part of the body, we chose not to include its mass in any particular segment of the body during the modelling process, nor to include its mass in the total body weight of the subject in the inverse dynamics equations. Due to its non-rigid and non-conforming properties (that is, it is not a cylinder, a sphere or a square) the load could not be assigned a moment of inertia. When modelling external joint loads, it was assumed that the load was constantly applied above the joint of interest (i.e., ankles, knees, etc.).

In addition to variations in point of application of the external load during the task itself, the physical properties of the load are constantly changing as the tree seedlings are being unloaded from the bag. Thus tracking joint loading over the course of the day becomes more challenging than during the planting of a single tree. Cumulative loading would therefore be difficult to determine.

To get a better representation of load application, future studies could track loading patterns at the point of contact between the shoulder straps and the shoulders during the planting cycle. This could possibly be accomplished by using strain gauges imbedded in the shoulder straps to measure deformation in the strap material calibrated to applied load.

A secondary challenge is the loading/unloading forces that result from use of the shovel. There are many points during the cycle that the planter may lean on the shovel for support. At what points and with what force is currently unknown.

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Chapter 8 Summary and Conclusions

The goal of this thesis was to identify the biomechanical mechanisms that contribute to the musculoskeletal injuries sustained by tree-planters. The objectives were to (1) identify musculoskeletal symptoms in tree-planters, (2) provide a detailed biomechanical analysis of the tree-planting task, (3) examine postural differences during three tree unloading strategies, and (4) report biomechanical stresses (joint reaction forces patterns) during the task.

Summary of Findings

The main findings of the research studies were as follows:

Areas of the body with the greatest amount of musculoskeletal pain and discomfort were the feet, wrists and back, whereas the areas with the highest frequency of reported pain were the upper, middle and low back. Musculoskeletal symptoms worsened significantly over the course of a work season.

Deep trunk flexion occurred over 2600 times in a single workday. Fifty percent of the workday was spent in trunk flexion greater than 45 degrees, with peak flexion angles of over 130 degrees. Trunk flexion and lateral bend occurred simultaneously, further increasing risk for injury. Awkward postures were evident in the shoulder at various times during the planting task. The forearm was pronated throughout the planting cycle and the wrist was extended and in ulnar deviation. Trunk rotation during the task approached 50 degrees to both the left and the right.

Some differences were found between symmetric and asymmetric loading conditions: most notably, decreased trunk flexion and rotation when the planting bags were loaded asymmetrically with tree seedlings as compared with symmetrically loaded bags. These differences are suggested to be a result of relying more on the shovel for support during the later part of the planting cycle, though this is not confirmed.

Greatest joint reaction forces and non-neutral postures occur when the tree is inserted in the ground; therefore, this posture should be assumed for as little time as possible during the task. Right-loaded planting bags seemed to produce the most differences in posture and joint reaction forces, suggesting that it may be worse to carry the load on the right side of the body than on the left side of the body or evenly across the body.

Axial forces were greater in the right leg than the left leg throughout the planting task regardless of loading condition.

No differences in wrist posture were found between loading conditions, however, findings suggest that the wrist is in various combinations of ulnar deviation and forearm pronation which may be a substantial contributor the musculoskeletal pain experienced by workers as the work season progresses.

General Conclusions

Tree-planters are subjected to risk factors known to cause musculoskeletal injury including repetition, awkward postures and heavy loads. Deep flexion (> 100 degrees), lateral bend and rotation of the trunk occurred concurrently thousands of times per day. Results from all studies indicated that the point at which the tree is inserted into the ground produced greater joint reaction forces and non-neutral postures than any other point during the task.

Different seedling unloading strategies did not result in substantial overall differences in posture or joint reaction forces, suggesting that planters may adopt a seedling-unloading technique based on personal preference that is comfortable and time efficient.

When linked with epidemiological evidence and in-vitro and in-vivo injury studies, biomechanical data (postures, joint reaction forces and moments) suggest that tree-planters are at risk for developing injuries such as carpal tunnel syndrome or similar wrist pathologies, and low back disorders such as herniated intervertebral discs or facet fractures.

Recommendations for Future Work

To date, this dissertation provides the most comprehensive biomechanical data on the tree-planting task. Postures and joint reaction forces have been described and investigated under various loading conditions both in the field and in the lab. However, given the limitations of this research, much more research is required to accurately describe and document the biomechanics of the task and, moving forward, to measure the impact of changes in equipment design and postural/task strategies on joint reaction forces. The complexity of the task makes it difficult to replicate in a laboratory, therefore it is my opinion that the task is best evaluated in the environment in which it would naturally take place. Use of a portable system, such as the inertial motion sensors used in Chapter 4 is therefore ideal. Future studies would be wise to use a dynamic calibration method and validate the accuracy of the system during the task in a simulated environment before testing is started.

To best understand joint loading, a task-specific model would need to be developed to estimate external forces and moments. This would require modelling the variable load in the planting bags and taking into account force/load transfer from the hips to the shoulders as the worker bends forward to insert the tree into the ground. The load due to the shovel would also need to be taken into account.

Future research should look more closely at loading in the wrists and feet; two areas of the body reported in Chapter 2 as having high pain. Joint reaction forces in the wrist could be evaluated by using an instrumented shovel to measure forces and moments at the wrist throughout the cycle, specifically at ground contact. A pilot project using strain gauges mounted on the shaft of the shovel to record forces and moments is in fact currently underway.

Many workers complain of sore feet as the season wears on. There is currently no specialized foot wear for tree-planters, despite the unique foot movements that they perform. Contact pressure between the boot and foot could be measured in the field using an in-shoe plantar pressure and force measurement system to determine points of high pressure. This information could be use to re-design the work boot specific to the task.

Appendices

Appendix A: Data collection and Analysis Tools - Chapter 2

Letters of Industrial Partnership

Samantha Mussells
Ontario Regional Manager
Brinkman & Associates Reforestation
Kingston, Canada

Dear Samantha,

My name is Tegan Upjohn and I am a currently a PhD candidate in the School of Kinesiology and Health Studies at Queen's University. Although I now spend the majority of my summers in the city, I have spent many past summers working as a tree-planter in the bush in Northern Ontario and Manitoba.

As a PhD student, my area of research is occupational biomechanics, and, having strong ties to the Silviculture sector, I have designed a research project which proposes to examine the occupational biomechanics of the Northern Ontario tree-planting population in an effort to reduce the incidence of work-related injury, and increase worker production.

The study which I am proposing requires the collection of data in a bush camp, and I am writing to inquire whether your company and its employees would consider participating in this innovative research. I would be grateful if you would take the time to read the outlined proposal. The information provided in this document will describe the benefits of this research not only to the scientific community, but to your company and its employees.

Within the proposal you will find information on the rationale behind the study, the methodology of the study and your role and benefits to your company upon participation.

I would very much like the opportunity to clarify the research objectives and the role that your company and its employees would take in this project and look forward to speaking with you at your earliest convenience.

I look forward to your response.

Sincerely,
Tegan Upjohn M.Sc., PhD. Candidate

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RATIONALE FOR THE STUDY

As a well informed reforestation company, you are probably aware that the practice of Silviculture is of particular importance in Canada, as the nation holds over 10% of the world's forests. In 2004, Canada was the world's largest forestry exporter and the total value of Canadian forest-product exports increased by 12.6% to $44.6 billion. Nearly 900 000 hectares of Canada's land are harvested on an annual basis; 174 000 of which are harvested by Ontario (NFDP, 2006). In order to ensure sustainability for future generations, 379 000 ha of Canada's forested land are manually planted on an annual basis with an estimated 509 million seedlings.

As you are also probably aware, tree-planters are constantly subjected to biomechanical stresses, as they consistently carry loads exceeding 16 kg over distances greater than 3 km, while engaging in repetitive bending (lumbar flexion) motions at a rate of over 200 times per hour. Although injury rates in most industrial sectors have decreased in Canada over the past decade, injury rates in the forestry sector are continually rising. In fact, total days lost due to injury have increased 7% from 2003 to 2004, contributing to an overall increase of nearly 40% since 2001 (WSIB 2005, OFSWA, 2004). Forty-eight percent of injuries sustained in the Silviculture sector are work-related musculoskeletal disorders (WMSDs), and cost the industry an estimated $.5 million per year (OFSWA, 2004). Tree-planting injuries most often occur at the wrists (26%) and back (21%) (Work-Safe B.C., 2006) during the first and last two weeks of the planting season and are mainly due to muscle strain from reach, repetitive, or involuntary motion (Lyons, 2001). In fact, 9 out of 10 planters will likely suffer a work-related injury at some point during their planting career, with a 75% chance of sustaining an injury during each planting season (Smith, 1987).

Increases in number of trees planted in future years to play 'catch up' with land that has already been harvested, will lead to a larger population of tree-planters, putting more workers at risk for sustaining musculoskeletal disorders. It is therefore necessary to examine the occupational biomechanics of the current working population, and identify the biomechanical risk factors responsible for causing these musculoskeletal disorders. Once these risk factors are identified, alternative solutions can be suggested, decreasing the prevalence of work-related injury, and increasing worker productivity.

PROPOSED RESEARCH

Purpose: To examine the occupational biomechanics of the Northern Ontario tree-planting population in an effort to reduce incidence of work-related injury.

Objectives: To provide scientific evidence of biomechanical risk factors associated with work-related musculoskeletal disorders in the tree-planting population, leading to a reduction of injury, and increased productivity across the industry.

Aims: To determine incidence of musculoskeletal disorders, level of physical activity and productivity among workers by administration of a principal questionnaire and several supplemental questionnaires. To identify non-neutral working postures likely to lead to musculoskeletal disorders through a work-sampling approach. To track working postures over the course of a work-day (through digital video data) and identify any changes that may occur as a result of fatigue.

Methodology: Participants will be recruited from a tree-planting camp in Northern Ontario, on a volunteer basis. A composite questionnaire comprised of the Standardized Nordic Questionnaire for the analysis of musculoskeletal symptoms, the International Physical Activity Questionnaire (IPAQ), and a series of questions about planter anthropometrics, planting experiences, preferences and motivation, will be administered to all workers. The questionnaire will be administered at both the beginning and end of the planting season. A second questionnaire comprised of a body map (to determine onset of musculoskeletal discomfort) and questions related to worker productivity will be administered on the last day of each work cycle.
A work-sampling approach (PATH) will be used to identify potentially harmful working postures. A small group of workers will be observed individually for a period of three hours. Postural observations will be recorded every 45-60 seconds for a total of 2700 observations.
Digital video of the same small group of workers will be taken for 10 minutes at the beginning, middle and end of each of three consecutive work-days. A postural analysis will be performed using Dartfish® software.

ROLE OF THE REFORESTATION COMPANY IN THE RESEARCH

The reforestation company's primary roles in the research project would be as follows:

1. Allowing the principal investigator access to a planting camp and to employees willing to participate in the research project.
    - The primary investigator would reside in the camp for a period of two work cycles in order to collect the observational data (video and hand recorded data of working posture of 15 planters)
    - The primary investigator would be responsible for her own accommodation, and would pay the company camp costs for the duration of her stay.

2. Distribution and administration of the primary and secondary questionnaires among employees at the start of the planting season.
    - It is suggested that the primary questionnaire could be filled out at the first administrative meeting, along with tax forms etc. The secondary questionnaire would be distributed to the planters by the crew boss/foreman at the beginning and end of each work cycle before the day off.
    - Completed questionnaires would be mailed back to the researcher at Queen's University, Kingston, ON.

BENEFITS TO THE REFORESTATION COMPANY

By participating in this innovative research project, the reforestation company stands to benefit as follows:

1. **INCREASED CAMP PRODUCTIVITY**

By participating in this research project, you will be helping create a more ergonomically sound working environment for current and future employees, which could in fact reduce employee turnover and increase rate of return of workers. A greater percentage of experienced and returning workers would then reduce the amount of time spent training new employees at the beginning of the season, and again, INCREASE CAMP PRODUCTIVITY.

2. **DECREASED NUMBER OF MUSCULOSKELETAL DISORDERS AMONG WORKERS**

This project is the first of its kind dedicated to understanding the occupational biomechanics of the tree planter and identifying the biomechanical risks that are likely to cause musculoskeletal disorders among workers. Identification of these risk factors will lead to further biomechanical analysis and eventually to the elimination of these risk factors. Elimination of risk factors leads to:

- Decreased number of days lost due to injury

- Decreased claims to WSIB
- Decreased cost to the company and to the worker (due to lost wages and premiums paid to the WSIB)
- Increased worker productivity
- Improved worker attitude

3. **BETTER PRE-SEASON TRAINING PROGRAMS**

By understanding the biomechanical risk factors present within the working environment, it will be possible to design and implement more effective pre-season training programs aimed at strengthening specific areas of the body under biomechanical stress due to the physical nature of the job.

September 06, 2007

Ontario Forestry Safe Workplace Association
690 McKeown Avenue, P.O. Box 2050
North Bay, Ontario
P1B 9P1
Phone: (705) 474-7233
Fax: (705) 474-4530

Re: Project update: “Identification of biomechanical risk factors responsible for musculoskeletal disorders in the Northern Ontario tree-planting population”.

Dear Mr. Demers and Mr. Welton,

The following letter is to inform you of the progress of the research project “Identification of biomechanical risk factors responsible for musculoskeletal disorders in the Northern Ontario tree-planting population”.

This past spring planting season marked the beginning of field data collection in two tree-planting camps in Northern Ontario. Two trips were made to the planting camps; the first took place the week of May 01, at the beginning of the spring planting season, and the second took place the week of June 11, near the end of the spring plant.

On the first trip, the following questionnaires were distributed to the planters in both tree-planting camps:

- International Physical Activity Questionnaire (IPAQ) (to assess level of pre-season physical activity)

- Nordic Questionnaire (to assess existing musculoskeletal disorders)
- General Background Questionnaire (to assess planter characteristics and job experience)
- Musculoskeletal Symptom Onset Questionnaires (MSS) (to track onset of musculoskeletal symptoms over the course of the planting season).

A 'planter liaison' from each camp was hired to remind the planters to complete the MSS questionnaire regularly throughout the season. Data entry from the IPAQ, Nordic and General Background questionnaires was completed upon return to Kingston.

On the second trip, the MSS onset questionnaires were collected, and postural data from digital video and Virtual Corsets (inclinometers to measure trunk flexion and lateral bend) were collected. Unfortunately, due to a camp move and changes in forestry client, we were only able to collect data from one reforestation camp, although we were able to retrieve the MSS onset questionnaires from both planting camps.

Data reduction and analysis of the postural video data that was collected on the second trip has begun and is partially complete. All postures from the video data should be digitized by the end of October, at which point statistical analysis of the video data and Virtual Corset data will take place.

Dr. Dumas, Dr. Keir and I have applied for funding for the project for the next 6 months from CRE-MSD (Center of Research Expertise for the prevention of Musculoskeletal Disorders), a research centre funded by the WSIB. We are also in the process of applying for funding for the second field study (taking place spring 2008) through the WSIB RAC. We will be submitting a project proposal ('Short-Term Research Project') for funding through the *Bridging the Gap* competition.

I am also in the process of recruiting reforestation companies to participate in the second stage of field data collection during the spring 2008 planting season.

Please let me know if you require any further information on the progress of the project.

Sincerely,

Tegan Upjohn MSc
PhD Candidate
School of Kinesiology and Health Studies
Queen's University
Kingston, On
K7L 3N6
(613) 533-3060

5tru@queensu.ca t_upjohn@hotmail.com

Letter of Information and Informed Consent

LETTER OF INFORMATION FOR PARTICIPANTS

Project Title: Identification of Biomechanical Risk Factors Responsible for Musculoskeletal Disorders in the Northern Ontario Tree-Planting Population

This study is being conducted by Tegan Upjohn (M.Sc.) through the School of Kinesiology and Health Studies at Queen's University, Kingston, ON, CAN

The goal of the research is to identify the primary biomechanical variables that contribute to musculoskeletal injury and discomfort during tree-planting work. This will be accomplished by several means. First, you will be asked to complete a questionnaire identifying your current level of physical activity, any past or current musculoskeletal injuries that you have sustained, as well as any injuries or discomfort that you may sustain throughout the planting season. The initial questionnaire should take approximately 30 minutes to complete, plus an additional five minutes at the end of each work cycle (before your day off) throughout the season. Second, your working posture will be recorded with a digital video camera for ten minutes at the beginning, middle and end of three consecutive workdays. Finally, your working posture will be recorded on a data sheet by hand, using pencil and paper at regular intervals for a period of three hours during a single workday.

There are no known physical, psychological, economic, or social risks associated with this study. Your participation is voluntary and you are free to withdraw from the study at any time without any consequences. You are not obligated to answer any questions that you find objectionable or that you feel uncomfortable with. Your consent will be obtained before use of any recording device, including the digital video camera, as well as the hand-recording of postures on paper. There is no remuneration for participation in this study. You will not benefit directly from participating in this research study.

This research may result in publications of various types, including journal articles, professional publications, and newsletters. Your identity will be kept confidential. You will be assigned a subject number for all data that you provide to protect your identity. Only researchers associated with this project will have access to data that is collected. If the data are made available to other researchers for secondary analysis, your identity will not be disclosed.

If you would like further information regarding this study, or have any questions or concerns about this study, please contact Tegan Upjohn email 5tru@qlink.queensu.ca or Dr. Genevieve Dumas at (613) 533-3060. You may also contact the Head of the School of Kinesiology and Health Studies, Dr. Jean Coté at (613) 533-6601, or the Chair of the Queen's University General Research Ethics Board, Dr. Joan Stevenson (613) 533-6288 email stevensj@post.queensu.ca

Participant Name: ________________________________

CONSENT FORM

For Tegan Upjohn of the School of Kinesiology and Health Studies, Queen's University

I ____________________(print name) have read and retained a copy of the letter of information and I have had any questions answered to my satisfaction.

I understand that I am being asked to participate in the research project entitled "Identification of biomechanical risk factors responsible for musculoskeletal disorders in the northern Ontario tree-planting population".

I understand that my participation involves the completion of an initial questionnaire that will take approximately 30 minutes, as well as an additional questionnaire at the end of each work cycle that will take approximately 5 minutes. In addition, my working posture will be recorded with a digital video camera for 10 minutes at the beginning, middle and end of each of three consecutive working days. Finally, my working posture will be recorded intermittently with pencil and paper for a period of three hours during a single work-day.

I understand that the purpose of the study is to identify the primary biomechanical variables that contribute to musculoskeletal injury and discomfort during tree-planting work.

I understand that my participation is voluntary and that I am free to withdraw from the study at any time without consequence. I will not benefit directly from my participation in this research study.

I understand that I can contact the principal investigator Tegan Upjohn (613) 533-3060 with questions about the study, or the Chair of the Queen's University General Research Ethics Board, Dr. Joan Stevenson (613) 533-6288, email stevensj@post.queensu.ca if I have questions regarding the ethics of this research study.

I have been assured that all data will remain confidential, including my identity.

Participant Name: ______________________________ Date: ________________________

Participant Signature: ______________________________

By initialing the statement below,
____ I am giving the researcher permission to use a digital video camera to record my working posture.

Musculoskeletal Symptoms Questionnaire

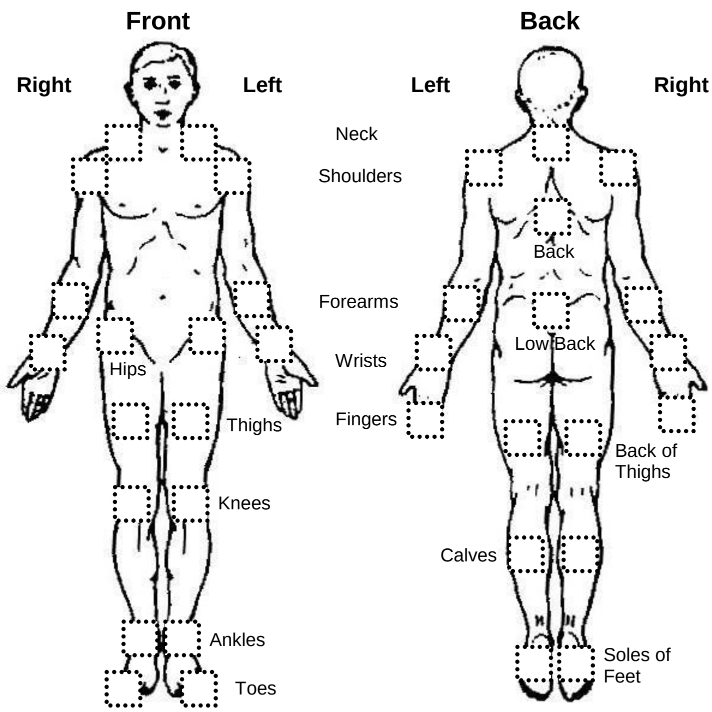
Frequency and Severity of Musculoskeletal Symptoms

Subject ID **Date: ____________________**

What day of the month were you born on? _____
What is the first letter of your mother's first name? _____
What is the first letter of the street name of your home address? _____
How many siblings do you have? _____

On the body map below please rate any pain (numbness, stiffness, tingling, pulling, burning, aching etc) that you are currently experiencing in each of the areas indicated. Please rate your pain on a scale of 0 – 10 as follows:

0	1	2	3	4	5	6	7	8	9	10
No Pain										Severe Pain



1. On average, I planted ☐**<1000** ☐**1000-1500** ☐**1500-2000** ☐**2000-2500** ☐**2500-3000** ☐>**3000** trees/day this shift.
2. My productivity was negatively influenced by external factors (weather, land, no trees etc) ☐ **Yes** ☐ **No**
3. My productivity was influenced by the pain that I am experiencing ☐ **0%** ☐ **25%** ☐ **50%** ☐ **75%** ☐ **100%**
4. My pain was caused by a single incident/accident ☐ **Yes** ☐ **No**
5. If Yes, please indicate which areas of the body are affected by the incident (eg. fall) and describe the incident:

____

6. My pain occurred gradually ☐ **Yes** ☐ **No**
7. My pain is greatest ☐ **At the BEGINNING of the work-day** ☐ **At the END of the workday**

THANK YOU!

General Background Questionnaire

<u>General Background Questions</u>

Subject ID:
What day of the month were you born on?____
What is the first letter of your mother's first name?____
What is the first letter of the street name of your home address?____
How many siblings do you have?____

Date of Questionnaire Completion (dd/mm/yyyy): ___ / ___ / ______

Date of Birth (dd/mm/yyyy): ____ / ____ / ______

Sex: □M □F

Weight: _____lbs

Height: ___ ft ___ in

Handedness: □Right □Left

1. How many seasons of planting experience do you have?
□ < 1 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ > 6

2. How many seasons have you been with the company you are currently with?
□ <1 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ > 6

3. How many companies have you tree-planted for?
□ 1 □ 2 □ 3 □ > 3

4. How long is a typical workday?
□ < 8 hours □ 8-10 hours □ 10-12 hours □ > 12 hours

5. Do you currently have a consistent work/rest cycle (ie 4 days on, 1 day off)?
□ Yes □ No

6. If so, what is the length of your typical work/rest cycle?
□ 4 days on, 1 day off □ 5 days on, 1 day off □ 6 days on, 1 day off
□ 9 days on, 2 days off □ other, please specify

7. How many workdays have you planted this season?
□ 0-5 □ 6-10 □ 11-15 □ 16-20 □ 21-25 □ 26-30

□ 31-35 □ 36-40 □ 41-45 □ 46-50 □ 51-55 □ > 55

8. How many days do you typically plant in a season?
□ < 30 □ 31-35 □ 36-40 □ 41-45 □ 46-50 □ 51-55 □ > 55

9. What kind of shovel do you plant with?
□ D-Handle □ Ergonomic D-Handle □ Staff

10. How long have you been using your current shovel?
□ < 1 season □ 1 season □ 2 seasons □ 3 seasons □ > 3 seasons

11. Have you altered your current shovel?
□ No □ Yes If yes, how?
____
____
____

12. Which hand do you use your shovel with?
□ Right □ Left □ Both

13. When planting, do you use the shoulder straps on your bags? □ Yes □ No

Please explain why or why not.
____
____
____

14. When unloading your bag, do you usually unload:
□ All of the bundles of the grab bag first, then transfer all bundles from side bag to grab bag (asymmetric unloading)
□ Some of the bundles of the grab bag, then transfer some bundles from the side bag etc (symmetric unloading)
□ Half of the bundles from the grab bag first, then transfer half of the bundles from the side bag (semi-symmetric unloading)
□Evenly from both side bags (plant ambidextrously) alternating shovel hands.
□Other
Please Explain:
____
____
____

Thank You!

International Physical Activity Questionnaire

Subject ID:
What day of the month were you born on?____
What is the first letter of you mother's first name?____
What is the first letter of the street name of your home address?____
How many siblings do you have?____

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about how active you are during the two month period before the planting season begins. The **last 7 days** should be representative of the physical activity that you do during these two months. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport. ****Please note this questionnaire is double-sided.*

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐ No moderate physical activities → ***Skip to question 5***

PLEASE CONTINUE ON BACK OF PAGE →

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don’t know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

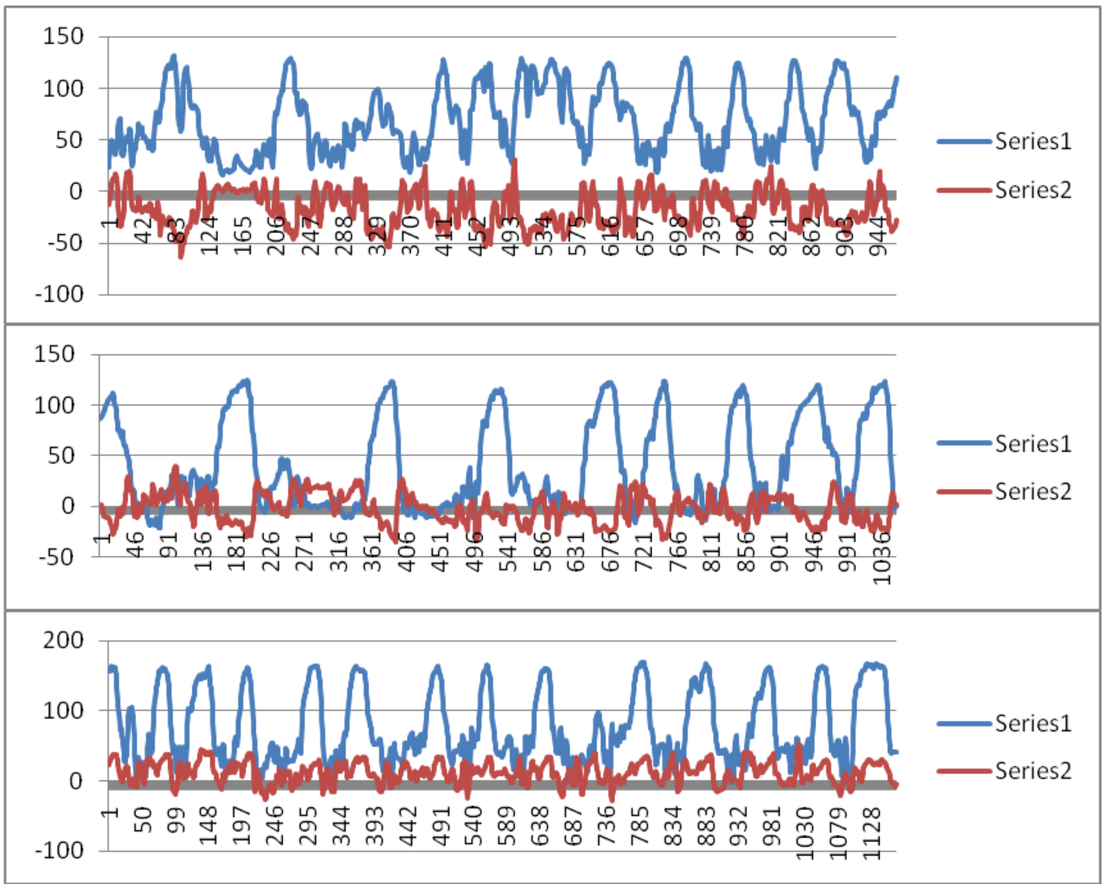
☐ Don’t know/Not sure

This is the end of the questionnaire, THANK YOU!! for participating.

Appendix B: Raw data - Chapter 3

Raw Data

Sample of raw data from three subjects collected with the Virtual Corset and, graphed in Excel. Series 1 is trunk flexion, series 2 is trunk lateral bend. Vertical axis is angles in degrees, Horizontal axis is sample points. Data were collected at 7.5 Hz.



Example of trunk flexion angles from digital video data from a single subject on day 3 of filming. Events were defined manually and angles at each event were calculated by Dartfish Software and exported to Excel. Timecodes are output by Dartfish and are representative of time (in seconds) from start of recording.

Timecode (seconds)	Event	Trunk Flexion (degrees)
44.811479	1	22.6938
45.31198	2	64.204
47.681015	3	60.5242
48.631966	4	111.5617
49.115784	5	111.5617
67.767769	1	21.8603
68.101436	2	31.5459
69.803138	3	63.4113
70.587256	4	108.36
71.071073	5	108.36
84.617953	1	32.4211
84.818153	2	50.2462
85.635638	3	60.8141
126.00935	4	105.0184
127.21055	5	99.3947
135.36871	1	21.3251
135.68569	2	43.3856
140.37371	3	64.989
141.05773	4	100.2678
141.42476	5	100.2678
156.80681	1	25.085
157.04038	2	43.7758
158.15816	4	103.95
158.55856	5	103.6973
190.991	1	29.1975
191.2913	2	53.7234
193.72706	3	53.7234
194.66133	4	110.9245
195.22857	5	110.9245
234.06741	1	15.6086
234.98499	2	44.9797
235.41876	3	79.3565
236.11946	4	101.2593
237.02036	5	101.2593

Appendix C: Data collection and Analysis Tools - Chapter 4

Letter of Information and Informed Consent

Letter of Information and Informed Consent Form for the Project Entitled:
Identification of Biomechanical Risk Factors Responsible for Musculoskeletal Disorders in the Northern Ontario Tree-planting Population

OVERVIEW OF STUDY

You are being invited to participate in a research study conducted by Tegan Upjohn and Dr. Genevieve Dumas to evaluate the effect of planting strategies (such as use of shoulder straps, and tree-unloading methods) on posture during the tree-planting task. Tegan Upjohn will read through this consent form with you and describe procedures in detail and answer any questions you may have. This study is being funded through the Workplace Safety Insurance Board of Ontario. This study has been reviewed for ethical compliance by the Queen's University Sciences and Affiliated Teaching Hospitals Research Ethics Board.

DETAILS OF STUDY

Aims of Study: The aims of the study are twofold. **1)** To determine the kinematics at the joints most susceptible to injury during the tree-planting task. **2)** To determine the effects of various planting techniques, such as use of planting-bag shoulder straps and tree-unloading strategies on whole body kinematics.

Description of Participation: Inertial motion sensors will be secured to the head, upper trunk (C7 vertebrae), sacrum, right and left upper arms, forearms and hands using medical tape. To ensure minimal movement of the sensors relative to the skin, you will be asked to wear a tight-fitting shirt overtop of the sensors (UnderArmor). You will be asked to complete your normal planting activities during four bag-ups, under four separate conditions (one condition per bag-up). The length of the study will be approximately 4 hours and the conditions are as follows:

1) Unloading the planting bags symmetrically (drawing from both right and left bags equally) while wearing shoulder straps
2) Unloading the planting bags asymmetrically (drawing only from one side until it is empty, then proceeding to the opposite side-bag) while wearing shoulder straps

3) Unloading the planting bags symmetrically while NOT wearing shoulder straps
4) Unloading the planting bags asymmetrically while NOT wearing shoulder straps

Randomization: The conditions above will be randomized for each participant; for example, the order of the conditions may not be exactly as listed above.

Risks and Benefits of Participation: There are no known physical, psychological, economic, or social risks associated with this study. You are not obligated to answer any questions that you find objectionable or that you feel uncomfortable with. You will not benefit directly from participating in this research study.

Confidentiality: All information during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be assigned a subject number, and will be identified only by your subject number. Data will be stored in locked files and will be available only to Dr. Genevieve Dumas and Tegan Upjohn. You will not be identified in any publication or report.

Freedom to Withdraw: Your participation in this study is voluntary. You may withdraw from this study at any time without any consequences.

Liability: In the event that you are injured as a result of the study procedures, medical care will be provided to you until resolution of the medical problem. By signing this consent form, you do not waive your legal rights nor release the investigator(s) and sponsors from their legal and professional responsibilities.

Payment: You will receive $100 compensation for lost time and productivity upon the completion of the study.

PARTICIPANT STATEMENT AND SIGNATURE

I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems, or adverse events, I can contact

Tegan Upjohn Phone: (613) 533-3060 email: 5tru@queensu.ca
(Principal Investigator, PhD candidate, Kinesiology and Health Studies, Queen's University)

Or

Dr. Jean Coté Phone: (613) 533-6601 email: jc46@queensu.ca
(Department Head, Kinesiology and Health Studies, Queen's University)

If I have questions regarding my rights as a research subject I can contact Dr. Albert Clark, Chair, Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board at (613) 533-6081

By signing this consent form, I am indicating that I agree to participate in this study.

______________________________	______________________________
Signature of Participant	Date
______________________________	______________________________
Signature of Witness	Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands the nature of the study and demands, benefits, and risks involved to participate in this study.

______________________________	______________________________
Signature of Principal Investigator	Date

Data Processing Code

Sample MySQL syntax for data storage and access

Delete records

```
SELECT Cycle FROM quaternions q where Comment = 2 AND fileID=95;
delete from tree-planting. quaternions where Cycle IN ( ) and FileID=22;
```

Create table

```
USE tree-planting;
CREATE TABLE test (test DECIMAL);
```

Insert data from a txt file into mySQL

```
USE tree-planting;
LOAD DATA LOCAL INFILE 'c:/program files/matlab704/work/wristangles.txt' INTO
TABLE test (test);
SELECT test from test;
```

MATLAB Main Program for data analysis. Data were stored in MySQL and accessed and processed using Matlab.

```
addpath('..')

clear all;
clc;
clf;

%Open the mySQL
mysql('open', '130.15.73.125', 'tree', 'tree-planting')

%Select tree-planting database
mysql('use tree-planting')

%Check that the database is working
%      Display information about the connection and the server.
%      Return    0  if connection is open and functioning
%                1  if connection is closed
%                2  if should be open but we cannot ping the server
mysql('status')

%Read in Trial Data
[RFq0, RFq1, RFq2, RFq3, Handq0,Handq1, Handq2, Handq3]...
   = mysql('SELECT RUAq0, RUAq1, RUAq2, RUAq3, RFq0, RFq1, RFq2, RFq3
FROM quaternions q where FileID = 71 AND Cycle >0 AND Cycle <500 ') ;

display('trial data read in');
trialdata=zeros(length(RFq0),8);

%put quaternions into trialdata
for i=1:length(Handq0)
   trialdata(i,1)=RFq0(i,:);
   trialdata(i,2)=RFq1(i,:);
   trialdata(i,3)=RFq2(i,:);
   trialdata(i,4)=RFq3(i,:);
   trialdata(i,5)=Handq0(i,:);
   trialdata(i,6)=Handq1(i,:);
   trialdata(i,7)=Handq2(i,:);
```

```
    trialdata(i,8)=Handq3(i,:);
end
%Filter Data
%Using Butterworth filter
%fs = 50Hz
%fc = 3Hz

[a,b]=butter(2,0.08);
trialdata(:,:)=filtfilt(a,b,trialdata(:,:));

display('trial data filtered');

plotdata = trialdata;
filename = 'TrialData';

% *** Limit dataset size ***
step = 5;
end_v = (size(plotdata, 1));
plotdata = plotdata(1:step:end_v,:);

% Decompose data into Sensors
RF = (plotdata(:,1:4));
Hand = (plotdata(:,5:8));

RF_axis = 1;
Hand_axis = 1;

delta_t = 1/50 * step;

%Pre-rotate all of the right-hand sensors about their sensor z-axis
%Store the result in RHand_2
N = size(Hand, 1); % get # of samples
Hand2 = Hand;  % make a copy of the same size
q = [0 0 0 1];  % or [cos(pi/2), [0, 0, sin(pi/2)]]
for (i = 1:N)
    Hand_2(i,:) = quaternion_mult(Hand(i,:), q);  % This actually does the rotation of the
sensor
end

% Plot the angles again, but now with the RHand_2
A=plotJointAngles(RF, Hand_2, RF_axis, Hand_axis, 'RF', 'Hand', delta_t);
```

```
val1=(A(:,1));
val2=(A(:,2));
val3=(A(:,3));
% for i=1:length(A)
%     mym('INSERT INTO wristresults(wristflex,wristrot,wristdev) VALUES("{S}",
"{S}", "{S}")', '1.2', 'adfa', '1.55566');
% end
print('-dpng', filename);
```

MATLAB Sample program to calculate the angles for the right wrist.

```
addpath('..')

clear all;
clc;
clf;

%Open the mySQL
mysql('open', '130.15.73.125', 'tree', 'tree-planting')

%Select tree-planting database
mysql('use tree-planting')

%Check that the database is working
%     Display information about the connection and the server.
%     Return   0  if connection is open and functioning
%              1  if connection is closed
%              2  if should be open but we cannot ping the server
mysql('status')

%Read in Trial Data
[RFq0, RFq1, RFq2, RFq3, Handq0,Handq1, Handq2, Handq3]...
   = mysql('SELECT RFq0, RFq1, RFq2, RFq3, Hq0, Hq1, Hq2, Hq3 FROM quaternions
q where FileID = 80 And id > 1594847 and id < 1599607') ;

display('trial data read in');
trialdata=zeros(length(RFq0),8);

%put quaternions into trialdata
for i=1:length(Handq0)
   trialdata(i,1)=RFq0(i,:);
   trialdata(i,2)=RFq1(i,:);
   trialdata(i,3)=RFq2(i,:);
   trialdata(i,4)=RFq3(i,:);
   trialdata(i,5)=Handq0(i,:);
   trialdata(i,6)=Handq1(i,:);
   trialdata(i,7)=Handq2(i,:);
   trialdata(i,8)=Handq3(i,:);
```

```
end
%Filter Data
%Using Butterworth filter
%fs = 50Hz
%fc = 3Hz

[a,b]=butter(2,0.08);
trialdata(:,:)=filtfilt(a,b,trialdata(:,:));

display('trial data filtered');

plotdata = trialdata;
filename = 'TrialData';

% *** Limit dataset size ***
step = 5;
end_v = (size(plotdata, 1));
plotdata = plotdata(1:step:end_v,:);

% Decompose data into Sensors

RF = (plotdata(:,1:4));
Hand = (plotdata(:,5:8));


%Plot data

RF_axis = 1;
Hand_axis = 1;

% subplot(2,1, 1);
delta_t = 1/50 * step;

% Rotate the right-hand sensors about their z axis
% Store result in RHand_2
N = size(Hand, 1); %get # of samples
Hand2 = Hand; %make a copy of the same size
q = [0 0 0 1]; %or [cos(pi/2), [0, 0, sin(pi/2)]]
for (i = 1:N)
   Hand_2(i,:) = quaternion_mult(Hand(i,:),q); %this rotates the sensor
end
```

```
plotJointAngles(RF, Hand_2, RF_axis, Hand_axis, 'RF', 'Hand', delta_t);
print('-dpng', filename);
```

MATLAB Subprogram for rotation matrices from raw data collected in quaternions

```
function v = quaternion_mult(a, b)
% Assumes a and b are the same size
% and are row-quaternions
if (size(a, 2) ~= 4)
    a = a';
end
if (size(b, 2) ~= 4)
    b = b';
end

v = zeros(size(a));
At = a(:,1);  Bt = b(:,1);
Ax = a(:,2);  Bx = b(:,2);
Ay = a(:,3);  By = b(:,3);
Az = a(:,4);  Bz = b(:,4);

% From Wikipedia "Quaternion"
v(:,1) = At.*Bt - Ax.*Bx - Ay.*By - Az.*Bz;
v(:,2) = At.*Bx + Ax.*Bt + Ay.*Bz - Az.*By;
v(:,3) = At.*By - Ax.*Bz + Ay.*Bt + Az.*Bx;
v(:,4) = At.*Bz + Ax.*By - Ay.*Bx + Az.*Bt;
```

MATLAB Subprogram to rotate distal segment to proximal segment coordinate system

```
addpath('..')

clear all;
clc;
clf;

%Open the mySQL
mysql('open', '130.15.73.125', 'tree', 'tree-planting')

%Select tree-planting database
mysql('use tree-planting')

%Check that the database is working
%     Display information about the connection and the server.
%     Return    0  if connection is open and functioning
%               1  if connection is closed
%               2  if should be open but we cannot ping the server
mysql('status')

%Read in Trial Data
[Sq0, Sq1, Sq2, Sq3, c7q0,c7q1, c7q2, c7q3]...
   = mysql('SELECT Sq0, Sq1, Sq2, Sq3, c7q0, c7q1, c7q2, c7q3 FROM quaternions q
where FileID = 71 AND Sample>1 and Sample<50000') ;

data = zeros(length(Sq0),8);


for i=1:length(c7q0)
   data(i,1)=Sq0(i,:);
   data(i,2)=Sq1(i,:);
   data(i,3)=Sq2(i,:);
   data(i,4)=Sq3(i,:);
   data(i,5)=c7q0(i,:);
   data(i,6)=c7q1(i,:);
   data(i,7)=c7q2(i,:);
   data(i,8)=c7q3(i,:);
end
```

```
% *** Limit dataset size ***
step = 5;
end_v = (size(data, 1));
data = data(1:step:end_v,:);

%change in time
delta_t = 1/50 * step;

%plot data
t = (1:length(data)) * delta_t;
hold off;
plot(t, data(:,1), '-r');
hold on;
plot(t, data(:,2), '-b');
plot(t, data(:,3), '-k');
plot(t, data(:,4), '-g');

A(:,1)=Sq0;
A(:,2)=Sq1;
A(:,3)=Sq2;
A(:,3)=Sq3;
legend('Sq0', 'Sq1', 'Sq2', 'Sq3');

hold off;
ylabel('Quaternions')
%ylim([min([-90; Sq0; Sq1; Sq2; Sq3]), max([90; Sq0; Sq1; Sq2; Sq3])]);
xlabel('Seconds')
% title(sprintf('%s to %s', label1, label2));
```

MATLAB Subprogram to calculate and plot joint angles. Spherical coordinate system approach was taken to calculate flexion and abduction while rotation was defined using a polar coordinate system.

```
function A=plotJointAngles(limb1, limb2, limb1_axis, limb2_axis, label1, label2, delta_t)

% Set up the plot constants, type
rf = [0, 0, 0]';

% Rotate both systems so that limb 1 is in canonical position
limb1_inv = limb1;
limb1_inv(:,2:4) = -1 * limb1_inv(:,2:4);  % conjugate = inverse for unit quaternions

norm_limb1 = quaternion_mult(limb1_inv, limb1);
norm_limb2 = quaternion_mult(limb1_inv, limb2);

N = size(limb1, 1);
%a1 = zeros(N, 1);
a2 = zeros(N, 1);
a3 = zeros(N, 1);
a4 = zeros(N, 1);
a5 = zeros(N, 1);

for (i = 1:N)
   % limb1 is the standard axes, so R is relative to that
   R = fsm_a_to_R_1_0(norm_limb2(i, :));
   v = R(:, limb2_axis); % get the vector of limb 2's principal axis

   % Convert to spherical coordinates
   % theta = xy-plane, angle away from x axis
   % phi = angle from xy plane
   [theta, phi, r] = cart2sph(v(1), v(2), v(3));
   % theta*180/pi

   % flexion = phi
   % abduction/adduction = theta
   %a1(i) = theta*180/pi;
   a2(i) = phi*180/pi;
```

```
    % internal rotations involve relative axes
    % how far is new z-axis from normalized z-axis
    vz = R(:, 3);
    [theta, rho] = cart2pol(vz(3), vz(2));
    theta*180/pi;
    a3(i) = theta*180/pi;

    a4(i) = 20; %subject ID
    a5(i) = 5; %condition: 1 = sym; 2 = asym before; 3 = asym after

end

%Write to .txt file
% d(:,1)=a1;
% d(:,2)=a2;
% d(:,3)=a3;
% d(:,4)=a4;
% d(:,5)=a5;

d(:,1)=a2;
d(:,2)=a3;
d(:,3)=a4;
d(:,4)=a5;

dlmwrite('trunk1005.txt', d, 'delimiter', '\t', 'newline', 'pc');


% t = (1:N) * delta_t;
% hold off;
% plot(t, a1, '-r');
% hold on;
% plot(t, a2, '-b');
% plot(t, a3, '-k');

t = (1:N) * delta_t;
hold off;
plot(t, a2, '-b');
hold on;
plot(t, a3, '-k');
```

```
%A(:,1)=a1;
A(:,1)=a2;
A(:,2)=a3;

legend('Flexion', 'Rotation');

hold off;
ylabel('Angles (degrees)')
ylim([min([-90; a2; a3]), max([90; a2; a3])]);
xlabel('Seconds')
title(sprintf('%s to %s', label1, label2));
```

MATLAB Program to calculate APDF from Angle data stored in MySQL

```
ddpath('..')

clear all;
clc;
clf;

%Open the mySQL
mysql('open', '130.15.73.125', 'tree', 'tree-planting')

%Select tree-planting database
mysql('use tree-planting')

%Check that the database is working
%     Display information about the connection and the server.
%     Return    0  if connection is open and functioning
%               1  if connection is closed
%               2  if should be open but we cannot ping the server
mysql('status')

%Read in Data
[angle]= mysql('SELECT t.`Rotation` FROM tree-planting.trunk t where fileID = 20 and
cond = 6');

data = angle(:,1);

%Define the bins for the histogram (from -360 to 360 degrees)
bins=-180:1:180;

%Calculate number of elements in each bin
n_elements = histc(data,bins);

%Calculate the cumulative sum of these elements
cumsum_elements = cumsum(n_elements);

%To get the APDF divide the cummulative sum by the total number of samples
APDF = cumsum_elements/length(data);
```

```
%Find the 10th, 50th and 90th percentile angles
[w] = find(APDF >.09 & APDF < 0.12); %APDF 10
[x]= find(APDF >.49 & APDF < 0.53); %APDF 50
[y] = find(APDF >.89 & APDF < .92); %APDF 90

APDF10 = mean(w);
APDF50 = mean(x);
APDF90 = mean(y);

M=mean(data);
```

Appendix D: Subject Recruitment - Chapters 5 and 6

Subject Recruitment

EXPERIENCED TREE PLANTERS NEEDED FOR RESEARCH STUDY!

COMPENSATION PROVIDED FOR PARTICIPATION

WSIB Workplace Safety & Insurance Board / CSPAAT Commission de la sécurité professionnelle et de l'assurance contre les accidents du travail

$50.00 for 2 hours of your time!!

If interested, please contact Tegan Upjohn at (613) 533-3060 or 5tru@queensu.ca

Tree Planting Study
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Letter of Information and Informed Consent

Letter of Information and Informed Consent Form for the Project Entitled:
Identification of Biomechanical Risk Factors Responsible for Musculoskeletal Disorders in the Ontario Tree-planting Population

OVERVIEW OF STUDY

You are being invited to participate in a research study conducted by Tegan Upjohn and Dr. Genevieve Dumas to evaluate the effect of tree unloading strategies on posture and joint reaction forces during the tree-planting task. Tegan Upjohn will read through this consent form with you and describe procedures in detail and answer any questions you may have. This study is being funded through the Workplace Safety Insurance Board of Ontario. This study has been reviewed for ethical compliance by the Queen's University Sciences and Affiliated Teaching Hospitals Research Ethics Board.

DETAILS OF STUDY

Aims of Study: The aims of the study are **1)** To determine whole body postures during three unloading strategies commonly used in the tree-planting task (*evenly loaded trees, right-loaded trees and left-loaded trees*) **2)** to determine joint reaction forces at the knees, hips, back and wrist during the three unloading strategies above.

Description of Participation: Rigid clusters of infrared emitting diodes will be secured to your feet, shanks, thighs, sacrum, thoracic spine, hand, and forearm using Velcro straps. You will be asked to simulate the planting task under three separate conditions as follows:

1) While having a load evenly distributed to the right and left planting bags
2) While having a load distributed only to the right planting bag
3) While having a load distributed only to the left planting bag

You will perform 10 planting cycles for each of the above tasks. After these data are recorded, two of the rigid clusters will be moved from your forearm and hand and placed on the planting bags. You will repeat the task. During these tasks, your posture will be recorded by two Optotrak® systems, and the forces at your joints will be recorded via forces measured at your feet (using two AMTI forceplates) and at your wrists (Using strain gauges on the planting shovel).

Randomization: The conditions above will be randomized for each participant; for example, the order of the conditions may not be exactly as listed above.

Risks and Benefits of Participation: There are no known physical, psychological, economic, or social risks associated with this study. You are not obligated to answer any questions that you find objectionable or that you feel uncomfortable with. You will not benefit directly from participating in this research study.

Confidentiality: All information during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be assigned a subject number, and will be identified only by your subject number. Data will be stored in locked files and will be available only to Dr. Genevieve Dumas and Tegan Upjohn. You will not be identified in any publication or report.

Freedom to Withdraw: Your participation in this study is voluntary. You may withdraw from this study at any time without any consequences.

Liability: In the event that you are injured as a result of the study procedures, medical care will be provided to you until resolution of the medical problem. By signing this consent form, you do not waive your legal rights nor release the investigator(s) and sponsors from their legal and professional responsibilities.

Payment: You will receive $50 compensation for your time and travel expenses upon completion of the study.

PARTICIPANT STATEMENT AND SIGNATURE

I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems, or adverse events, I can contact

Tegan Upjohn Phone: (613) 533-3060 email: 5tru@queensu.ca
(Principal Investigator, PhD candidate, Kinesiology and Health Studies, Queen's University)

Or

Dr. Jean Coté Phone: (613) 533-6601 email: jc46@queensu.ca
(Department Head, Kinesiology and Health Studies, Queen's University)

If I have questions regarding my rights as a research subject I can contact
Dr. Albert Clark, Chair, Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board at (613) 533-6081

By signing this consent form, I am indicating that I agree to participate in this study.

______________________________ ______________________________
Signature of Participant Date

______________________________ ______________________________
Signature of Witness Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands the nature of the study and demands, benefits, and risks involved to participate in this study.

______________________________ ______________________________
Signature of Principal Investigator Date