Characterizing Full Shift Physical Risk Factors among Hand Planter Forestry Workers

by

Robert Frederick Granzow

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 10, 2016

Keywords: occupational ergonomics, electromyography, posture, industrial engineering, forestry

Approved by

Mark Schall, Chair, Associate Professor of Industrial and Systems Engineering
Mathew Smidt, Professor of Forestry and Wildlife Sciences
Richard Sesek, Assistant Professor of Industrial and Systems Engineering
Jerry Davis, Professor of Industrial and Systems Engineering
Sean Gallagher, Associate Professor of Industrial and Systems Engineering

Abstract

Low back and neck/shoulder pain are commonly reported among reforestation hand planters. While some studies have documented the intensive cardiovascular demands of hand planting, limited information is available regarding exposures to physical risk factors associated with the development of musculoskeletal disorders (MSDs) among hand planters. This study used surface electromyography (EMG) and inertial measurement units (IMUs) to characterize the muscle activation patterns, upper arm and trunk postures, movement velocities, and physical activity (PA) of Southeastern reforestation hand planters over one entire work shift. Results indicated that hand planters are exposed to higher muscle activation patterns and more extreme upper arm and trunk postures and movement velocities than workers in several other occupational groups that commonly report a high prevalence of MSDs. The findings indicate a need for continued field-based research among hand planters to identify and/or develop maximally effective intervention strategies and tools.

Acknowledgments

This research was supported by a pilot project grant from the Southeast Center for Agricultural Health and Injury Prevention at the University of Kentucky. The Southeast Center is supported by Cooperative Agreement No. 5U54OH00754 from the Centers for Disease Control and Prevention (CDC) / National Institute for Occupational Safety and Health (NIOSH).

Table of Contents

List of Tables

List of Figures

CHAPTER ONE

1. INTRODUCTION

Reforestation, or the intentional restocking of depleted forests and woodlands, provides many valuable resources and amenities to our society including clean air and water, healthy habitats for wildlife, and recreational opportunities. Quality seedlings and plantings are a requirement for successful reforestation (South & Mexal, 1984). Planting quality is typically highest when performed by hand planting crews (Stjernberg, 2003).

Hand planting, shown in Figure 1, involves carrying a large bag of seedlings and planting them one at a time at a desired spacing using a planting tool (e.g., spade, hoedad, dibble bar, etc.). Despite being physically demanding work (Giguere, Belanger, Gauthier, & Larue, 1993; Hodges & Kennedy, 2011; Roberts, 2002; Robinson, Trites, & Banister, 1993; Trites, Robinson, & Banister, 1993), hand planting has been observed to provide a yield of nearly 95% survival (Stjernberg, 2003). Another benefit of hand planting is the high rate of production that is possible regardless of terrain conditions.

Figure 1. Hand planter at work using a dibble bar and carrying a bag of seedlings

Although several studies are available describing the main elements of the planting cycle and the intensive cardiac demands of hand planters (Denbeigh, Slot, & Dumas, 2013; Giguere et al., 1993; Hodges & Kennedy, 2011; Upjohn, Keir, & Dumas, 2008), limited information is available regarding the full shift exposures to physical risk factors associated with the development of adverse musculoskeletal health outcomes. These physical risk factors include sustained and/or non-neutral postures of the low back and shoulder, high movement velocities, and forceful muscular exertions (da Costa & Vieira, 2010). Characterizations of such exposures during a full work shift are needed to design tools and interventions capable of mitigating exposures and preventing the development of musculoskeletal conditions (Quandt et al., 2013). The objective of the present study, therefore, was to (i) characterize the trunk and upper arm postures, movement velocities, and neck and shoulder muscle activation patterns during full-shift work, and (ii) compare these findings with data from other available studies in order to evaluate the exposures to physical risk factors challenging hand planters.

CHAPTER TWO

2. Literature Review

2.1 Hand Planting Production

Several studies have examined the production rates of hand planting crews across a variety of geographic worksites. Hand planters of containerized seedlings in eastern and central Canada have been observed to average 11.7 seconds per tree (Stjernberg, 1988). The variation was quite large both within and among planting crews with the fastest observed rate being 5.3 seconds per tree. Planting exhausted 66% of the workday, on average, with nonproductive time consuming 12% of the workday and other productive time 22% (Stjernberg, 1988). In British Columbia, average production rates have been measured to be above 1900 trees per day. This resulted in planting times of about 10 seconds per seedling (Stjernberg, 2003). Another survey of planters in Canada reported an average productivity of 1245 trees per day (Giguere et al., 1993). Planting a bareroot seedling with a dibble bar took 7 seconds or less 70% of the time (McDonald, Fulton, Darr, & Gallagher, 2008). With 60% productive time, the planting rate would be about 300 trees per hour or 2400 in an 8-hour shift.

Regardless of seedling type and tool, reforestation hand planters are expected to work quickly, often leading to chronic injury (Hodges & Kennedy, 2011). To complicate matters further, compensation for hand planting can be based on production. Piece rate payments have provided workers willing to work at a strenuous pace for long hours the opportunity to generate reasonable incomes. This practice can result in low desirability of these jobs and high worker turnover (McDaniel & Casanova, 2003).

2.2 Musculoskeletal Disorders among Forestry Workers

A major cause of disability and lost productivity, work-related musculoskeletal disorders (MSDs) are widespread in the United States. MSDs represent approximately 32% of all non-fatal occupational injuries and illnesses across industry sectors (BLS, 2015). MSDs are the second most common cause of disability worldwide, and have increased 45% since 1990 (Horton, 2013; Vos et al., 2012). Workers in the U.S. Agriculture, Forestry, and Fishing (AFF) industry sector report among the highest rates of work-related musculoskeletal disorders (MSDs) across all industry sectors every year (e.g., second in 2013; BLS, 2014; third in 2014, BLS, 2015).

Many forestry activities expose these workers to general safety hazards, psychosocial stressors, biomechanical stressors, and physical and biological agents causing the workers to be at an increased risk of adverse musculoskeletal pain. Hagen found that 86.0% of manual motor tool forest workers reported MSDs in at least one body part during the previous 12 months (Hagen, Magnus, & Vetlesen, 1998). The three most common sites for reporting symptoms were the lower-back, neck, and shoulders. Several other studies have concluded that the strenuous work pace in hand planting, along with inadequate rest periods and poor living conditions may have negative effects on forest worker safety and health (Giguere et al., 1993; Hodges & Kennedy, 2011; Roberts, 2002; Robinson et al., 1993; Trites et al., 1993). Work pace rather than work efficiency has been found to be related to higher productivity, therefore training does not appear to have much potential for reducing planting workload (Hodges & Kennedy, 2011). Moreover, planter's choice of tool for efficiency may contribute to injury and ergonomic risks (Robinson et al., 1993).

The use of mechanized forestry equipment has been found to not eliminate the risk of workers being injured or developing occupational health disorders. This may be due to exposure to whole-body vibration, which has been identified as a risk factor for the development of musculoskeletal disorders (Punnett, 2014). Prolonged exposure to vibration in forestry workers using mechanized planting methods has been shown to be a significant risk factor for diminished muscle force and reduced joint function (Bovenzi, Zadini, Franzinelli, & Borgogni, 1991).

CHAPTER THREE

3. Methodology

3.1 Participants and study design

Ten male reforestation workers (mean age = 25.8 ± 5.9 years; mean body mass index = 24.9 ± 1.8 kg/m^2) were recruited from a reforestation contractor registered with the Alabama Forestry Commission for hand planting services in the state of Alabama. Participants self-reported 1) no history of physician-diagnosed MSDs in the neck/shoulder or back regions, 2) no neck/shoulder or back pain two weeks prior to participation in the study, and 3) no history of neurodegenerative disease. All participants were right-hand dominant. Institutional Review Board approval of all study procedures from Auburn University was obtained prior to commencing study activities, and each participant provided written informed consent. Data were collected in January, during the regular planting season.

3.2 Data collection procedures

Data were collected as subjects performed hand planting tasks. The work location varied based on the planting schedule, but each participant started and ended the workday in the same general plot of land. Each participant was observed for one full "daylight" work shift (i.e., dawn to dusk) during the prime planting month of January. A research assistant shadowed each worker and recorded the time on a notepad (to the nearest minute) at which specific tasks began and ended. Tasks observed included but was not limited to 1) unloading boxes of tree seedlings from a cooler trailer, 2) loading seedlings into bag for planting, and 3) the actual hand planting of the seedlings. After the conclusion of the study each day, the research assistant transferred the field notes onto a computer for reference during data analysis.

3.3 Surface electromyography and forceful muscular exertions

Continuous surface electromyography (EMG) recordings were acquired from the bilateral upper trapezius and anterior deltoid muscles. Preamplified EMG electrodes (model SX230, Biometrics Ltd, Gwent, UK) were secured to the skin according to published guidelines (Criswell, 2010). A reference electrode was attached to the skin over the non-dominant clavicle. The electrode cables were connected to a portable data logging system (DataLog, Biometrics Ltd, Gwent, UK). The raw EMG signals were sampled at 1000 Hz and stored on a compact memory card for analysis.

EMG signals were post-processed using custom LabVIEW software (version 2013, National Instruments, Inc., Austin, TX, USA). Unprocessed EMG signals were first visually scanned for transient artifacts which were subsequently removed and replaced with the mean voltage of the recording period. After resolving the transients, the mean voltage value of each unprocessed EMG file was subtracted in order to remove DC offset and the power spectral density of each EMG recording was examined to identify possible sources of interferences with the EMG signals (e.g., 60 Hz or electrocardiogram). If interference was detected, it was attenuated using standard filtering methods (Drake & Callaghan, 2006; Redfern, Hughes, & Chaffin, 1993). Each raw EMG recording was converted to instantaneous root-mean-square (RMS) amplitude using a 100-sample moving window with a 50-sample overlap.

Submaximal, isometric reference contractions were collected prior to the beginning of each participant’s work shift. For the upper trapezius, the participant held a 2 kg weight in each hand with the upper arms abducted 90° in the scapular plane, elbows fully extended and forearms pronated (Fethke, Schall Jr., Determan, & Kitzmann, 2015; Mathiassen, Winkel, & Hägg, 1995). For the anterior deltoid, participants held a 2 kg weight in each hand with upper arms flexed forward to 90° of elevation and the elbows fully extended (Cook, Burgess-Limerick, & Papalia, 2004; Fethke et al., 2015; Rota, Rogowski, Champely, & Hautier, 2013; Yoo, Jung, Jeon, & Lee, 2010). RMS-processed EMG amplitudes during the work shift were expressed as a percentage of the RMS EMG amplitudes observed for the submaximal reference contractions (%RVE). Three repetitions of each reference contraction were performed, with a 1-minute rest between repetitions. Subjects maintained each contraction for roughly 15 seconds and the mean RMS amplitude of the middle 10 seconds was calculated. The average of the mean RMS EMG amplitudes of the three reference contractions was used as the RVE activation level. Baseline noise was defined as the lowest RMS EMG amplitude observed during the full-shift EMG recording and subtracted from all other RMS EMG amplitude values in a power sense (Jackson, Mathiassen, & Dempsey, 2009; Thorn et al., 2007).

The mean amplitude of the RMS signal for each muscle across the entire recording period was calculated as a global index of muscular load. Gaps in muscular activity were defined as any periods in which muscle activity fell below 5% RVE for at least 0.25 s (Hansson et al., 2000). Gap frequency was expressed as the number of gaps/min and muscular rest was defined as the summed duration of all gaps expressed as a percentage of total recording time. For each muscle, static, median, and peak amplitudes of muscle activity were calculated as the normalized RMS EMG amplitudes associated with the 10^{th}, 50^{th}, and 90^{th} percentiles of the amplitude probability distribution function (APDF; (Jonsson, 1982)).

3.4 Direct measurements of posture, movement velocity, and rest / recovery

Direct measurements of non-neutral working postures were obtained using Actigraph GT9X Link inertial measurement units (IMUs) (Actigraph, Pensacola, Florida, USA). Specifically, four IMUs were affixed to each study participant on the 1) trunk (secured to the anterior torso at the sternal notch), 2) each upper arm (approximately one-half the distance between the lateral epicondyle and the acromion), and 3) on the dominant hip. Each IMU contained a tri-axial accelerometer, gyroscope, and magnetometer and stored data at a sampling rate of 100 Hz. Similar sensors have been used recently to characterize non-neutral postures and PA among laborers in other industries such as construction and healthcare (Arias, Caban-Martinez, Umukoro, Okechukwu, & Dennerlein, 2015; Schall Jr., Fethke, & Chen, 2016a; Umukoro et al., 2013).

A custom complementary weighting algorithm developed in MATLAB (r2014a, The Mathworks, Natick, MA) was used to transform raw acceleration and angular velocity information obtained with the IMU attached to the torso into trunk flexion and trunk lateral bending angles and the IMU attached to the upper arms into elevation (flexion and/or abduction) angles. Joint angles of the upper arm relative to the torso were defined using relative spatial orientation estimates. Specifically, the relative orientation between the IMUs R_C^B was calculated using equations 1 and 2, where R_B^A and R_C^A were the orientations provided by the IMU attached to the proximal and distal body segments, respectively. R_C^B was subsequently decomposed into Euler rotations using a Y-X'-Z'' rotation sequence, where Y, X, Z, is defined as movement along the sagittal plane, frontal, and transverse plane, respectively. Previous analysis of the complementary weighting algorithm has indicated that the approach has good accuracy and repeatability when used with IMUs similar to those employed in this study (Schall Jr., Fethke, Chen, Oyama, & Douphrate, 2016).

$$R_C^A = R_B^A R_C^B \quad (1)$$

$$R_C^B = R_C^A (R_B^A)^T \quad (2)$$

Amplitude probability distribution functions (APDF) of the trunk and the upper arm elevation waveforms were used to obtain median, peak, and static flexion and elevation levels for each IMU. The peak flexion and elevation levels are defined as the flexion and elevation values associated with the 90th percentile of the APDF, and the static flexion and elevation levels are defined as those associated with the 10th percentile of the APDF. The difference between the estimates of the 90th and 10th percentiles (referred to as angular displacement variation) was calculated to estimate the amplitude of the range of motion for each body segment.

To describe movement velocity consistent with previous research (Douphrate, Fethke, Nonnenmann, Rosecrance, & Reynolds, 2012; Kazmierczak, Mathiassen, Forsman, & Winkel, 2005; Schall Jr., Fethke, & Chen, 2016a; Wahlström et al., 2010) the angular displacement waveforms of trunk flexion / extension and upper arm elevation was differentiated and then analyzed. Exposure metrics included the proportion of time working with high (≥90° per second) and low (<5° per second) angular velocities and selected percentiles (10th, 50th, 90th, and the difference between 90th and 10th) of the APDF. 'Rest' and 'recovery' descriptive variables were computed for contextual purposes. 'Rest' was defined as having the trunk or upper arm in a non-extreme posture (<45° for the trunk and <60° for the arms) and moving with an angular velocity of <5° per second. 'Recovery' periods were defined as the number of times per minute of substantial periods (≥3 second) in a non-extreme posture (<45° for the trunk or <60° for the upper arms).

3.5 Occupational Physical Activity

Full shift occupational physical activity summary measures were obtained from the IMUs using available software (ActiLife 6.13, Actigraph, Pensacola, Florida USA). Activity "counts" were

summed at each data sample across non-overlapping epochs of one minute to attain counts/min according to definitions provided by Freedson, Melanson, & Sirard (1998).
Specifically, the physical activity counts/min were categorized as “sedentary” (0-99 counts/min), “light” (100-1951 counts/min), “moderate” (1952-5724 counts/min), “vigorous” (5725-9498 counts/min), or “very vigorous” (>9498 counts/min). The total number of minutes assigned to each physical activity category were summed for each participant across the full sampling duration. For purposes of comparisons to comparable studies of other occupational groups, particular attention was afforded to the physical activity associated with the dominant hip IMU.
In addition to counts per minute, the energy cost of PA was determined by calculating metabolic equivalents (METs) from the acceleration data obtained from the IMU worn on the dominant hip. Physical activity software (ActiLife 6.13, Actigraph, Pensacola, Florida USA) was used to obtain the METs according to an energy expenditure algorithm described in Freedson et al. (1998). Categorizations were made of PA intensity as “sedentary” (1.0-1.5 METs), “light” (1.5-3 METs), “moderate” (3.0-6.0 METs), and “intense/vigorous” (>6 METs) per standard definitions (Whaley et al., 2005).

3.6 Statistical analysis

Each posture, movement velocity, and rest/recovery exposure metric was described with descriptive statistics (mean, standard deviation [SD]) across all participants.

CHAPTER FOUR

4. Results

4.1 Exclusion of EMG data

The right and left anterior deltoid EMG recordings were excluded from the analyses for three of the 10 participants. The right and left upper trapezius EMG recordings were excluded from the analyses for two of the 10 participants. For these study participants, the integrity of the skin-to-electrode interface was compromised resulting in a loss of data quality.

4.2 Full-shift planting muscle activity levels

Descriptive statistics and probabilities for the bilateral upper trapezius and anterior deltoid EMG summary measures are provided in Table 1. In general, muscle activity was greater in the dominant (right) arm than the non-dominant (left) arm regardless of summary metric. Additionally, muscular effort associated with planting was observed to be greater than non-planting (i.e., other) activities such as placing seedlings in bags before engaging in planting.

Table 1. Distributions of full-shift, hand planting, and non-planting occupational tasks EMG summary measures by muscle.

Exposure Variable	Full Shift		Planting		Non-planting	
Right Upper Trapezius (N=8)	Mean	SD	Mean	SD	Mean	SD
Mean RMS (%RVE)	49.3	20.4	52.8	22.2	35.8	15.8
10th Percentile APDF (%RVE)	7.6	3.5	7.6	4.5	4.6	2.5
50th Percentile APDF (%RVE)	35.9	14.0	36.9	17.3	26.2	13.1
90th Percentile APDF (%RVE)	112.1	44.9	118.2	49.4	76.3	34.1
Muscle Rest (% time)	9.1	10.4	7.1	9.6	16.4	14.3
Gaps / Min	6.8	5.9	5.8	6.5	10.5	5.2
Left Upper Trapezius (N=8)	Mean	SD	Mean	SD	Mean	SD
Mean RMS (%RVE)	39.3	11.8	41.1	13.3	33.2	10.0
10th Percentile APDF (%RVE)	6.0	3.1	6.2	3.0	4.3	2.1
50th Percentile APDF (%RVE)	34.2	17.1	36.8	18.3	23.5	14.4
90th Percentile APDF (%RVE)	88.7	24.7	91.2	26.1	79.5	30.7
Muscle Rest (% time)	15.8	23.7	13.6	25.2	23.6	18.6
Gaps / Min	12.2	6.4	9.4	5.9	22.8	13.4
Right Anterior Deltoid (N=9)	Mean	SD	Mean	SD	Mean	SD
Mean RMS (%RVE)	42.7	29.1	47.8	32.4	25.0	17.3
10th Percentile APDF (%RVE)	5.1	4.1	5.5	4.4	3.1	2.5
50th Percentile APDF (%RVE)	19.5	13.8	21.9	15.1	10.6	7.5
90th Percentile APDF (%RVE)	118.8	95.3	133.0	109.5	67.7	46.1
Muscle Rest (% time)	23.9	21.8	20.6	21.3	34.4	23.6
Gaps / Min	14.8	11.8	14.1	13.1	17.0	7.5
Left Anterior Deltoid (N=9)	Mean	SD	Mean	SD	Mean	SD
Mean RMS (%RVE)	16.7	9.0	17.6	9.4	13.7	8.6
10th Percentile APDF (%RVE)	2.9	2.0	2.4	1.2	1.6	1.0
50th Percentile APDF (%RVE)	9.8	6.1	8.4	4.9	5.5	3.6
90th Percentile APDF (%RVE)	43.1	18.7	43.2	18.6	32.2	15.9
Muscle Rest (% time)	35.3	24.6	32.6	24.7	43.6	25.5
Gaps / Min	24.4	7.2	23.9	5.5	26.6	14.8

4.3 Full-shift planting non-neutral working postures and movement velocities

Hand planters in this study were observed to spend a large percentage of their work time in extreme postures and moving at high velocities (Tables 2 and 3). Specifically, 29.4% of the observed work time was spent with the trunk flexed ≥45°, 10.4% of the work time was spent with the left arm elevated ≥60°, and 14.8% of the work time was spent with the right arm elevated ≥60°. On average, roughly 4% of work time was spent flexing or laterally bending the trunk at a high velocity (≥90°/s). The left arm was moving at a high velocity for 2.7% of the work shift, while the right arm moved at a high velocity for 12.2% of the work shift.

In addition to the high exposures experienced, hand planters had few opportunities for rest and recovery. Hand planters spent only 6.6% of their work time with the upper arms in a neutral posture (<20°) and moving at a low velocity (<5°/s) for a minimum of 3 consecutive seconds. Similarly, hand planters spent only 14.9% of their work time with the trunk in a neutral posture (<20°) and moving at a low velocity (<5°/s) for a minimum of 3 consecutive seconds. Figure 2 illustrates the repetitive nature of hand planting that requires extreme trunk flexion with very few opportunities for rest.

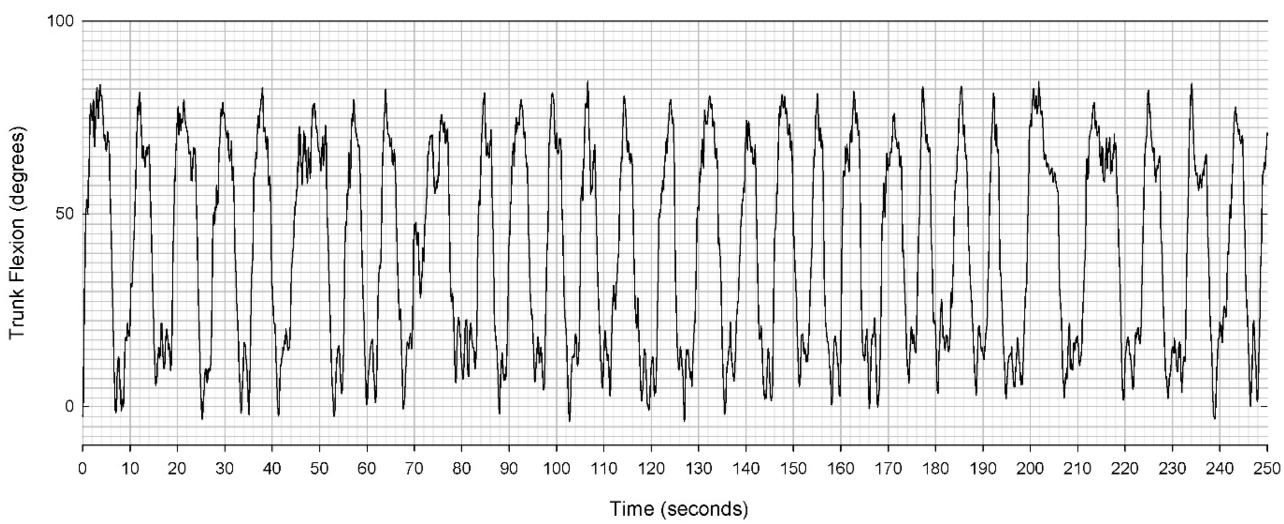

Figure 2. Representative segment of trunk flexion angle (degrees) during hand planting illustrating the repetitive nature of the task.

Table 2. Distributions of full-shift, hand planting, and non-planting occupational tasks postural summary measures.

Exposure Variable	Flexion						Lateral Bending					
	Full Shift		Planting		Non-planting		Full Shift		Planting		Non-planting	
Posture [a]	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10th Percentile (°)	-4.2	11.0	-3.0	10.0	-8.2	15.3	-16.3	19.2	-18.2	20.0	-8.2	7.1
50th Percentile (°)	19.0	13.4	18.7	12.3	19.7	21.6	5.0	15.5	3.4	11.9	0.5	5.6
90th Percentile (°)	65.9	13.0	69.6	11.8	52.9	22.4	19.7	21.4	17.4	14.8	10.2	7.4
Percentile Range (90^{th} – 10^{th}) (°)	70.2	5.1	72.6	4.7	61.2	14.4	36.0	13.5	35.6	15.7	18.4	2.5
Time in neutral posture (<15°) (%)	-	-	-	-	-	-	70.0	21.5	65.9	25.1	90.2	4.7
Time in neutral posture (<20°) (%)	50.4	15.5	48.8	14.8	56.3	22.9	-	-	-	-	-	-
Time in extreme posture (≥30°) (%)	-	-	-	-	-	-	2.2	3.6	2.3	3.6	0.4	0.6
Time in extreme posture (≥45°) (%)	29.4	9.9	30.9	9.3	24.2	17.3	-	-	-	-	-	-
Movement velocity	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10th Percentile (°/s)	2.3	0.4	2.7	0.4	0.9	0.3	13.0	23.1	13.1	23.1	0.9	0.7
50th Percentile (°/s)	15.8	2.0	18.5	1.8	6.7	1.7	50.8	73.8	51.9	73.5	7.3	4.3
90th Percentile (°/s)	53.0	5.2	59.8	5.2	30.6	5.1	51.1	26.9	55.1	31.0	30.3	11.3
Percentile Range (90^{th} – 10^{th}) (°/s)	50.7	5.0	57.1	4.9	29.7	4.9	38.1	44.8	42.0	48.1	29.4	10.6
Velocity EVA (<5°/s for <3s)	19.9	2.0	17.0	1.9	29.9	3.6	30.4	23.6	29.3	23.1	26.3	5.8
Velocity EVA (<5°/s for ≥3s)	4.0	2.3	0.7	0.7	18.1	15.5	6.2	3.9	3.7	5.5	23.6	16.7
Time at low velocities (<5°/s) (%)	23.9	3.2	17.7	2.1	48.0	14.0	36.7	24.4	33.0	23.7	49.9	18.6
Time at high velocities (≥90°/s) (%)	4.2	6.4	2.7	1.1	0.6	0.4	4.1	3.7	4.7	4.1	1.2	1.5
Rest/Recovery	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time in neutral posture (<15°) for substantial periods (≥3s) (%)	-	-	-	-	-	-	50.2	20.6	44.8	25.2	75.9	15.5
Time in neutral posture (<20°) for substantial periods (≥3s) (%)	37.7	18.9	34.6	19.5	49.4	22.3	-	-	-	-	-	-
Time at low velocities for substantial periods (≥3s) (%)	4.0	2.3	0.7	0.7	14.4	8.9	11.9	12.7	9.4	12.1	20.1	12.8
Time in neutral posture (<15°) and low velocity for substantial periods (≥3s) (%)	-	-	-	-	-	-	22.7	5.4	19.2	9.5	42.6	13.6
Time in neutral posture (<20°) and low velocity for substantial periods (≥3s) (%)	14.9	5.3	11.1	3.3	27.7	13.9	-	-	-	-	-	-
#per min. of substantial periods (≥3s) in neutral posture (<15°) and low velocity (<5°/s)	-	-	-	-	-	-	0.4	0.2	0.3	0.4	1.1	0.6
#per min. of substantial periods (≥3s) in neutral posture (<20°) and low velocity (<5°/s)	0.2	0.1	0.1	0.0	0.7	0.4	-	-	-	-	-	-

[a] Negative values denote trunk extension or lateral bending to the left; Positive values denote trunk flexion or lateral bending to the right.

Table 3. Distributions of full-shift, hand planting, and non-planting occupational tasks postural summary measures.

Exposure Variable	Left Arm Elevation						Right Arm Elevation					
	Full Shift		Planting		Non-planting		Full Shift		Planting		Non-planting	
Posture	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10th Percentile (°)	15.7	3.3	16.5	3.5	13.2	3.4	15.9	3.5	16.0	3.8	15.3	3.5
50th Percentile (°)	32.9	3.6	34.3	4.4	28.1	2.5	32.5	5.2	33.4	5.6	28.8	4.5
90th Percentile (°)	59.9	11.2	61.8	11.8	52.9	11.3	66.4	7.4	69.7	8.1	54.5	13.6
Percentile Range (90^{th} – 10^{th}) (°)	44.2	13.2	45.3	13.6	39.7	13.2	50.5	5.1	53.7	6.9	39.2	12.5
Time in neutral posture (<30°) (%)	43.3	7.6	39.2	9.2	57.5	8.3	45.7	9.6	43.0	9.3	55.2	12.4
Time in extreme posture (≥60°) (%)	10.4	7.4	11.3	8.3	7.0	5.3	14.8	5.9	16.6	6.8	7.9	4.7
Movement velocity	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10th Percentile (°/s)	2.3	0.4	2.7	0.4	1.1	0.5	3.2	1.0	3.8	1.1	1.3	0.5
50th Percentile (°/s)	16.1	2.3	18.0	1.8	9.7	3.7	24.5	5.7	28.1	6.1	12.2	3.5
90th Percentile (°/s)	53.7	9.0	57.6	8.4	41.2	10.9	98.9	18.1	112.8	19.5	51.1	11.1
Percentile Range (90^{th} – 10^{th}) (°/s)	51.3	8.7	54.8	8.3	40.0	10.4	95.7	17.3	109.1	18.7	49.8	10.7
Velocity EVA (<5°/s for <3s)	17.8	2.0	16.0	1.3	23.7	4.1	13.8	2.2	12.0	2.0	20.1	2.6
Velocity EVA (<5°/s for ≥3s)	4.2	1.7	1.4	1.2	13.2	6.1	4.1	1.7	1.4	1.2	12.6	5.9
Time at low velocities (<5°/s) (%)	22.0	3.3	17.3	1.8	36.9	8.6	17.9	3.4	13.4	2.7	32.7	7.4
Time at high velocities (≥90°/s) (%)	2.7	1.6	3.0	1.7	1.7	1.2	12.2	4.0	14.8	4.5	3.2	1.4
Rest/Recovery	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time in neutral posture (<30°) for substantial periods (≥3s) (%)	20.0	8.2	13.6	8.2	41.6	10.4	21.1	9.7	16.4	9.0	36.9	13.3
Time at low velocities for substantial periods (≥3s) (%)	4.2	1.7	1.4	1.2	13.2	6.1	4.1	1.7	1.4	1.2	12.6	5.9
Time in neutral posture (<30°) and low velocity for substantial periods (≥3s) (%)	12.0	2.7	8.2	1.8	24.5	7.4	11.1	3.5	8.5	2.8	19.5	6.1
#per min. of substantial periods (≥3s) in neutral posture (<30°) and low velocity (<5°/s)	0.2	0.1	0.1	0.0	0.7	0.3	0.2	0.1	0.1	0.1	0.5	0.2

4.4. Full-shift planting occupational physical activity

The hand planters spent the majority (>50%) of their time performing moderate, vigorous, or very vigorous levels of PA regardless of IMU location (Table 4). The IMU located on the right arm registered the most intense PA with 73.5% of work time categorized as vigorous or very vigorous. The left arm registered 63.1% of work time categorized as vigorous or very vigorous. Energy expenditure expressed as METs determined by the IMU on the dominant hip indicated a majority of full-shift time spent in "moderate" physical activity (mean = 3.2 METs, SD = 0.66).

Table 4. Distributions of percentage of work time in different PA categories.

IMU Location	**Sedentary/ Light**		**Moderate**		**Vigorous**		**Very Vigorous**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Left Arm	8.8	3.8	28.1	9.2	60.3	8.5	2.8	5.4
Right Arm	7.4	3.2	19.1	5.7	43.9	16.7	29.6	20.7
Trunk	13.4	4	49.8	20.1	36.8	22	0	0
Hip	15.9	4.5	75.2	7.6	8.9	9.4	0	0
Average	11.4	3.9	43.1	10.7	37.5	14.2	8.1	6.5

CHAPTER FIVE

5. Discussion

Health and safety outcomes for hand planters are generally not well understood. Vulnerability due to immigration / seasonal worker status, language difficulties, and adverse working conditions likely contribute to the lack of research (Grzywacz et al., 2013; McDaniel & Casanova, 2005; Sarathy & Casanova, 2008). The few studies that have been performed among hand planters have concluded that strenuous work pace, inadequate rest periods, and poor living conditions may have negative effects on planter safety and health (Giguere et al., 1993; Hodges & Kennedy, 2011; Roberts, 2002; Trites et al., 1993). The results of the current study contribute to the scientific literature by providing novel information regarding hand planter exposures to physical risk factors that are associated with work-related MSDs in the Southeastern United States.

5.1 Occupational physical activity

In general, hand planters were exposed to high levels of occupational PA. “Vigorous” and “very vigorous” was measured to be the predominant PA intensity levels exhibited by the workers for the left and right arms (63.1% and 73.5% of shift duration, respectively). Similarly, “moderate”, “vigorous”, and “very vigorous” PA comprised 84.1% of the hand planters’ work shifts when using data from the IMU secured to the right hip, the most common location for assessing PA (Freedson, Bowles, Troiano, & Haskell, 2012; Welk, McClain, & Ainsworth, 2012). This is dramatically higher than what has been measured among registered nurses (7.9%; (Schall Jr., Fethke, & Chen, 2016b)), construction workers (12.0%; (Arias et al., 2015)), and patient care workers (1.0%; (Umukoro et al., 2013)). Average METs for the present study indicate comparable summary values with other farming, fishing, and forestry workers, and higher METs than production healthcare support occupational groups (Tudor-Locke, Ainsworth, Washington, & Troiano, 2011).

5.2 Posture and movement velocities

Results from the present study indicate that hand planters are exposed to higher levels of extreme postures and movement velocities for the upper arms and trunk when compared to several other occupational groups that report a high prevalence of work-related MSDs. Hand planters in the present study were observed to exhibit a mean 90th percentile trunk inclination angle of 65.9°. This was greater than material pickers (26.0°, (Christmansson et al., 2002)), poultry processing workers (16.0°, (Juul-Kristensen, Hansson, Fallentin, Andersen, & Ekdahl, 2001)), automobile assembly workers (28.0°, (Kazmierczak et al., 2005)), and registered nurses (35.9°, (Schall Jr., Fethke, & Chen, 2016b)). Trunk flexion ≥45° was measured for 29.4% of the work shift, presumably due to the high frequency of forward bending to plant seedlings at ground level (Figure 2). Right arm elevation results indicate mean dominant arm elevation levels of 49.3° which is higher than what has been observed for apple orchard workers (22.7°, (Thamsuwan & Johnson, 2015)). While it is unclear how high and for what duration the arms must be elevated for MSDs of the shoulder to occur, existing evidence suggests angles >60° are associated with shoulder pain (Hanvold, Wærsteda, Mengshoel, Bjertness, & Veiersted, 2015; Putz-Anderson et al., 1997; Svendsen, Gelineck, et al., 2004; Svendsen, Bonde, Mathiassen, Stengaard-Pedersen, & Frich, 2004). High movement velocities (>90°/s) were also measured for the right and left upper arms (98.9°/s and 53.7°/s, respectively). These movement velocities were greater than studies of air traffic controllers (37.0°/s and 31.0°/s, (Arvidsson et al., 2006)) and dairy parlor workers (14.3°/s and 12.2°/s, (Douphrate et al., 2012)). The results indicate that hand planting reforestation workers may be at increased risk of developing neck and shoulder pain as a direct result of their work-related activities.

5.3 Muscle activity

Studies examining full shift anterior deltoid muscle activity are limited in the scientific literature. A recent study examining muscular effort of ophthalmologists using comparable reference voluntary contraction procedures indicated considerably lower muscle activity exposures of the dominant (right) arm anterior deltoid muscle group among ophthalmologists (mean = 19.9 %RVE and 90th percentile APDF = 77.9 %RVE; (Fethke et al., 2015)) when compared to the hand planters in the present study (mean = 42.7 %RVE and 90th percentile APDF = 118.8 %RVE). However, it is important to note that ophthalmologists were observed to have greater muscle activity exposures of the non-dominant (left) arm anterior deltoid muscle group (mean = 22.6 %RVE and 90th percentile APDF = 65.3 %RVE; (Fethke et al., 2015)) in comparison to the hand planters in this study (mean = 16.7 %RVE and 90th percentile APDF = 43.1 %RVE). This result, as well as the documented increased muscle activity required of the dominant (right) arm anterior deltoid muscle group during planting only (mean = 47.8 %RVE and 90th percentile APDF = 133.0 %RVE; Table 1), demonstrates the high intensity work required of hand planters while using a dibble bar to plant. The increased anterior deltoid muscle activity among hand planters suggests that hand planters may be at increased risk for developing neck and shoulder pain in comparison to ophthalmologists, an occupational group that reports a high prevalence of neck and shoulder pain (Kitzmann et al., 2012).

While available research on upper trapezius muscle activity is more widely available, variability in normalization procedures limits comparisons. Dominant upper trapezius 90th percentile mean APDF full shift results suggest hand planters experience markedly higher trapezius muscle activity (112.1 %RVE) when compared to stud welders (54.1%, (Fethke, Gant, & Gerr, 2011)), ophthalmologists (62.9%, (Fethke et al., 2015)), office workers (61.1%, (Fethke, Gerr, Anton, Cavanaugh, & Quickel, 2012)), custodians (64.1%, (Fethke et al., 2012)), and maintenance workers at a university (77.5%, (Fethke et al., 2012)). Other studies using a similar RVE normalization methodology indicate greater upper trapezius muscle activity among laminate workers (Balogh, Hansson, Ohlsson, Strömberg, & Skerfving, 1999), word processing task completion subjects (Cook et al., 2004), hospital workers and cleaners (Hansson et al., 2000), and lab simulated material pickers, light material handlers, and heavy material handlers (Nordander et al., 2004).

Although the act of planting with a dibble bar was clearly the most demanding task performed by the hand planters, muscle activity during non-planting work tasks was still relatively high and even exceeded planting activities in some cases (e.g., left upper trapezius muscle group). The high peak muscle activity levels observed during non-planting (79.5 %RVE 90th percentile APDF for left upper trapezius muscle group) tasks demonstrate the intense level of physical demand required of hand planters. Non-planting tasks include rigorous shaking and striking of seedlings against objects in order to dislodge ice particles prior to placing in bags, as well as unloading and carrying the boxes of seedlings to staging areas inaccessible by vehicles. These physically demanding work tasks likely contribute to the high levels of muscle activity observed during the non-planting portion of the work shift and suggest that all aspects of hand planting may benefit from increased research attention.

5.4 Interventions

Available research regarding interventions for reducing exposure to physical risk factors for MSDs among hand planters is limited. Administrative controls, such as improvements in worker training, may not have substantial potential for reducing planting workload since work pace rather than work efficiency is related to higher productivity (Hodges & Kennedy, 2011). However, it is important to note that Hodges and Kennedy studied hand planters in Canada that were compensated via a piece rate strategy in comparison to the hand planters in this study that were compensated at an hourly rate. Planter's choice of tool for efficiency may contribute to injury and ergonomic risks (Robinson et al., 1993). Development of an ambidextrous planting tool or methodology may help to decrease the disparity of muscle activity between dominant and non-dominant muscle groups and potentially help prevent the development of MSDs among hand planters. Ground conditions may also be an important factor when considering physical demands during the planting process. Frozen ground in the morning is an environmental condition that can change the force requirements for the worker to reach planting depth in the soil. Further investigation into environmental and soil variations may provide insight into ideal planting conditions for the reduction of worker physical stress.

5.5 Study limitations

Several limitations of this feasibility study should be acknowledged. First, a small sample size of geographically homogenous workers from one contractor limits the generalizability of our results to the wider field of hand planting reforestation work. This study did however show comparable average planting time (78.4%) to the 71-94% observed in a previous study (Hodges & Kennedy, 2011). Second, the hand planters recruited for this study were paid on an hourly compensation scale which differs from the piece rate payment strategy that is often used among hand planters. The exposures to physical risk factors observed in this study may, therefore, not be representative of the exposures among hand planters paid via piece rate. Third, time constraints in the field for data collection setup made it infeasible to collect low back EMG data in the present study. The addition of low back muscle activation data would allow for a more thorough characterization of the physical risk factors associated with hand planting and is recommended for future studies when feasible. The intense physical demands of hand planting itself also presents a challenge to future research. The location of the seedling bag worn directly over the EMG sensors on the right and left trapezius muscles can result in a loss of EMG to skin contact when donning and doffing the bag. While water-proof protective sealants and tapes were used to reduce the potential for compromise of the skin-electrode interface, loss of some participant's EMG data did still occur. Finally, this study did not address certain job stressors, such as psychosocial stress and time pressure, which are commonly associated with MSDs (da Costa & Vieira, 2010; Hagen et al., 1998). Research evaluating the broad spectrum of work demands challenging hand planters is needed. Additionally, more research is needed to understand the exposures to risk factors of mechanized planting, an alternative to hand planting for reforestation.

CHAPTER SIX

6. Conclusions

This study represents the first effort to characterize the upper arm postures, movement velocities, and muscle activation patterns of reforestation hand planters using direct measurement methods. Results of this study indicate that hand planters are exposed to higher levels of extreme posture and movement velocities for the upper arms and trunk in comparison to several other occupational groups that report a high prevalence of work-related MSDs, such as healthcare and construction. The findings indicate a need for continued field-based research among hand planters to identify and/or develop maximally effective intervention strategies and tools.

References

Arias, O. E., Caban-Martinez, A. J., Umukoro, P. E., Okechukwu, C. A., & Dennerlein, J. T. (2015). Physical Activity Levels at Work and Outside of Work Among Commercial Construction Workers: *Journal of Occupational and Environmental Medicine*, *57*(1), 73–78. https://doi.org/10.1097/JOM.0000000000000303

Arvidsson, I., Arvidsson, M., Axmon, A., Hansson, G.-Å., Johansson, C. R., & Skerfving, S. (2006). Musculoskeletal disorders among female and male air traffic controllers performing identical and demanding computer work. *Ergonomics*, *49*(11), 1052–1067. https://doi.org/10.1080/00140130600733816

Balogh, I., Hansson, G.-Å., Ohlsson, K., Strömberg, U., & Skerfving, S. (1999). Interindividual variation of physical load in a work task. *Scandinavian Journal of Work, Environment & Health*, *25*(1), 57–66. https://doi.org/10.5271/sjweh.384

BLS. (2014). *Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2013* (No. USDL-14-2246). Washington, DC: Department of Labor.

BLS. (2015). *Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2014* (News Release No. USDL 15-2205). Washington, DC: Department of Labor.

Bovenzi, M., Zadini, A., Franzinelli, A., & Borgogni, F. (1991). Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration. *Ergonomics*, *34*(5), 547–562. https://doi.org/10.1080/00140139108967336

Christmansson, M., Medbo, L., Hansson, G.-Å., Ohlsson, K., Unge Byström, J., Möller, T., & Forsman, M. (2002). A case study of a principally new way of materials kitting—an evaluation of time consumption and physical workload. *International Journal of Industrial Ergonomics*, *30*(1), 49–65. https://doi.org/10.1016/S0169-8141(02)00077-X

Cook, C., Burgess-Limerick, R., & Papalia, S. (2004). The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use. *Applied Ergonomics*, *35*(3), 285–292. https://doi.org/10.1016/j.apergo.2003.12.005

Criswell, E. (2010). *Cram's introduction to surface electromyography*. Jones and Bartlett Publishers.

da Costa, B. R., & Vieira, E. R. (2010). Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. *American Journal of Industrial Medicine*, *53*(3), 285–323. https://doi.org/10.1002/ajim.20750

Denbeigh, K., Slot, T. R., & Dumas, G. A. (2013). Wrist postures and forces in tree planters during three tree unloading conditions. *Ergonomics*, *56*(10), 1599–1607. https://doi.org/10.1080/00140139.2013.824615

Douphrate, D. I., Fethke, N. B., Nonnenmann, M. W., Rosecrance, J. C., & Reynolds, S. J. (2012). Full shift arm inclinometry among dairy parlor workers: A feasibility study in a challenging work environment. *Applied Ergonomics*, *43*(3), 604–613. https://doi.org/10.1016/j.apergo.2011.09.007

Drake, J. D. M., & Callaghan, J. P. (2006). Elimination of electrocardiogram contamination from electromyogram signals: An evaluation of currently used removal techniques. *Journal of Electromyography and Kinesiology*, *16*(2), 175–187. https://doi.org/10.1016/j.jelekin.2005.07.003

Fethke, N. B., Gant, L. C., & Gerr, F. (2011). Comparison of biomechanical loading during use of conventional stud welding equipment and an alternate system. *Applied Ergonomics*, *42*(5), 725–734. https://doi.org/10.1016/j.apergo.2010.11.007

Fethke, N. B., Gerr, F., Anton, D., Cavanaugh, J. E., & Quickel, M. T. (2012). Variability in Muscle Activity and Wrist Motion Measurements Among Workers Performing Non-Cyclic Work. *Journal of Occupational and Environmental Hygiene*, *9*(1), 25–35. https://doi.org/10.1080/15459624.2012.634361

Fethke, N. B., Schall Jr., M. C., Determan, E. M., & Kitzmann, A. S. (2015). Neck and shoulder muscle activity among ophthalmologists during routine clinical examinations. *International Journal of Industrial Ergonomics*, *49*, 53–59. https://doi.org/10.1016/j.ergon.2015.06.001

Freedson, P., Bowles, H. R., Troiano, R., & Haskell, W. (2012). Assessment of physical activity using wearable monitors: Recommendations for monitor calibration and use in the field. *Medicine and Science in Sports and Exercise*, *44*(1 Suppl 1), S1–S4. https://doi.org/10.1249/MSS.0b013e3182399b7e

Freedson, P., Melanson, E., & Sirard, J. (1998). Calibration of the Computer Science and Applications, Inc. accelerometer: *Medicine & Science in Sports & Exercise*, *30*(5), 777–781. https://doi.org/10.1097/00005768-199805000-00021

Giguere, D., Belanger, R., Gauthier, J.-M., & Larue, C. (1993). Ergonomics aspects of tree-planting using “multipot” technology. *Ergonomics*, *36*(8), 963–972. https://doi.org/10.1080/00140139308967960

Grzywacz, J. G., Lipscomb, H. J., Casanova, V., Neis, B., Fraser, C., Monaghan, P., & Vallejos, Q. M. (2013). Organization of work in the agricultural, forestry, and fishing sector in the US southeast: Implications for immigrant workers’ occupational safety and health. *American Journal of Industrial Medicine*, *56*(8), 925–939.

Hagen, K., Magnus, P., & Vetlesen, K. (1998). Neck/shoulder and low-back disorders in the forestry industry relationship to work tasks and perceived psychosocial job stress. *Ergonomics*, *41*(10), 1510–1518. https://doi.org/10.1080/001401398186243

Hansson, G.-Å., Nordander, C., Asterland, P., Ohlsson, K., Strömberg, U., Skerfving, S., & Rempel, D. (2000). Sensitivity of trapezius electromyography to differences between work tasks — influence of gap definition and normalisation methods. *Journal of Electromyography and Kinesiology*, *10*(2), 103–115. https://doi.org/10.1016/S1050-6411(99)00030-9

Hanvold, T. N., Wærsteda, M., Mengshoel, A. M., Bjertness, E., & Veiersted, K. B. (2015). Work with prolonged arm elevation as a risk factor for shoulder pain: A longitudinal study among young adults. *Applied Ergonomics*, *47*, 43–51.

Hodges, A. N., & Kennedy, M. D. (2011). Physical exertion and working efficiency of reforestation workers. *Journal of Occupational Medicine and Toxicology*, *6*, 20. https://doi.org/10.1186/1745-6673-6-20

Horton, R. (2013). GBD 2010: understanding disease, injury, and risk. *The Lancet*, *380*(9859), 2053–2054.

Jackson, J. A., Mathiassen, S. E., & Dempsey, P. G. (2009). Methodological variance associated with normalization of occupational upper trapezius EMG using sub-maximal reference contractions. *Journal of Electromyography and Kinesiology*, *19*(3), 416–427. https://doi.org/10.1016/j.jelekin.2007.11.004

Jonsson, B. (1982). Measurement and evaluation of local muscular strain in the shoulder during constrained work. *Journal of Human Ergology*, *11*(1), 73–88.

Juul-Kristensen, B., Hansson, G.-Å., Fallentin, N., Andersen, J. H., & Ekdahl, C. (2001). Assessment of work postures and movements using a video-based observation method and direct technical measurements. *Applied Ergonomics*, *32*(5), 517–524. https://doi.org/10.1016/S0003-6870(01)00017-5

Kazmierczak, K., Mathiassen, S. E., Forsman, M., & Winkel, J. (2005). An integrated analysis of ergonomics and time consumption in Swedish "craft-type" car disassembly. *Applied Ergonomics*, *36*(3), 263–273. https://doi.org/10.1016/j.apergo.2005.01.010

Kitzmann, A. S., Fethke, N. B., Baratz, K. H., Zimmerman, M. B., Hackbarth, D. J., & Gehrs, K. M. (2012). A survey study of musculoskeletal disorders among eye care physicians compared with family medicine physicians. *Ophthalmology*, *119*(2), 213–220.

Mathiassen, S. E., Winkel, J., & Hägg, G. M. (1995). Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies — A review. *Journal of Electromyography and Kinesiology*, *5*(4), 197–226. https://doi.org/10.1016/1050-6411(94)00014-X

McDaniel, J., & Casanova, V. (2003). Pines in Lines: Tree Planting, H2B Guest Workers, and Rural Poverty in Alabama. *Southern Rural Sociology*, *19*(1), 73–96.

McDaniel, J., & Casanova, V. (2005). Forest Management and the H2B Guest Worker Program in the Southeastern United States: An Assessment of Contractors and Their Crews. *Journal of Forestry*, *103*(3), 114–119.

McDonald, T. P., Fulton, J. P., Darr, M. J., & Gallagher, T. V. (2008). Evaluation of a system to spatially monitor hand planting of pine seedlings. *Computers and Electronics in Agriculture*, *64*(2), 173–182. https://doi.org/10.1016/j.compag.2008.04.011

Nordander, C., Balogh, I., Mathiassen, S. E., Ohlsson, K., Unge, J., Skerfving, S., & Hansson, G.-Å. (2004). Precision of measurements of physical workload during standardised manual handling. Part I: Surface electromyography of m. trapezius, m. infraspinatus and the forearm extensors. *Journal of Electromyography and Kinesiology*, *14*(4), 443–454. https://doi.org/10.1016/j.jelekin.2003.12.003

Punnett, L. (2014). Musculoskeletal disorders and occupational exposures: How should we judge the evidence concerning the causal association? *Scandinavian Journal of Public Health*, *42*(13 suppl), 49–58. https://doi.org/10.1177/1403494813517324

Putz-Anderson, V., Bernard, B. P., Burt, S. E., Cole, L. L., Fairfield-Estill, C., Fine, L. J., … others. (1997). Musculoskeletal disorders and workplace factors. *National Institute for Occupational Safety and Health (NIOSH)*. Retrieved from http://static-cdn.compliancetrainingonline.com/docs/97-141.pdf

Quandt, S. A., Kucera, K. L., Haynes, C., Klein, B. G., Langley, R., Agnew, M., … Nussbaum, M. A. (2013). Occupational health outcomes for workers in the agriculture, forestry and fishing sector: Implications for immigrant workers in the southeastern US. *American Journal of Industrial Medicine*, *56*(8), 940–959. https://doi.org/10.1002/ajim.22170

Redfern, M., Hughes, R., & Chaffin, D. (1993). High-pass filtering to remove electrocardiographic interference from torso EMG recordings. *Clinical Biomechanics*, *8*(1), 44–48. https://doi.org/10.1016/S0268-0033(05)80009-9

Roberts, D. (2002). In-Season Physiological and Biochemical Status of Reforestation Workers. *Journal of Occupational & Environmental Medicine*, *44*(6), 559–567.

Robinson, D. G., Trites, D. G., & Banister, E. W. (1993). Physiological effects of work stress and pesticide exposure in tree planting by British Columbia silviculture workers. *Ergonomics*, *36*(8), 951–961. https://doi.org/10.1080/00140139308967959

Rota, S., Rogowski, I., Champely, S., & Hautier, C. (2013). Reliability of EMG normalisation methods for upper-limb muscles. *Journal of Sports Sciences, 31*(15), 1696–1704. https://doi.org/10.1080/02640414.2013.796063

Sarathy, B., & Casanova, V. (2008). Guest workers or unauthorized immigrants? The case of forest workers in the United States. *Policy Sciences*, *41*(2), 95–114.

Schall Jr., M. C., Fethke, N. B., & Chen, H. (2016a). Evaluation of four sensor locations for physical activity assessment. *Applied Ergonomics*, *53*, *Part A*, 103–109. https://doi.org/10.1016/j.apergo.2015.09.007

Schall Jr., M. C., Fethke, N. B., & Chen, H. (2016b). Working postures and physical activity among registered nurses. *Applied Ergonomics*, *54*, 243–250. https://doi.org/10.1016/j.apergo.2016.01.008

Schall Jr., M. C., Fethke, N. B., Chen, H., Oyama, S., & Douphrate, D. I. (2016). Accuracy and repeatability of an inertial measurement unit system for field-based occupational studies. *Ergonomics*, *59*(4), 591–602. https://doi.org/10.1080/00140139.2015.1079335

South, D., & Mexal, J. (1984). Growing the “best” seedling for reforestation success. Alabama Agricultural Experiment Station, Auburn University.

Stjernberg, E. (1988). *A study of manual tree planting operations in Central and Eastern Canada*. Forest Engineering Research Institute of Canada.

Stjernberg, E. (2003). Injury reduction and performance enhancements in tree planters: productivity and quality analysis. *Advantage*, *4*(11).

Svendsen, S. W., Bonde, J. P., Mathiassen, S. E., Stengaard-Pedersen, K., & Frich, L. H. (2004). Work related shoulder disorders: quantitative exposure-response relations with reference to arm posture. *Occupational and Environmental Medicine*, *61*(10), 844–853.

Svendsen, S. W., Gelineck, J., Mathiassen, S. E., Bonde, J. P., Frich, L. H., Stengaard-Pedersen, K., & Egund, N. (2004). Work above shoulder level and degenerative alterations of the rotator cuff tendons: a magnetic resonance imaging study. *Arthritis & Rheumatism*, *50*(10), 3314–3322.

Thamsuwan, O., & Johnson, P. (2015). Comparing Upper Arm and Back Postural Exposures between Apple Harvesting with Ladders and Mobile Platform. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*.

Thorn, S., Søgaard, K., Kallenberg, L. A. C., Sandsjö, L., Sjøgaard, G., Hermens, H. J., … Forsman, M. (2007). Trapezius muscle rest time during standardised computer work – A comparison of female computer users with and without self-reported neck/shoulder complaints. *Journal of Electromyography and Kinesiology*, *17*(4), 420–427. https://doi.org/10.1016/j.jelekin.2006.04.010

Trites, D. G., Robinson, D. G., & Banister, E. W. (1993). Cardiovascular and muscular strain during a tree planting season among British Columbia silviculture workers. *Ergonomics*, *36*(8), 935–949. https://doi.org/10.1080/00140139308967958

Tudor-Locke, C., Ainsworth, B., Washington, T. L., & Troiano, R. (2011). Assigning Metabolic Equivalent Values to the 2002 Census Occupational Classification System. *Journal of Physical Activity and Health*, *8*(4), 581–586.

Umukoro, P., Arias, O. E., Stoffel, S. D., Hopcia, K., Sorensen, G., & Dennerlein, J. T. (2013). Physical activity at work contributes little to patient care workers' weekly totals. *Journal* *of Occupational and Environmental Medicine*, *55*(Supplement 12S), S63–S68. https://doi.org/10.1097/JOM.0000000000000046

Upjohn, T., Keir, P., & Dumas, G. (2008). Upper body posture during tree planting work. In *Proceedings NACOB.*

Vos, T., Flaxman, A. D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., … Murray, C. J. (2012). Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2163–2196. https://doi.org/10.1016/S0140-6736(12)61729-2

Wahlström, J., Mathiassen, S. E., Liv, P., Hedlund, P., Ahlgren, C., & Forsman, M. (2010). Upper Arm Postures and Movements in Female Hairdressers across Four Full Working Days. *Annals of Occupational Hygiene*, *54*(5), 584–594. https://doi.org/10.1093/annhyg/meq028

Welk, G. J., McClain, J., & Ainsworth, B. E. (2012). Protocols for evaluating equivalency of accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise*, *44*(1 Suppl 1), S39–49.

Whaley, M. H., Brubaker, P. H., Otto, R. M., Armstrong, L. E., Medicine, A. C. of S., & others. (2005). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins, US.

Yoo, I.-G., Jung, M.-Y., Jeon, H.-S., & Lee, J. (2010). Effects of Wrist-extension Orthosis on Shoulder and Scapular Muscle Activities during Simulated Assembly Tasks. *Industrial Health*, *48*(1), 108–114. https://doi.org/10.2486/indhealth.48.108