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Characterizing exposure to physical risk factors among reforestation hand planters in the Southeastern United States

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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 fourteen Southeastern reforestation hand planters over one work shift. Results indicated that hand planters are exposed to physical risk factors such as extreme trunk postures (32.5% of time spent in ≥45° trunk flexion) and high effort muscle exertions (e.g., mean root-mean-square right upper trapezius amplitude of 54.1% reference voluntary exertion) that may place them at increased risk for developing MSDs. The findings indicate a need for continued field-based research among hand planters to identify and/or develop maximally effective interventions.

1. Introduction

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

Hand planters carry a large bag of seedlings over the shoulders and plant the seedlings one at a time at a desired spacing using a planting tool. Commonly used planting tools include a hoedad, which resembles an axe with a long blade, and a dibble bar, which is a narrow spade shovel (Fig. 1A). Typically, the planter forces the planting tool into the ground using the dominant arm and his or her foot to dig a hole for the seedling. He or she then reaches behind their back into the carried bag to remove a seedling, bends at the waist to place the seedling into the hole, and seals the hole with his or her hand or foot. Planting crews range in size depending on the size of the acreage to be planted (Fig. 1B). Despite being physically demanding work (Giguère et al., 1993; Hodges and Kennedy, 2011; Roberts, 2002; Robinson et al., 1993; Trites et al., 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. Hand planters of containerized seedlings in eastern and central Canada have been observed to average 11.7 s per planting (Stjernberg, 1988). In British Columbia, average production rates were above 1900 plantings per day or roughly 10 s per seedling (Stjernberg, 2003). Another survey of planters in Canada reported an average productivity of 1245 plantings per day (Giguère et al., 1993). McDonald et al. (2008) observed that hand planting of bareroot seedlings with a dibble bar took 7 s or less for 70% of plantings. Assuming 60% productive time, the planting rate would be about

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Fig. 1. (A) A hand planter using a 'T' handle dibble bar to plant a seedling. (B) A hand planting crew working in a forest in the Southeastern United States.

300 plantings per hour or 2400 plantings across an 8-h shift. For these reasons, hand planting has been reported on six times more acres than machine planting (Folegatti et al., 2007).

Hand planters are often compensated based upon production. This practice results in low job desirability and high turnover, and creates working conditions in which injuries and musculoskeletal pain may go unreported (Grzywacz et al., 2013; Hodges and Kennedy, 2011; McDaniel and Casanova, 2003). 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 (BLS, 2014; BLS, 2015). The low back, neck, and shoulder are common sites for pain symptoms among hand planters (Hagen et al., 1998; Slot and Dumas, 2010).

Although several studies are available describing the main elements of the planting routine and the intensive cardiovascular demands of hand planting (Denbeigh et al., 2013; Giguère et al., 1993; Hodges and Kennedy, 2011; Slot, 2010; Slot et al., 2010; Upjohn et al., 2008), limited information is available regarding exposures to physical risk factors (e.g., sustained and/or non-neutral postures of the low back and upper arm, high movement velocities, and forceful muscular exertions; da Costa and Vieira, 2010) associated with the development of adverse musculoskeletal health outcomes among hand planters. The most comprehensive assessment to date was performed by Slot et al. (2010) and Upjohn et al. (2008) who evaluated the upper body and trunk postures of 14 tree planters working in Northern Ontario. Results of their work indicated that planters spent over 50% of the work day (4.3 h) with the trunk flexed >45° and that extreme shoulder postures (defined in the current study as elevation ≥60°) were required for particular aspects of the planting cycle. However, many common summary measures used to characterize and compare exposures among occupational groups such as percentiles of the amplitude probability distribution function (APDF; Jonsson, 1982) were not reported for the shoulder. Furthermore, the shoulder data were only collected in two, 15 min increments at the very beginning and very end of the work shift using observational methods. The study also did not involve any measurement of the muscle activity required during the planting tasks and the study sample only included Canadian tree planters using a different type of planting tool ('D' handle spade) that may not be representative of the exposures experienced by planters in the Southeastern United States.

Characterizations of exposures to physical risk factors among Southeastern forestry workers are needed to design tools and interventions capable of mitigating exposures and preventing the development of musculoskeletal conditions (Quandt et al., 2013). The objectives of this pilot study, therefore, were to (i) characterize the trunk and upper arm postures, movement velocities, and neck/shoulder muscle activation patterns of hand planters during full-shift work using direct measurement technologies, and (ii) compare these findings with data from other studies of occupational groups that commonly perform tasks associated with a high prevalence of musculoskeletal pain and symptoms in order to better understand the exposures to physical risk factors affecting hand planters.

2. Methods

2.1. Participants and study design

Fourteen male reforestation workers (mean age = 26.9 ± 6.0 years; mean body mass index = 24.8 ± 1.7 kg/m^2) were recruited from a reforestation contractor registered with the Alabama Forestry Commission for hand planting services. All of the participants enrolled in the study were compensated on an hourly basis by their employer. The participants were seasonal workers employed through H-2B visas. 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 was obtained from Auburn University prior to commencing study activities, and each participant provided informed consent.

2.2. Data collection procedures

Data were collected as participants performed hand planting tasks using direct measurement methods. The work location varied based on the planting schedule, but each participant started and ended the workday in the same forest stand. Each participant was observed for one full work shift during the prime planting season of January–February. The planting occurred when soil moisture conditions ranged from fresh to moist. The planting sites were within the coastal plain of Alabama and the soils are mostly free of stones in the surface horizons.

A research assistant shadowed each worker and recorded the time on a notepad (to the nearest minute) at which specific tasks began and ended. Observed tasks included, but were not limited to: 1) unloading boxes of tree seedlings from a refrigerated trailer, 2) loading seedlings into a bag for planting, and 3) the actual hand planting of the seedlings. The participants were provided all items necessary to complete their work by the contractor, and conducted their work as normal. The contractor reported an expected daily production rate of 2200 seedlings planted per day by each worker. Each participant used a dibble bar with a T-style handle as the primary tree planting tool and carried a bag of seedlings on his back. After conclusion of data collection each day, the research assistant transferred the field notes onto a computer for reference during data analysis.

2.3. Surface electromyography and forceful muscular exertions

Continuous surface electromyography (EMG) recordings were acquired bilaterally from the upper trapezius and anterior deltoid muscles. Pre-amplified 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). For each muscle, the mean voltage value of each unprocessed EMG signal was subtracted in order to remove DC offset. The file was visually scanned for the presence of electrocardiogram and/or electromagnetic (i.e., 60 Hz) interference. If interference was detected, it was attenuated using standard filtering methods (Drake and Callaghan, 2006; Redfern et al., 1993). Transient artifacts were also removed and replaced with the mean voltage of the recording period. 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 performed 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 et al., 2015; Mathiassen et al., 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 et al., 2004; Fethke et al., 2015; Rota et al., 2013; Yoo et al., 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-min rest between repetitions. Participants maintained each contraction for roughly 15 s and the mean RMS amplitude of the middle 10 s 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 et al., 2009; Thorn et al., 2007).

The mean amplitude of the normalized 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, the 10th, 50th, and 90th percentiles of the APDF (in %RVE) were calculated as well (Jonsson, 1982).

2.4. Direct measurements of posture, movement velocity, and rest/recovery

Direct measurements of non-neutral working postures were calculated using ActiGraph GT9X inertial measurement units (IMUs) (Actigraph, Pensacola, Florida, USA) secured to each participant using elastic neoprene straps. Specifically, an IMU was worn outside the workers clothes 1) on the anterior trunk at the sternal notch, 2) on each upper arm approximately one-half the distance between the lateral epicondyle and the acromion, and 3) on the dominant hip near the anterior superior iliac spine. Each IMU contained a tri-axial accelerometer, gyroscope, and magnetometer and stored data at a sampling rate of 100 Hz. Similar sensors have been recently used to characterize non-neutral postures and physical activity (PA) among workers in other industries such as construction and healthcare (Arias et al., 2015; Schall et al., 2016a; Umukoro et al., 2013).

A rotation matrix was used to align the x, y, and z-axis of each trunk IMU to the transverse, sagittal, and longitudinal (i.e., vertical) axis, respectively. Inclination measurements relative to gravity were subsequently calculated using a first-order complementary filter that combined raw acceleration and angular velocity information obtained from each IMU. Specifically, the complementary filter that had the following generalized structure:

$$\theta_n = (1-K)\left[\theta_{n-1} + \left(\dot{\theta}_n \times dt\right)\right] + K(\alpha_n) \quad (1)$$

where $\boldsymbol{\theta_n}$ represents the complementary inclination angle estimate at the current sample, $\boldsymbol{\theta_{n-1}}$ is the complementary inclination angle estimate at the previous sample, $\dot{\boldsymbol{\theta}}_{\boldsymbol{n}}$ is the angular velocity at the current sample, $\boldsymbol{\alpha_n}$ is the inclination angle at the current sample based solely on the inclination of the accelerometer with respect to gravity, and dt is the time between samples (Schall et al., 2016b; Schall et al., 2014). $\boldsymbol{\alpha_n}$ was calculated as $\tan^{-1}$ $(-\mathrm{Ax}/\sqrt{\mathrm{Ay}^2 + \mathrm{Az}^2})$ for rotations about the sagittal axis and as $\tan^{-1}$ (Ay/Az) for rotations about the transverse axis. $\dot{\boldsymbol{\theta}}_{\boldsymbol{n}}$ was calculated according to procedures outlined by Von Marcard (2010). An Euler rotation sequence of trunk lateral bending [right (+), left (−)] followed by trunk inclination [flexion (+), extension (−)] was used to ensure that trunk inclination was not constrained to a range of 180°.

For the upper arms, the local coordinate sensor frame was used. Specifically, the x, z, and y-axis of each upper arm IMU aligned with the sagittal, transverse, and longitudinal (i.e., vertical) axis, respectively. Upper arm elevation was calculated as rotation about the sagittal axis with an offset of 90° added to ensure that upper arm elevation was between 0° and 180°. This approach was used to improve the accuracy of the inclination estimates given the high speed motions used by the planters. High speed motions have been observed to negatively affect the accuracy of inclination measurements derived solely from an accelerometer (Amasay et al., 2009; Bernmark and Wiktorin, 2002; Ligorio and Sabatini, 2015). The complementary filter has shown RMS differences of 5.4° for the trunk and 8.5° for the upper arm in comparison to a “gold-standard” optical motion capture system when used with IMUs similar to those employed in this study (Schall et al., 2016b). All inclination estimates were down sampled to 20 Hz using linear interpolation to match the effective sampling rate of the EMG data following RMS processing.

The resulting trunk and the upper arm elevation waveforms were used to obtain median, peak, and static flexion and elevation levels. The peak flexion and elevation levels were defined as those associated with the 90th percentile of the APDF, while the static flexion and elevation levels were defined as those associated with the 10th percentile of the APDF. Differences between the estimates of the 90th and 10th percentiles (referred to as angular displacement variation) were calculated to estimate the range of motion for each body segment. ‘Extreme’ postures were defined as having the trunk flexed ≥45°, the trunk laterally bent ≥30°, and/or the upper arms elevated ≥60°. 'Neutral' postures were defined as having the trunk flexed <20°, the trunk laterally bent <15°, and/or the upper arms elevated <30°.

The angular displacement waveforms of trunk flexion/extension and upper arm elevation were differentiated and full-wave rectified to obtain movement velocities. Consistent with previous studies (Douphrate et al., 2012; Kazmierczak et al., 2005; Schall et al., 2016a; Wahlstrom et al., 2010), 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 neutral posture (<20° for trunk flexion and <30° 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 s) in a neutral posture.

2.5. Occupational physical activity

Full shift occupational PA summary measures were obtained from the IMUs using available software (ActiLife 6.13, Actigraph, Pensacola, Florida USA). 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 of PA intensity were "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).

2.6. Statistical analysis

Each posture, movement velocity, and rest/recovery exposure metric was described with descriptive statistics (mean, standard deviation [SD]) across all participants. The frequencies and durations of planting and non-planting activities were described using proportions and means and SDs, respectively.

3. Results

The average shift length for the 14 hand planters that participated in this study was 433.9 (SD = 88.0) minutes. Planting comprised 75.8% of the shift time. The remaining 24.2% of the shift time was comprised of non-planting activities such as loading seedlings into bags, shaking and striking of seedlings against objects in order to dislodge ice particles, unloading and carrying the boxes of seedlings to staging areas inaccessible by vehicles, and a lunch break. The planters were observed to expend an average of 3.1 METs (SD = 0.7) during the course of a shift.

3.1. Full-shift planting muscle activity levels

Descriptive statistics 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 generally observed to be greater than non-planting activities.

It should be noted that four participants' right anterior deltoid, two participants' left anterior deltoid, one participant's right trapezius, and two participant's left trapezius EMG recordings were excluded from the analyses. For these participants, the integrity of the skin-to-electrode interface was compromised by task-related electrode contact resulting in an obvious loss of signal quality. Additionally, the EMG data for two participants was lost due to instrumentation failure. None of the EMG data from these participants was included in the analysis.

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	
	Mean	SD	Mean	SD	Mean	SD
Right Upper Trapezius (N=11)						
Mean RMS (%RVE)	54.1	24.4	56.7	24.8	44.4	24.2
10th Percentile APDF (%RVE)	7.0	4.1	7.5	4.4	5.1	3.0
50th Percentile APDF (%RVE)	37.5	18.9	39.0	19.8	31.8	18.4
90th Percentile APDF (%RVE)	122.5	54.4	129.1	55.1	97.5	55.3
Muscle Rest (% time)	8.6	9.4	6.8	8.5	14.8	13.7
Gaps/Min	6.7	5.6	6.0	6.1	9.2	5.5
Left Upper Trapezius (N=10)						
Mean RMS (%RVE)	42.1	13.5	43.7	14.1	36.5	13.2
10th Percentile APDF (%RVE)	5.6	3.2	5.9	3.5	4.5	2.5
50th Percentile APDF (%RVE)	31.5	15.8	33.7	16.6	23.3	14.7
90th Percentile APDF (%RVE)	94.8	27.4	97.2	27.3	86.3	33.4
Muscle Rest (% time)	14.4	21.5	12.7	22.6	20.8	18.0
Gaps/Min	12.3	7.7	10.3	7.7	20.3	13.5
Right Anterior Deltoid (N=8)						
Mean RMS (%RVE)	31.4	16.8	34.8	19.7	20.6	10.3
10th Percentile APDF (%RVE)	4.8	4.3	5.4	4.9	2.5	2.0
50th Percentile APDF (%RVE)	17.2	13.9	19.5	16.2	9.2	6.5
90th Percentile APDF (%RVE)	75.9	33.3	83.1	37.1	52.8	23.9
Muscle Rest (% time)	23.2	20.9	19.5	21.0	34.8	21.1
Gaps/Min	14.3	11.2	13.4	12.7	17.6	7.6
Left Anterior Deltoid (N=10)						
Mean RMS (%RVE)	17.0	5.7	18.3	6.7	13.4	4.6
10th Percentile APDF (%RVE)	2.2	0.7	2.4	0.7	1.6	0.7
50th Percentile APDF (%RVE)	7.8	4.0	8.7	4.6	5.4	2.9
90th Percentile APDF (%RVE)	43.6	13.7	47.3	17.0	33.2	11.7
Muscle Rest (% time)	36.6	18.9	33.4	19.9	46.0	16.6
Gaps/Min	22.8	7.2	22.7	5.8	24.7	13.7

3.2. 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, 32.5% of the observed work time was spent with the trunk flexed ≥45°, 10.1% of the work time was spent with the left arm elevated ≥60°, and 15.2% of the work time was spent with the right arm elevated ≥60°. On average, 2.5% of work time was spent flexing the trunk at a high velocity (≥90°/s). The left arm was moving at a high velocity for 2.6% of the work shift, while the right arm moved at a high velocity for 11.9% of the work shift.

In addition to the exposures experienced, hand planters had few opportunities for rest and recovery. Hand planters spent 12.2% and 11.1% of their work time with the left and right upper arms in a neutral posture (<30°) and moving at a low velocity (<5°/s). Similarly, hand planters spent only 11.3% of their work time with the trunk flexed in a neutral posture (<20°) and moving at a low velocity (<5°/s). Fig. 2 illustrates the repetitive nature of hand planting that requires extreme trunk flexion with very few opportunities for rest.

It should be noted that one participant's right arm elevation data was excluded as the participant felt the IMU was obstructive to his natural motion. Two participants' entire posture recordings were

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

Exposure variable	Flexion						Lateral bending					
	Full shift		Planting		Non-planting		Full shift		Planting		Non-planting	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Posture[a]												
10th Percentile (°)	−1.4	11.7	0.0	11.2	−6.1	16.1	−14.0	7.5	−15.1	8.2	−9.1	6.6
50th Percentile (°)	23.2	14.8	24.0	15.3	20.4	21.7	−1.3	6.5	−1.9	4.7	0.0	6.3
90th Percentile (°)	75.2	14.6	80.2	14.1	57.0	25.9	9.4	6.3	9.7	4.9	9.2	6.8
Time in neutral posture (<15°) (%)	–	–	–	–	–	–	83.0	7.9	79.6	9.9	90.2	6.0
Time in neutral posture (<20°) (%)	40.3	12.6	38.9	13.4	43.6	16.3	–	–	–	–	–	–
Time in extreme posture (≥30°) (%)	–	–	–	–	–	–	0.2	0.3	0.2	0.3	0.2	0.4
Time in extreme posture (≥45°) (%)	32.5	10.6	34.4	10.9	27.0	17.3	–	–	–	–	–	–
Movement velocity												
10th Percentile (°/s)	2.3	0.4	2.8	0.3	0.9	0.3	1.6	0.4	1.8	0.4	0.7	0.3
50th Percentile (°/s)	15.9	2.5	18.6	2.4	6.7	1.7	12.3	1.9	14.1	1.8	5.6	2.2
90th Percentile (°/s)	53.9	7.3	61.1	7.9	30.1	5.5	38.0	5.2	41.5	5.4	24.3	6.5
Time at low velocities (<5°/s) (%)	23.8	3.5	17.5	2.0	48.0	13.4	29.6	4.4	22.9	3.5	54.0	12.5
Time at high velocities (≥90°/s) (%)	2.5	1.1	3.1	1.4	0.6	0.3	0.4	0.3	0.5	0.3	0.1	0.1
Rest/Recovery												
Time in neutral posture (<15°) for substantial periods (≥3s) (%)	–	–	–	–	–	–	64.1	14.0	58.3	15.5	80.6	10.5
Time in neutral posture (<20°) for substantial periods (≥3s) (%)	36.6	12.5	32.6	14.3	44.5	17.7	–	–	–	–	–	–
Time at low velocities for substantial periods (≥3s) (%)	3.6	1.7	0.5	0.3	13.7	6.5	7.3	2.9	2.7	1.6	22.4	10.1
Time in neutral posture (<15°) and low velocity (%)	–	–	–	–	–	–	25.9	4.6	19.4	3.8	46.5	9.8
Time in neutral posture (<20°) and low velocity (%)	11.3	3.5	8.7	2.4	19.3	8.3	–	–	–	–	–	–

[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 for the upper arms.

Exposure variable	Left arm elevation						Right arm elevation					
	Full Shift		Planting		Non-planting		Full shift		Planting		Non-planting	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Posture												
10th Percentile (°)	16.0	3.1	16.5	3.2	14.1	3.7	15.8	3.4	15.8	3.7	15.6	3.5
50th Percentile (°)	33.0	3.3	34.1	4.0	29.0	3.1	32.5	5.0	33.3	5.4	29.4	4.7
90th Percentile (°)	59.5	10.2	61.2	10.8	53.4	10.3	67.5	7.9	70.9	8.6	55.4	13.3
Time in neutral posture (<30°) (%)	43.1	6.9	39.7	8.4	54.7	10.0	45.6	9.1	43.3	8.9	53.7	12.7
Time in extreme posture (≥60°) (%)	10.1	6.7	10.9	7.6	7.1	4.8	15.2	5.7	16.9	6.5	8.7	5.1
Movement velocity												
10th Percentile (°/s)	2.3	0.4	2.6	0.4	1.1	0.5	3.1	0.9	3.7	1.1	1.2	0.5
50th Percentile (°/s)	15.5	2.6	17.5	2.1	9.2	3.5	24.1	5.6	27.7	6.0	11.7	3.7
90th Percentile (°/s)	52.4	8.9	56.3	8.6	39.9	10.4	97.4	17.9	111.4	19.1	49.7	11.4
Time at low velocities (<5°/s) (%)	22.9	3.7	17.9	2.2	38.2	8.5	18.3	3.5	13.6	2.6	33.9	8.1
Time at high velocities (≥90°/s) (%)	2.6	1.5	3.0	1.6	1.6	1.1	11.9	3.9	14.5	4.4	3.0	1.5
Rest/Recovery												
Time in neutral posture (<30°) for substantial periods (≥3s) (%)	21.0	7.8	15.5	8.7	39.5	10.7	21.3	9.3	17.1	8.8	35.8	13.1
Time at low velocities for substantial periods (≥3s) (%)	4.5	1.8	1.4	1.2	13.9	5.8	4.1	1.6	1.4	1.1	13.0	5.8
Time in neutral posture (<30°) and low velocity (%)	12.2	2.5	8.6	1.9	23.5	7.1	11.1	3.3	8.6	2.6	19.0	6.0

excluded from the analyses due to pre-shift battery charging failure.

4. Discussion

Health and safety outcomes among hand planters and other AFF workers are generally not well understood and are under-studied. 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 and Casanova, 2005; Sarathy and 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 (Giguère et al., 1993; Hodges and Kennedy, 2011; Roberts, 2002; Robinson et al., 1993; Trites et al., 1993). The results of the current study contribute to the scientific literature by providing novel information regarding exposures to physical risk factors that are associated with work-related MSDs among hand planters working in the Southeastern United States.

Although studies examining full shift anterior deltoid muscle activity are limited in the scientific literature, a recent study examining muscular effort of faculty ophthalmologists using comparable reference voluntary contraction procedures indicated considerably lower muscle activity exposures of the dominant (right) arm anterior deltoid muscle group (mean = 13.5 %RVE and

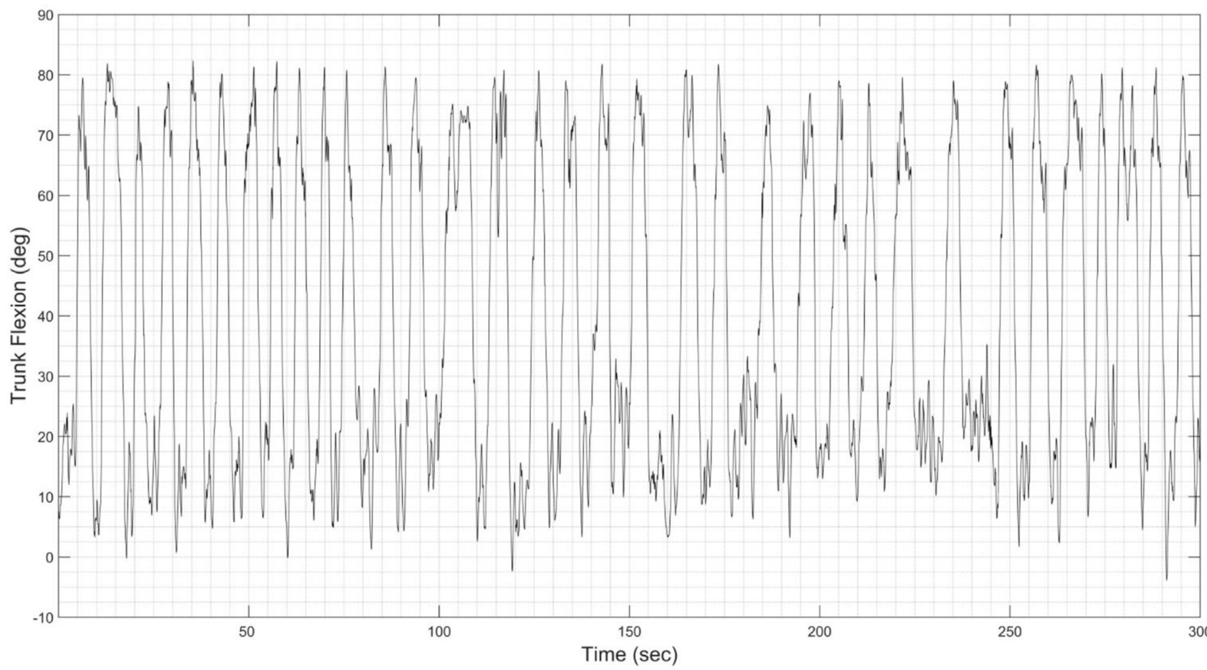

Fig. 2. Representative 5 min segment of trunk flexion during hand planting for one participant illustrating the repetitive nature of the task.

90th percentile APDF = 35.7 %RVE; Fethke et al., 2015) when compared to the hand planters in the present study (mean = 31.4 % RVE and 90th percentile APDF = 75.9 %RVE). However, it is important to note that faculty ophthalmologists were observed to have very similar muscle activity exposures of the non-dominant (left) arm anterior deltoid muscle group (mean = 14.4 %RVE and 90th percentile APDF = 35.8 %RVE; Fethke et al., 2015) in comparison to the hand planters (mean = 17.0 %RVE and 90th percentile APDF = 43.6 %RVE). This result, as well as the documented increased muscle activity required of the dominant (right) anterior deltoid muscle group during planting (mean = 34.8 %RVE and 90th percentile APDF = 83.1 %RVE; Table 1), demonstrates the high intensity muscle activity 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/shoulder discomfort and/or MSDs similar to ophthalmologists, an occupational group that reports a high prevalence of neck/shoulder pain (Kitzmann et al., 2012).

While available research on upper trapezius muscle activity is more widely available, variability in normalization procedures limits ability for direct comparisons to a few studies. Dominant upper trapezius 90th percentile mean APDF full shift results suggest hand planters experience markedly higher trapezius muscle activity (122.5 %RVE) than stud welders using conventional equipment (54.1%, Fethke et al., 2011), faculty ophthalmologists (37.4 %RVE, Fethke et al., 2015), and university office workers (61.1 % RVE), custodians (64.1 %RVE), and maintenance workers (77.5 % RVE, Fethke et al., 2012). Although the act of planting with a dibble bar was the most demanding task performed by the hand planters, muscle activity during non-planting work was also observed to be relatively high. 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. Dominant upper trapezius muscle rest (% of time during shift) results indicate hand planters experience fewer opportunities for rest (average of 8.6%) when compared to the faculty ophthalmologists (31.4%), stud welders (39.5%), and university custodial (19.8%), maintenance (11.9%), and office workers (17.4%).

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 in comparison 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 flexion angle of 75.2°. This was greater than material pickers (26.0°, Christmansson et al., 2002), poultry processing workers (16.0°, Juul-Kristensen et al., 2001), automobile disassembly workers (40.2°, Kazmierczak et al., 2005), and registered nurses (35.9°, Schall et al., 2016a). Trunk flexion ≥45° was measured for 32.5% of the work shift, presumably due to the high frequency of forward bending to plant seedlings at ground level. While this result is less than what has been observed among hand planters in Northern Ontario (Slot et al., 2010; Upjohn et al., 2008), it exceeds values measured among registered nurses (6.1%, Schall et al., 2016a). Differences with the hand planters from Northern Ontario may be explained by the use of a different planting tool ('D' handle spade), terrain, and factors related to the experience and personal characteristics of the two study samples.

Previous studies suggest that routine exposure to elevated arm positions and high movement velocities may be associated with increased risk of shoulder MSDs (Hanvold et al., 2015; Putz-Anderson et al., 1997; Svendsen et al., 2004a, 2004b). Arm elevation results in this study indicate that hand planters are exposed to mean dominant arm elevations of 37.7° for the right arm and 35.7° for the left arm (not reported in Table 3) which is higher than what has been observed for apple orchard workers (22.7° and 19.2° for the right and left arm, respectively; Thamsuwan and Johnson, 2015). Mean 90th percentile arm elevation angles of 67.5° and 59.5° were observed for the right and left arm, respectively. Dairy parlor workers (71.9° right arm and 61.3° left arm) were observed to be exposed to higher levels of exposure (Douphrate et al., 2012), while poultry processing workers (42° right arm and 41° left arm) were observed to exhibit lower levels (Juul-Kristensen et al., 2001). High movement velocities were also measured for the right and left upper arms (mean 90th percentile of 97.4°/s and 52.4°/s, respectively). These movement velocities were greater than those observed in studies of air traffic controllers (37.0°/s and 31.0°/s, Arvidsson et al., 2006) and lower than that observed among dairy parlor workers (148.0°/s and 134.9°/s, Douphrate et al., 2012).

In addition to the muscle activity and posture results, we observed an average energy expenditure of 3.1 METs (SD = 0.7) among the planters in this study. This level of energy expenditure compares well with observations for other AFF workers (mean = 3.67), and is higher than those reported for workers within production (mean = 2.69) and healthcare (mean = 2.83) industries (Tudor-Locke et al., 2011). Together, the results indicate that reforestation workers who plant by hand may be at increased risk of developing neck/shoulder pain as a direct result of their work-related activities that involve a combination of high effort muscular exertions, non-neutral postures, generation of high movement speeds, and generally physically intensive labor with few opportunities for rest and recovery.

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 and 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 while the hand planters in this study were compensated at an hourly rate. Planter's tool choice may also 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 necessary soil planting depth. Further investigation into environmental and soil variations may provide insight into ideal planting conditions for the reduction of worker exposure to physical stressors.

Several limitations of this pilot study should be acknowledged. First, this study involved data collection from a small sample of workers operating in a geographically homogenous region. Although we observed a comparable average planting time (75.8%) to the 71–94% observed in a previous study (Hodges and Kennedy, 2011), the small sample limits the generalizability of our results. We also did not ask participants to report their level of experience. Reports from the contractor suggested that experience levels among the planters varied (some workers were first year planters while some had over 10 years of experience). However, it is unknown which participants had more experience. Second, the hand planters recruited for this study were paid on an hourly compensation scale that differs from the piece rate payment strategy that is often used among hand planters. The exposures to physical risk factors observed in this study, therefore, may not be representative of the exposures among hand planters paid via a piece rate payment strategy. 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. Fourth, observation of planting occurred on sites that were typical of planting sites in the Southeastern United States, but do not represent the full range of planting site variability with regard to slope, obstacles, and soil strength and depth.

The intense physical demands of hand planting presents a challenge to direct measurement. The location of the seedling bag worn near the EMG sensors on the neck/shoulders may result in a loss of quality EMG electrode-skin contact when donning and doffing the bag as well as unintended electrode impact. While water-proof protective sealants and tapes were used to reduce the potential of compromising the skin-electrode interface, loss of some participants' EMG data did still occur in this study. The average length of the analyzed EMG recordings was 329.4 min (with 78.7% consisting of planting and 21.3% other activities). The reported findings should, therefore, be interpreted pragmatically until additional data may be collected and more precise estimates of exposure can be developed. Finally, this study did not address certain job stressors, such as psychosocial stress and time pressure, which are commonly associated with MSDs (da Costa and Vieira, 2010; Hagen et al., 1998). Research evaluating the broad spectrum of work demands challenging hand planters is needed. This includes further assessment of the effects of the seedling bag weight and design on muscle activity and posture. More research is also needed to understand the exposures to risk factors of mechanized planting, an alternative to hand planting.

5. Conclusions

Results of this study indicate that hand planters are exposed to a combination of high effort muscular exertions, non-neutral postures, generation of high movement speeds, and generally physically intensive labor that place them at increased risk for the development of neck, shoulder, and low back 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.

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