Measuring the Effect of Tool Design on Exposure to Physical Risk Factors among Novice Hand Planters

Robert Granzow, Mark C. Schall, Jr., Mathew Smidt, Jerry Davis, Richard Sesek, Sean Gallagher

Auburn University

The majority of reforestation in the southeastern United States is achieved using hand planting methods. Previous research suggests a high prevalence of musculoskeletal pain and other symptoms among hand planters as a result of exposure to physical risk factors while hand planting. The design of hand planting tools has been posited as a potential means to reduce exposures to physical risk factors among hand planters. This study compared exposures to directly measured physical risk factors including forceful muscular exertions (collected using surface electromyography), non-neutral postures (collected using an upper body inertial measurement unit system), and workload (collected using a heart rate monitor) among 14 novice hand planters using four different "dibble bar" planting tools commonly used by southeastern planters. Results indicated no statistically significant differences between the tools, suggesting that minor differences in tool design may play an insignificant role on exposures to physical risk factors among novice hand planters relative to other factors. The characterizations of exposure described here provide additional evidence of the job demands hand planters are exposed to during planting.

INTRODUCTION

Work-related musculoskeletal disorders (MSDs) accounted for approximately 35 percent of all nonfatal workplace injuries and illnesses involving days away from work in 2017 (BLS, 2018). The MSD incidence rate among workers within the agriculture, Fishing, and Forestry (AFF) sector (39.1 per 10,000 full-time workers) exceeded those in all other industry sectors (BLS, 2018). Reforestation hand planters represent an important subset of the AFF sector responsible for replenishing U.S. forests through the planting of seedlings. In the southeastern U.S., the planting season typically runs from December through April and hand planting is almost exclusively performed by seasonal migrant workers (McDaniel et al., 2005). Planting takes place on tracts of land by workers carrying a bag of seedlings and using a `dibble' or planting bar to dig a hole. After a hole has been made in the soil, the worker reaches behind his or her back to remove a seedling from the bag, bends at the waist to place the seedling into the hole, and then seals the hole with his or her foot (Granzow et al., 2018). The task is repeated throughout the work shift, with some studies reporting more than 3,000 seedlings planted per worker per day (Trites et al., 1993).

Physical risk factors associated with the development of MSDs include non-neutral working postures, forceful muscle exertions, and excessive repetition of motions (da Costa et al., 2010). Previous studies have characterized exposures to physical risk factors among reforestation hand planters in various environments (Denbeigh et al., 2013; Granzow et al., 2018; Giguère et al., 1993; Hodges et al., 2011; Roberts, 2002; Robinson et al., 1993; Slot & Dumas, 2010; Trites et al., 1993). Results of those studies have suggested that the work demands associated with hand planting places reforestation hand planters at increased risk for MSDs.

The design of hand planting tools has been posited by previous research teams as a means to potentially reduce exposures to physical risk factors among hand planters (Giguère et al., 1993; Denbeigh et al., 2013). However, the available literature lacks comparisons of direct measurement evaluations of exposures to physical risk factors among planters while using different tools. The objective of this study was to evaluate and compare exposures to physical risk factors measured among novice hand planters using four different commercially available tools. It was hypothesized that the design of certain tools (e.g. pointed vs. flat edge) may lead to reductions in exposures to physical risk factors. This information could prove valuable to hand planters and contractors interested in reducing injuries and improving productivity through a reduction in lost time due to MSD symptoms and injuries.

METHODS

Study participants

Fourteen male participants (mean age = 26.9 ± 3.8 years; mean height = 178.4 ± 2.4 cm; mean body mass index [BMI] = 24.8 ± 3.2 kg/m^2) were recruited for this study. Participants all had a measured BMI of <30 kg/m^2, no history of physician-diagnosed MSDs in the neck/shoulder or back regions, no neck/shoulder or back pain within two weeks prior to participation in the study, and no history of neurodegenerative disease. All participants were right-hand dominant. The study took place on a tract of cleared land that was prepared for professional reforestation. The study was approved by the institution's Institutional Review Board and each participant provided informed consent.

Instrumentation and Data Collection

Heart rate. Participants were fitted with a chest-worn heart rate (HR) monitor (Polar H10) that wirelessly transmitted data to a data logging watch (Polar M400) worn by a research team member. Resting HR (HR_{REST}) was determined prior to data collection by having the subject sit in a relaxed position for several minutes until the subject's HR reached a constant (±3 $\text{beats}^{-1}\cdot\text{min}$) rate for 60 seconds. Working HR (HR_{WORK}) was determined as the arithmetic mean of heart rates measured over the course of each trial (Jankovský et al., 2018).

HR summary measures were expressed according to:

$$\text{Ratio} = HR_{WORK} / HR_{REST} \quad (1)$$

which provides a normalized ratio of working HR to resting HR (Diament et al., 1969; Kirk et al., 2001).

Posture. A three-dimensional motion capture system was used to collect upper-body kinematic data from each participant during planting (Xsens, Enschede, Netherlands). Specifically, the Xsens system involved securing 11 inertial measurement units (IMUs) to the sternum, pelvis, bilateral upper arms, bilateral forearms, hands, shoulders, and head. The system was calibrated prior to data collection per manufacturer guidelines. Xsens MVN Studio (Version 4.2) software was used for exporting the posture data into Extensible Markup Language (XML) structured files for analysis.

A custom Python (version 3.5) program was used to calculate posture summary measures of the trunk, dominant upper arm, bilateral wrists, and neck. Percentiles of the amplitude probability distribution function (APDF) were determined for each body segment using a custom Python program and the NumPy package (version 1.13). Percent time in neutral and extreme postures were determined for the trunk, with threshold values determined according to previously published research (Douphrate et al., 2012; Granzow et al., 2018; Schall Jr. et al., 2016).

Muscle activity. Pre-amplified surface electromyography (EMG) electrodes (Model SC230, Biometrics Ltd, Gwent, UK) connected to a belt-worn data logger (Datalog MWX8, Biometrics Ltd., UK) were used to continuously digitize raw EMG signals of the bilateral upper trapezius and anterior deltoid muscles at a sampling rate of 1,000 Hz. Electrodes were secured using published guidelines (Criswell, 2010). The EMG signals were post-processed using custom LabVIEW (version 2013, National Instruments, Inc., Austin, TX, USA) and Python (version 3.5) software. 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 et al., 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.

Forceful muscle exertions were expressed as percentages of maximal isometric contractions (%MVC), which were collected prior to the beginning of the participants' planting trials. The contractions were performed against manual resistance applied at the wrist by a research assistant while the arms were forward flexed to 120° with the elbows in full extension. The participant was instructed to maintain the maximal contraction for 5 seconds. Three repetitions of MVCs were performed, with a 2.5-minute rest between each contraction. The maximum RMS amplitude of the middle 3 seconds of each contraction was used for both the upper trapezius and anterior deltoid muscle groups (Boettcher et al., 2008, Douphrate et al., 2017). The maximum RMS EMG amplitude across all three MVCs was identified as the absolute maximum (Douphrate et al., 2017; Mathiassen et al., 1995). An EMG recording while the subject was resting was collected prior to the MVCs. The minimum RMS EMG amplitude among all of the recordings, including the resting recording, was determined to be the baseline noise and was subtracted from all other RMS EMG amplitude values in a power sense (Thorn et al., 2007; Jackson et al., 2009).

The mean amplitude of the normalized RMS signal for each muscle across the entire recording period was calculated as an index of overall muscular load. Static (10th percentile), median (50th percentile), and peak (90th percentile) amplitudes of muscle activity were also calculated for each muscle using the APDF (Jonsson, 1982).

Experimental Procedures

After the participant was fitted with the HR, EMG, and Xsens systems and the resting HR, reference muscle exertions, and motion capture calibrations were completed, the participant was trained in the hand planting process. The participant was trained using a standard video produced by a professional forestry sector educator (Texas A&M Forest Service, 2012). After watching the training video, each participant practiced planting until they passed a qualitative assessment of planting quality assessed by a research team member. The assessment evaluated proper depth of planting and soil compaction around the seedling.

Once trained, each participant was provided a tool in a random sequence. Planting locations were established prior to the trials by marking a typical planting route for 30 trees with flags. The direct measurement systems were started by the research assistant and the participant began planting seedlings. The trial ended after 30 seedlings were planted. After each trial, the participant rested until their HR_{REST} returned to within ± 5 $\text{beats}^{-1}\cdot\text{min}$ of the previously established HR_{REST}. The participant was then provided the next randomly assigned tool and the next trial began. This was repeated for each of the four tools.

Figure 1. (a) KBC `Short'. (B) `OST'. (c) `Speedy'. (d) KBC `Long'

Table 1. Tool characteristics

Tool	Weight (kg)	Length (cm)
Jim-Gem KBC 'Short'	4.7	96.8
Jim-Gem OST	3.3	96.5
Jim-Gem Speedy	3.0	92.0
Jim-Gem KBC 'Long'	4.3	105.4

Data Reduction and Statistical Analysis

HR, EMG, and Xsens data files were synchronized and data quality checks were performed before any statistical analysis was performed. Substantial loss of signal due to wireless transmission failure or data file corruption resulted in three HR trials and three posture trials being lost. Four participants' posture data (all trials) were not measured due to signal interference in the testing location. Four left deltoid muscle group recordings were removed from analysis due to interruption of electrode-skin contact. This resulted in a total of 53 HR, 37 posture, and 56 EMG trials included in the final analysis.

The exposure summary metrics were described across all participants using means and standard deviations. Standard tests for normality (i.e. Anderson-Darling test) and other tests of assumptions (i.e. Grubb's test for outliers, evaluations of homogeneity) for using analysis of variance (ANOVA) were performed. Differences between summary measures were examined using one-way analysis of variance and an alpha value of 0.05. Two-sample t-tests were used to determine differences among dominant and non-dominant muscle groups and joints. All statistical analyses were conducted using Minitab 18.0 (Minitab, Inc., State College, PA, USA).

RESULTS

The average planting time per trial (30 trees) across study participants was 11.5 minutes (SD = 4.1 min). This pace of planting is comparable to what has been previously reported (Giguère et al., 1993; McDonald et al., 2008).

Heart rate

HR summary measures by tool are presented in Table 2. No statistically significant differences among tools were observed.

Table 2. Heart rate summary measure by tool.

	Tool							
HR	KBC Long (N=13)		KBC Short (N=13)		OST (N=13)		Speedy (N=14)	
Measure	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$\frac{HR_{WORK}}{HR_{REST}}$	1.5	0.2	1.4	0.3	1.5	0.3	1.5	0.3

Working postures

No statistically significant differences were observed among tools for any of the measured posture summary measures. Mean trunk posture for the subjects did not differ significantly between tools, $F(3,29) = 0.87$, $p = 0.47$. Figure 2 illustrates the magnitude and repetitive nature of trunk flexion exposures during planting, with each cycle resulting in ≥45° trunk flexion while reaching to the ground to plant the seedling.

Table 3. Dominant upper arm summary measures.

Flexion (+) / Extension (-) (°)	Tool							
	KBC Long (N=9)		KBC Short (N=9)		OST (N=10)		Speedy (N=9)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mean	21.4	8.6	21.4	8.9	19.9	9.1	19.8	9.1
10th %ile	6.2	11.6	6.8	10.0	4.5	12.8	4.7	10.4
50th %ile	20.0	8.1	20.0	7.9	17.8	8.8	17.8	8.6
90th %ile	38.7	10.2	37.9	10.5	38.1	8.7	37.4	10.2

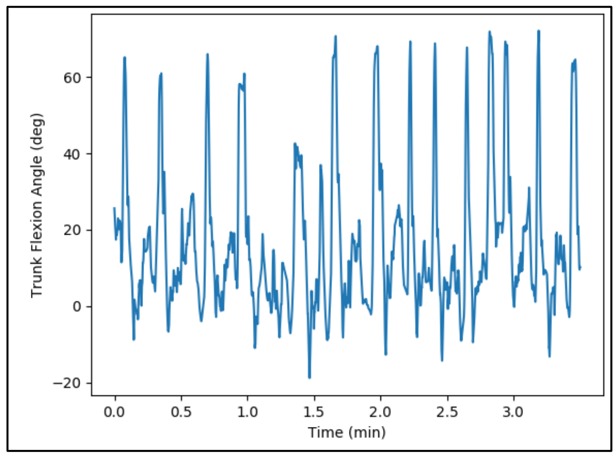

Figure 2. Representative 3.5 min segment of trunk flexion for one participant.

Across all tools, wrist pronation/supination was more pronounced, $t(72)=-2.70$, $p = <0.01$, in the dominant wrist (mean=-15.2°; SD=31.1°) than the non-dominant wrist (mean=4.4°; SD=31.3°). Similarly, wrist flexion/extension was greater, $t(70)=-2.75$, $p= <0.01$, for the dominant wrist (mean=-23.4°; SD=13.4°) than for the non-dominant wrist (mean=-13.4°; SD=17.1°). Mean and 50th percentile wrist rotation suggests more time spent by planters across all tools in supination (-) compared to pronation (+). Positive mean and 50th percentile values for wrist deviation indicate that, on average, participants are exposed to ulnar rather than radial deviation.

Forceful muscle exertions

No statistically significant differences among tools were determined. Mean muscle activity was greater in the dominant arm (anterior deltoid and upper trapezius groups) than the non-dominant arm.

DISCUSSION

No statistically significant differences were observed among tools, suggesting that selecting between the four tools considered in this study may not have a significant effect on exposures to physical risk factors among novice hand planters.

The results of the present study contribute to the scientific literature on the occupational health and safety of hand planters by providing a detailed characterization of novice hand planter exposures to physical risk factors. The work is particularly valuable as it considers southeastern U.S. hand planting practices, which can differ substantially from other geographic regions and has been less commonly studied. For example, Denbeigh et al., 2013 examined wrist postures and forces during different seedling unloading conditions. However, the study was conducted using the most common type of planting instrument in Canada, a `D'-Handle planting shovel, which has several distinct design features (weight, length, handle material, spade shape) that differentiate it from the `T'-Handle `dibble' bars commonly used in the southeastern U.S.

The results of the present study provide additional evidence of the stresses hand planters are exposed to while planting. Across all tools, the measured working HR to resting HR ratios were lower than forestry choker setters (1.84; Kirk et al., 2001), but higher than those reported among steel workers (1.24; Vitalis et al., 1994), cane cutting workers (1.38; Vitalis, 1981), nurses (1.45; Fordham et al., 1978), and car assemblers (1.45; Minard et al., 1971).

Trunk flexion of greater than 45° has been identified as a risk factor for fatigue, pain, and/or injury (Andersson, 1981; Keyserling et al., 1992; Punnett et al., 1991; Sato et al., 1973). Dibble bars as a tool do not eliminate or reduce the potentially severe non-neutral trunk posture required to reach the ground. Similarly, hand planters are exposed to non-neutral wrist postures exceeding recommended levels for injury prevention. Study participants were exposed to mean wrist extension between -26.1° and -22.3° across the tools. Exposures to wrist extension of greater than 15° may result in a marked reduction in grip strength (O'Driscoll et al., 1992). Wrist postures measured during the present study are comparable to those previously studied (Denbeigh et al., 2013). In addition to non-neutral working postures of the wrist, Denbeigh et al. (2013) observed high wrist loading during the planting cycle suggesting a potential high force-high repetition loading cycle associated with elevated risk of MSD incidence (Silverstein et al., 1987; Gallagher et al., 2013). Previous research into wrist postures during varied seedling unloading strategies (symmetric or asymmetric) suggested workers maintained more neutral postures during asymmetric unloading (Slot et al., 2010). This finding may suggest that factors other than tool design may have more significant effects on exposures.

Results of the study suggest that limited data collection (30 seedlings) among novice hand planters can provide comparable results to full-shift measurements on professional planters. Planting rates, working HR measures, wrist postures, and muscle activity were all comparable to what has been reported in previous studies of hand planters (Appelroth et al., 1970; Denbeigh et al., 2013; Granzow et al., 2018; Giguère et al., 1993; McDonald et al., 2008; Roberts, 2002; Slot et al., 2010; Stjernberg, 1988; Stjernberg, 2003; Trites et al., 1993; Vyse, 1973). This may suggest that the repetitive nature of the work can allow for the increased use of simulation studies similar to the present study that are generalizable to professional hand planters.

Several limitations of this study should be addressed. Study participants were selected from members of a university campus and were not professional hand planters. Demographic differences among the sample of study participants and the typical southeastern U.S. hand planter limit direct comparisons and applicability of study results to the planting community. While the planting site used in the study was prepared for professional hand planting it was not representative of the variability encountered by hand planting crews. This variability includes the degree of plot preparation, grade of the terrain, soil composition, and ground moisture. The site was not a controlled environment so fluctuations in ambient temperature may have affected HR response to work. Each subject planted 120 trees over the course of the study, a small quantity compared to the daily planting rates of professional hand planters. The effect of fatigue on HR, working postures, and muscle exertions over the course of a full-shift was not analyzed in the present study. Finally, ratings of perceived exertions were not collected for each tool. Borg CR-10 scale self-reporting has been used to relative exertion levels of the elbow, shoulder, and total task (Freivalds et al., 1993; Lloyd et al., 1991; Spielholz, 2006).

While the present study did not suggest substantive differences among tools as they relate to physical risk factors, future research has the potential to identify effective means for mitigating exposures. Mechanized planting, while not as prevalent as manual planting in the southeastern U.S., may require lower physical demands and should be compared to hand planting. Engineering new hand planting tools that require less force to penetrate the soil may reduce forces, such as `bullet' planting previously studied for productivity (Vyse, 1973). Extreme trunk flexion is a primary risk factor identified through the characterization of working postures, which could be alleviated through the development of a planting device that transports the seedling into the ground without bending. In addition to engineering controls, research into certain administrative controls, such as determining effective work-rest cycles, could potentially reduce MSD symptom development. Results of the present study indicate that working heart rate, exposure to non-neutral postures, and forceful muscle exertions of the upper arm and back did not significantly differ among the evaluated tools. However, characterization of novice hand planter risk factor exposures may provide insight for future researchers interested in implementing interventions intended to reduce exposures to physical risk factors associated with work-related MSDs. The findings indicate a need for additional research among novice and professional hand planters to determine optimal interventions that will result in the reduction of risk factor exposures and, consequently, musculoskeletal symptoms.

REFERENCES

Andersson, G. B. (1981). Epidemiologic aspects on low-back pain in industry. *Spine*, *6*(1), 53-60.

Appelroth, S. E., & Harstela, P. (1970). The use of the semi-circular hoe, the field spade, plant basket, plant bag and the Heger and LMD-1 tree planters in planting spruce in fields. *Folia Forestalia*, *85*, 32.

BLS. (2018). Incidence rates for nonfatal occupational injuries and illnesses involving days away from work per 10,000 full-time workers by industry and selected natures of injury or illness, private industry,

2017. U.S. Department of Labor Publication Table R5. Retrieved from https://www.bls.gov/web/osh/cd_r5.htm

Boettcher, C. E., Ginn, K. A., & Cathers, I. (2008). Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. *Journal of Orthopaedic Research*, *26*(12), 1591-1597.

Criswell, E. (2010). *Cram's Introduction to Surface Electromyography* (2nd ed.). Burlington, MA: Jones & 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.

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.

Diament, M. L., Goldsmith, R., Hale, T., & Kelman, G. R. (1969). On the assessment of habitual physical activity. *The Journal of Physiology*, *200*(1), 44P-5P.

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.

Douphrate, D. I., de Porras, D. G. R., Nonnenmann, M. W., Hagevoort, R., Reynolds, S. J., Rodriguez, A., & Fethke, N. B. (2017). Effects of milking unit design on upper extremity muscle activity during attachment among US large-herd parlor workers. *Applied Ergonomics*, *58*, 482-490.

Drake, J. D., & 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.

Fordham, M., Appenteng, K., Goldsmith, R., & O'brien, C. (1978). The cost of work in medical nursing. *Ergonomics*, *21*(5), 331-342.

Freivalds, Andris, and Jörgen Eklund. "Reaction torques and operator stress while using powered nutrunners." *Applied Ergonomics* 24.3 (1993): 158-164.

Gallagher, S. & Heberger, J. R. (2013). Examining the interaction of force and repetition on musculoskeletal disorder risk a systematic literature review. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *55*(1), 108-124.

Giguère, D., Bélanger, R., Gauthier, J.M., Larue, C. (1993). Ergonomics aspects of tree-planting using 'multipot'technology. *Ergonomics*, *36*(8), 963-972.

Granzow, R. F., Schall Jr, M. C., Smidt, M. F., Chen, H., Fethke, N. B., & Huangfu, R. (2018). Characterizing exposure to physical risk factors among reforestation hand planters in the Southeastern United States. *Applied Ergonomics*, *66*, 1-8.

Hodges, A. N., & Kennedy, M. D. (2011). Physical exertion and working efficiency of reforestation workers. *Journal of Occupational Medicine and Toxicology*, *6*(1), 20.

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.

Jankovský, M., Merganič, J., Allman, M., Ferenčík, M., & Messingerová, V. (2018). The cumulative effects of work-related factors increase the heart rate of cabin field machine operators. *International Journal of Industrial Ergonomics*, *65*, 173-178.

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

Keyserling, W. M., Brouwer, M., & Silverstein, B. A. (1992). A checklist for evaluating ergonomic risk factors resulting from awkward postures of the legs, trunk and neck. *International Journal of Industrial Ergonomics*, *9*(4), 283-301.

Kirk, P. M., & Sullman, M. J. (2001). Heart rate strain in cable hauler choker setters in New Zealand logging operations. *Applied Ergonomics*, *32*(4), 389-398.

Lloyd, A. R., Gandevia, S. C., & Hales, J. P. (1991). Muscle performance, voluntary activation, twitch properties and perceived effort in normal subjects and patients with the chronic fatigue syndrome. *Brain*, *114*(1), 85-98.

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.

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.

Minard, D., Goldsmith, R., Farrier, P. H., & Lambiotte, B. J. (1971). Physiological Evaluation of Industrial Heat Stress. *American Industrial Hygiene Association Journal*, *32*(1), 17-28.

O'Driscoll, S. W., Horii, E., Ness, R., Cahalan, T. D., Richards, R. R., & An, K. N. (1992). The relationship between wrist position, grasp size, and grip strength. *The Journal of Hand Surgery*, *17*(1), 169-177.

Punnett, L., Fine, L. J., Keyserling, W. M., Herrin, G. D., & Chaffin, D. B. (1991). Back disorders and nonneutral trunk postures of automobile assembly workers. *Scandinavian Journal of Work, Environment & Health*, 337-346.

Redfern, M. S., Hughes, R. E., & Chaffin, D. B. (1993). High-pass filtering to remove electrocardiographic interference from torso EMG recordings. *Clinical Biomechanics*, *8*(1), 44-48.

Roberts, D. (2002). In-season physiological and biochemical status of reforestation workers. *Journal of Occupational and 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.

Sato, M., & Tanaka, S. (1973). Postural effect on the relation between oxygen consumption and heart rate. *Journal of Human Ergology*, *2*(1), 21-30.

Schall Jr, M. C., Fethke, N. B., & Chen, H. (2016). Working postures and physical activity among registered nurses. *Applied Ergonomics*, *54*, 243-250.

Silverstein, B. A., Fine, L. J., & Armstrong, T. J. (1987). Occupational factors and carpal tunnel syndrome. *American Journal of Industrial Medicine*, *11*(3), 343-358.

Slot, T. R. & Dumas, G. A. (2010). Musculoskeletal symptoms in tree planters in Ontario, Canada. *Work*, *36*(1), 67-75.

Slot, T., Shackles, E., & Dumas, G. A. (2010). Upper limb and trunk kinematics in tree planters during three load carriage conditions. *Occupational Ergonomics*, *9*(3, 4), 169-182.

Spielholz, P. (2006). Calibrating Borg scale ratings of hand force exertion. *Applied Ergonomics*, *37*(5), 615-618.

Stjernberg, E. I. (1988). A Study of Manual Tree Planting Operations in Central and Eastern Canada. *Point Claire, Canada: Forest Engineering Research Institute of Canada*.

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

Texas A&M Forest Service. (2012). How to Plant a Seedling. Retrieved from https://www.youtube.com/watch?v=4xqeKRsaa0E

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.

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.

Vitalis, A. (1981). *An Investigation of the Relationship Between Pulse Rate, Environmental Heat, and Work Output of Cane Cutters in Figi* (Doctoral dissertation).

Vitalis, A., Pournaras, N. D., Jeffrey, G. B., Tsagarakis, G., Monastiriotis, G., & Kavvadias, S. (1994). Heart rate strain indices in Greek steelworkers. *Ergonomics*, *37*(5), 845-850.

Vyse, A. H. (1973). Work Study Techniques to Tree Planting: Tree Planter's Note. *Pacific Forest Research - Canadian Forestry Service*, *24*, 19-23.