Examining upper extremity and trunk muscle activation in novice participants during a simulated tree planting task.

by

© Emily Marguerite Colwell

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ABSTRACT

Manual reforestation is common in Canada and has a high rate of injury, many of which appear to go unreported, and approximately 80% of tree planting injuries are classified as "chronic". Previous research has suggested muscle activation levels as underlying factors in the development of upper extremity and back pain. The purpose of this study was to examine surface electromyography (sEMG) in novice participants during simulated tree planting tasks to describe the muscle activation in the trunk and upper extremity during tree planting. Twenty participants (10 female, 10 male; age: 23.8 ± 4.18; body mass index [BMI]: 25.3 ± 4.16 kg/m^2) completed an average of 25 ± 3 planting attempts to achieve 20 trials of acceptable quality plants (min: 21, max: 32). Six muscle groups were selected for sEMG recording: wrist extensors, wrist flexors, upper trapezius, erector spinae, rectus abdominus, and external obliques. All data from the rectus abdominus and external obliques were removed from analysis due to poor quality. Findings revealed that muscle activity in the shovel-side musculature was typically greater than in the draw-side in the earlier phases of planting, while activity in the draw-side musculature was typically greater than that in the shovel-side in the later phases of planting. Results of amplitude probability distribution function (APDF) analysis indicated that persistent low-level static exertions (10th percentile APDF of greater than 2% maximum voluntary contraction [MVC]) were observed in the shovel-side wrist flexors and extensors and erector spinae, as well as in the draw-side wrist extensors and upper trapezius. Although peak activation was not explicitly quantified, the linear envelope data showed maximum activations of approximately 25% MVC in all shovel-side musculature and in the draw-side forearm musculature. Persistent low-level muscle activation, high peak exertions, and high impact

forces are ergonomic risk factors that may contribute to development of pain and musculoskeletal disorders (MSDs). Thus, the study findings support the existing theory that persistent muscle activation plays a role in the high rate of injury present in this population.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Definition
APDF	Amplitude probability distribution function
ASTM	American Society for Testing and Materials
BCC	Björkemar Construction & Consulting
BMI	Body mass index
ECR	Extensor carpi radialis
ECU	Extensor carpi ulnaris
ED	Extensor digitorum
EMG	Electromyography
FCR	Flexor carpi radialis
FCU	Flexor carpi ulnaris
FDS	Flexor digitorum superficialis
FPL	Flexor pollicis longus
iEMG	Integrated electromyography
JRF	Joint reaction force
LE	Linear envelope
MSD	Musculoskeletal disorder
MVC	Maximum voluntary contraction
NFD	National Forestry Database
NRC	National Resources Canada
PAR-Q	Physical Activity Readiness Questionnaire
RMS	Root mean square
RVE	EMG amplitude observed during submaximal reference contraction
sEMG	Surface electromyography
TWIG	Tree Workers' Industrial Group
VBA	Visual Basic for Applications
VO_2max	Maximal oxygen uptake

CHAPTER 1: INTRODUCTION

Manual reforestation occurs at a high rate in Canada, with upwards of 500 million seedlings planted across 380 thousand acres annually (National Forestry Database [NFD], n.d.-c). Most of the tree planters completing this labour are university students in their early 20s (Sweeney, 2009). Most of the research completed to date has examined experienced tree planters, though novice planters make up a substantial portion of the workforce (Slot & Dumas, 2010). Manual tree planting involves a high degree of repetitive work, with experienced planters planting more than 3000 trees during an 8.5 hour workday (Trites et al., 1993). A substantial level of cardiovascular fitness is required to maintain a high production rate throughout a whole planting day (Hodges & Kennedy, 2011), and planting in general causes acute fatigue that accumulates as the season progresses (Roberts, 2002). The planting motion also requires repeated non-neutral postures across most joints (Slot, Shackles, & Dumas, 2010), and the forces experienced by the body throughout the planting cycle may be substantial (Sheahan et al., 2017). Though little research has been done on muscle activity during planting, that which has been completed showed high activation levels in the studied muscles (Granzow et al., 2018; Kinney et al., 2006; Sheahan et al., 2017). These studies were limited in scope and in some cases failed to report on muscle activation bilaterally, and a phasic approach to analysis of muscle activation may provide a better understanding of the injury risks of tree planting.

Tree planting has a high rate of injury (Roberts, 2009), many of which appear to go unreported (Lyons, 2001). Approximately 80% of tree planting injuries are classified as “chronic” (Lyons, 2001), and over 50% are MSDs, defined by Da Costa and Vieira

(2010) as “injuries or dysfunctions affecting muscles, bones, nerves, tendons, ligaments, joints, cartilages, and spinal discs”. The physical demands of tree planting include many risk factors for MSDs, and musculoskeletal pain is commonly reported in planters’ feet, wrists, and backs, with the severity of this pain increasing as the season progresses (Slot and Dumas, 2010; Slot, Shackles, & Dumas, 2010). The causes that underlie symptoms in the back and upper extremities may be more open to ergonomic intervention.

Sustained non-neutral postures, high forces, and repetitive movements are all well-documented risk factors for MSDs, and all are present to a high degree in tree planting. Numerous interventions, including guidelines for injury prevention, equipment modification, and ergonomic consulting, have been made available to tree planters in attempts to decrease injury risk, but anecdotal evidence suggests that these interventions have not entered widespread practice in the industry.

The level of muscle activation of the back and shoulders has been suggested to have a relationship with incidence of low back pain in the healthcare industry (Village et al., 2005), while studies examining muscle activity in the forearm suggest that the distribution of wrist flexor and extensor activity may play a role in upper extremity MSD development (Hägg & Milerad, 1997; Mogk & Keir, 2003). However, prior to this research, activation of back muscles had yet to be examined during tree planting tasks, while activation of upper extremity musculature had only been examined briefly. Based on the suggestions of trunk and upper extremity muscle activation levels as underlying factors in the development of upper extremity and back pain and MSD, these muscle groups were the focus of this study.

The aim of this research was to collect sEMG from novice participants during simulated tree planting tasks to describe the muscle activation in the back and upper extremity during tree planting. This thesis follows the traditional format. The author first discusses the existing literature regarding tree planting biomechanics and injury rates. Following the review of literature, the methodology of the research study and the subsequent results are detailed. As this research was descriptive and not hypothesis-driven, no statistical power analyses were done. Finally, the author presents a discussion of the results in the context of the existing literature, makes connections between the muscle activations observed and common tree planting injuries, and addresses the limitations and applications of the study.

CHAPTER 2: REVIEW OF LITERATURE

2.1 REFORESTATION IN CANADA

Canada contains 347 million hectares of forested area (around 9% of the world's forests), and the forestry industry accounts for approximately seven percent of Canada's total exports (Natural Resources Canada [NRC], 2016, 2018a). Ninety-four percent of Canada's forests are located on Crown (public) land, and forestry companies operating on this land are legally required to reforest all area harvested (NRC, 2018e). This legislation has allowed Canada to maintain one of the lowest deforestation rates in the world, with a total decrease in forested area of 1.3 million hectares (less than 0.5% of total area) between 1990 and 2016 (NRC, 2018c). Reforestation is the natural or intentional replenishment of depleted forests and is mandated by the Canadian government to ensure that the current level of forestry activity is maintainable for the foreseeable future (NRC, 2018b). Upwards of 700 thousand hectares of Canadian forest (less than 0.5% of total area) is harvested annually (NFD, n.d.-a; NRC, 2018b). Of this land, 45% will be able to naturally regenerate effectively, while the remaining 55% will require artificial regeneration (NRC, 2018d). Artificial regeneration in Canada occurs on a larger scale than in the United Kingdom, Finland, and Australia combined (Forest Commission, 2018; Peltola & Kankaanhuhta, 2018; Department of Climate Change and Energy Efficiency, 2013), but is dwarfed by the estimated one million hectares planted annually in the United States (Hernández et al., 2018).

There are two primary methods of artificial regeneration at use in reforestation work today: mechanical planting and hand planting. Mechanical planting is the use of heavy machinery to prepare microsites (the small-scale ecological environments in which individual seedlings are planted) and insert seedlings (Figure 2-1), while hand planting is the manual preparation of microsites and planting of seedlings by silviculture workers, known colloquially as tree planters. Planting machines have a productivity of 174-236 trees per hour (Rantala et al., 2009), while hand planting has a production rate advantage at approximately 350 trees per hour (Slot, Shackles, & Dumas, 2010; Trites et al., 1993). Hand planters can also access a wider range of terrains than machines and are better able to cope with poor worksite conditions (Laine, 2017). Due to these advantages, 95% of Canadian land requiring artificial regeneration is reforested by hand (NFD, n.d.-b). This amounts to 380 thousand hectares annually, which is planted with upwards of 500 million seedlings by an estimated 6000 silviculture workers (NFD, n.d.-c; Donahue, 2018). In 2016, 38% of those seedlings were planted in British Columbia, 20% in each of Quebec and Alberta, and 12% in Ontario (NFD, n.d.-c).

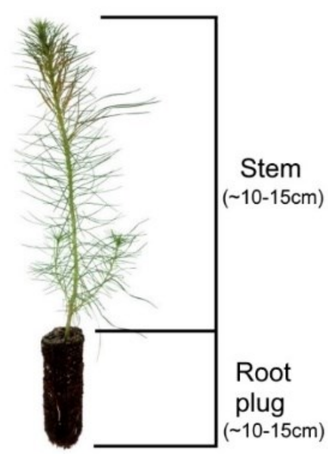

Figure 2-1. Basic anatomy of a tree seedling.

2.2 TREE PLANTING 101

2.2.1 Tree Planter Demographics

Canadian tree planting companies typically employ approximately 60 workers per camp, the majority of which are university students (Stjernberg, 2003; Sweeney, 2009). Traditionally, novice planters will spend their first season with a "rookie mill" (a company with a high rate of planter turnover) in Ontario or Quebec to gain experience before pursuing employment in Western Canada in subsequent seasons. As a result, Ontario planters tend to be in their early 20s and have little experience in terms of seasons spent planting, while planters in British Columbia are slightly older and have more seasons of planting experience (Table 2-1). Tree planting has a high rate of attrition, and by the end of a season the population of a planting camp can fall to as low as one-third of its initial size (Trites et al., 1993), a decrease attributable to factors such as workers quitting or departing due to injury mid-season, and workers departing for other engagements as the season draws to a close.

Table 2-1. Demographics of tree planter populations examined in previous research.

	Location	**Gender**	**Age (years)**	**# of seasons experience**	**Height (cm)**	**Body mass (kg)**
Sheahan et al. (2017)	ON, CA	5M	21.5 ± 1.4	2.6 ± 1.1^	180 ± 13	78.8 ± 7.1
		9F	22.1 ± 1.6	2.3 ± 1.9^	169 ± 5	58.3 ± 12.9
Denbeigh et al. (2013)	ON, CA	8M, 11F	21.5 ± 2.1	^	176.2 ± 8.1	73.5 ± 10.2
Slot & Dumas (2010)	ON, CA	73M, 41F	21.4 ± 2.1	0.61 ± 1.29	176 ± 9	72.1 ± 10.5
Slot, Shackles, & Dumas (2010)	ON, CA	14M, 6F	22.1 ± 2.8	2.2 ± 1.3^	173 ± 10	66.2 ± 17.7
Slot (2009)	ON, CA	8M, 12F	21.4 ± 2.0	^	175.3 ± 8.2	72.0 ± 10.0
Upjohn et al. (2008)	ON, CA	8M, 6F	21.83 ± 0.75	^	175 ± 9	75.7 ± 8.8
Hodges & Kennedy (2011)	BC, CA	20M, 14F	23.9 ± 3.9	3.4 ± 2.3	174.5 ± 10.2*	68.4 ± 12.2*
Roberts (2009)	BC, CA	12M, 8F	24 ± 3	2.2 ± 1.6	-	73.5 ± 10.0
		10M, 8F	22 ± 2	2.9 ± 2.4	-	77.7 ± 11.8
Hodges et al. (2005)	BC, CA	17M	21.8 ± 2.9	9 veterans averaging 1.6 8 novices	181.6 ± 8.7	80.6 ± 10.7
		5F	21.0 ± 1.9	1 veteran with 2 4 novices	163.4 ± 5.5	57.1 ± 6.6
Roberts (2002)	BC, CA	10M	25.6 ± 4.0	4.0 ± 2.2	182.7 ± 4.9	77.2 ± 7.5
Trites et al. (1993)	BC, CA	13M, 3W	26 ± 4 (range 18-39)	10 veterans averaging 3.6 (range 1-14) 6 novices	-	70.9 ± 6.7 (range 57-80)
Granzow et al. (2018)	AL, US	14M	26.9 ± 6	1-10+ (anecdotal)	BMI: 24.8 ± 1.7 kg/m^2	
*self-reported ^ Minimum 1 season						

2.2.2 Planting Equipment

2.2.2.1 Planting bags.

The typical Canadian planting contract sees planters carrying trees in bags secured around the hips with a belt (Clark, 2018). These bags are further supported by padded shoulder straps, which help redistribute the mass of the bags over the planter's hips and shoulders. Planting bags can be modified by adding or removing individual bags but are most often arranged in a three-bag formation when initially purchased (Figure 2-2). The left and right side bags are used to carry trees. The draw or trigger bag is the side bag contralateral to the dominant hand and is the bag from which the planter will actively draw trees with their non-dominant hand while planting. The back bag is typically used to carry water, food, and other personal supplies the planter might require.

Figure 2-2. Typical planting bags. (Bushpro Supplies Inc., n.d.-c)

2.2.2.2 Planting implements.

Worldwide, planters use a wide range of tools designed specifically for tree planting, including, but not limited to: D-handle spades, staff handle spades, dibble bars (narrow T-handle spades), and hoedads (long-bladed hoes). Tree planters colloquially refer to spades as shovels. The shovel most widely used in Canada is the Bushpro Stainless Steel Speed Spade (Bushpro Supplies Inc., n.d.-b; Figure 2-3), a D-handle spade weighing 1.4kg and measuring 86.4 cm in length when uncut.

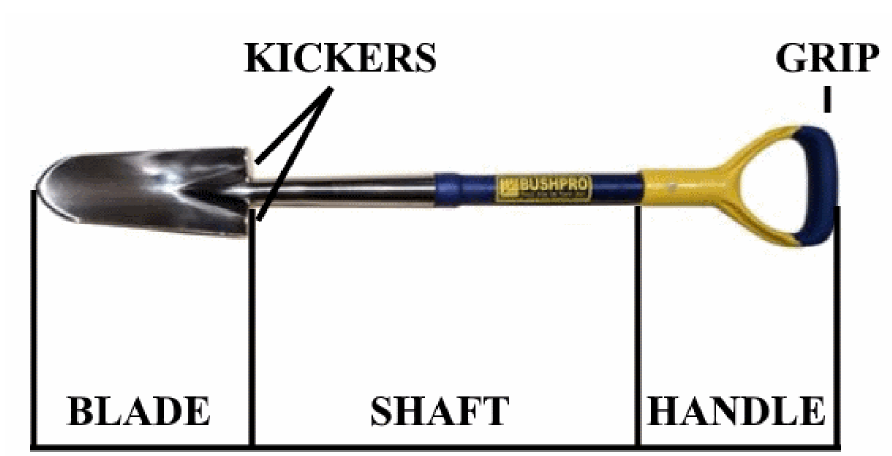

Figure 2-3. A Stainless Steel Speed Spade. (Bushpro Supplies Inc., n.d.-b)

As with their bags, veteran planters may modify their shovel to fit their planting style better; this can include shortening the shaft, replacing the handle, twisting the handle to sit at an angle to the blade, or shaving off one of the kickers (Clark, 2018). Bushpro offers four different D-handle options: Standard, Comfort, Ergo, and Oval (Bushpro Supplies Inc., n.d.-a, Figure 2-4). The Comfort handle is a modification of the plastic Standard handle, with a smaller diameter grip made of wear-resistant rubber. It was introduced in 2013 and is now the stock handle for Bushpro Speed shovels. First-year planters will typically purchase their equipment from their employer, and thus will receive the stock (Comfort) handle on their new shovel. Due to the isolated and transient nature of planting camps, a planter who identifies the need for a different handle during the season may be unable to acquire it before their season has ended.

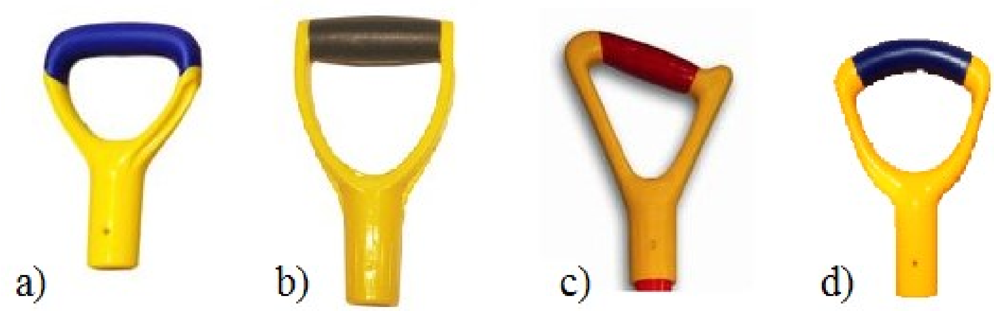

Figure 2-4. A range of D-shaped shovel handles, including a) Comfort D, b) Standard D, c) Ergo D, d) Oval D. (Bushpro Supplies Inc., n.d.-a)

2.2.3 Overview of the Work

Ontario tree planters generally begin the planting season in early May and finish their contracts in late June or early July, resulting in a season of approximately nine weeks duration, or 41-45 working days (Slot & Dumas, 2010). In British Columbia, a planting season can last 3-6 months (Hodges et al., 2005), with planting in the interior of the province occurring from early May through late July and planting on the coast occurring first in late winter through spring and again in late summer through early fall

(Ekers & Sweeney, 2010). The most frequently used shift schedule in Ontario is 6:1 (Slot & Dumas, 2010), or six workdays to one rest day, while schedules of 5:1 and 4:1 are more common in British Columbia (Lyons, 2001). Season lengths and shift schedules are highly fluid, as work shifts may be shortened or extended to accommodate personnel and contract requirements. Companies that see high planter attrition may also extend their planting season beyond the typical range in order to fulfill their contractual obligations, as the average number of seedlings every planter must plant in order to close a contract increases with each departing employee.

On a typical day, a planter will wake up around 6 AM, eat breakfast and pack their gear before a 7AM departure to the planting site (Clark, 2018). Travel time can vary widely, but the typical 9-10 hour workday sees planters arriving at the worksite around 8AM and departing at approximately 6PM. After arriving back at camp at 7PM, a portal-to-portal time (time spent at work inclusive of travel to and from the worksite) of 12 hours, planters will eat supper, do camp chores, ready their equipment for the following day, and socialize before retiring.

Planting trees by hand involves a substantial amount of repetitive work. A veteran planter can plant more than 3000 trees during an 8.5 hour workday (Trites et al., 1993), while exceptionally talented planters on quality land have been known to plant upwards of 7000 trees in a day (Donahue, 2018). Before planters begin planting, they must “bag up” by loading seedlings into their side bags. A planter will typically bag up 300-500 seedlings, a mass of approximately 10-30 kg or 20-39% of a planter’s body mass (Roberts, 2002; Slot, Shackles, & Dumas, 2010; Trites et al., 1993). Bag load and daily planter production can vary substantially depending on factors such as worker experience, piece dimensions, site preparation, and terrain. Once the worker plants all the seedlings in their bags, or "bags out", they will bag up again, and repeat this sequence until the end of the workday.

2.2.4 The Planting Cycle

The planting of each seedling follows a typical cycle: (1) movement between microsites, (2) microsite selection, (3) microsite preparation, (4) cavity creation, (5) seedling insertion, and (6) soil compaction (Clark, 2018). This cycle can take anywhere from 4.1 to 32.6 seconds to complete (Stjernberg, 1988), with the duration dependent on a variety of site- and planter-specific factors, but on average the planting cycle takes approximately 11 seconds (Slot, Shackles, & Dumas, 2010; Stjernberg, 1988; Stjernberg, 2003).

2.2.4.1 Movement between microsites.

The planting cycle begins when the previous seedling has been planted and the planter moves toward the next planting site. Tree spacing, or the distance between adjacent microsites, is dependent on land quality and thus may differ across blocks (sections of logged land) and between contracts. Planters will estimate this distance by sight or take the number of steps that they have previously determined to be equivalent to the required spacing. When moving between microsites, the planter must identify hazards and navigate around them, while they simultaneously retrieve a seedling from their bag with their non-dominant hand and ensure that the planting tool carried in their dominant hand does not get caught up in debris.

2.2.4.2 Microsite selection.

While moving forward from the last planted site, the planter evaluates the ground in front of them to select their next site. The planter must take into account several variables to ensure the seedling has a high probability of survival, including but not limited to distance from young natural-growth trees, soil quality, availability of organic matter, debris level, and avoidance of significantly wet or dry areas.

2.2.4.3 Microsite preparation.

Planting contracts specify the level of site preparation expected around a planted seedling. Levels of site preparation, from least to most extensive, include no prep (the microsite is planted as-is), scalping (clearing the microsite of loose litter and debris), and screefing (clearing the microsite of all matter down to bare mineral soil). Scalping and screefing are typically performed by swiping the sole of a boot across the microsite, though the hand or shovel blade may also be used depending on the type of debris.

2.2.4.4 Cavity creation.

The shovel is used to create an opening in the ground (Figure 2-5). The planter will raise the shovel with their dominant hand and then drive it into the ground, ensuring that the blade of the shovel remains vertical. If this motion alone does not achieve a depth of 10-15cm (the approximate length of a seedling root plug), the planter will place the sole of their boot on one of the shovel kickers and apply downward pressure until they have reached a sufficient depth. Once the shovel blade has been inserted in the ground, there are multiple methods by which a hole can be opened to create space for the root plug. Of these, the C-cut is one of the most frequently taught to novices in Ontario camps. When making a C-cut, the planter will drive the shovel handle forward (away from their body), move it laterally to their dominant side, and then pull it back towards themselves. This creates a wedge-shaped cavity against the back of the shovel blade, with the wide end of the wedge towards the planter's dominant side and the point of the wedge towards the planter's non-dominant side.

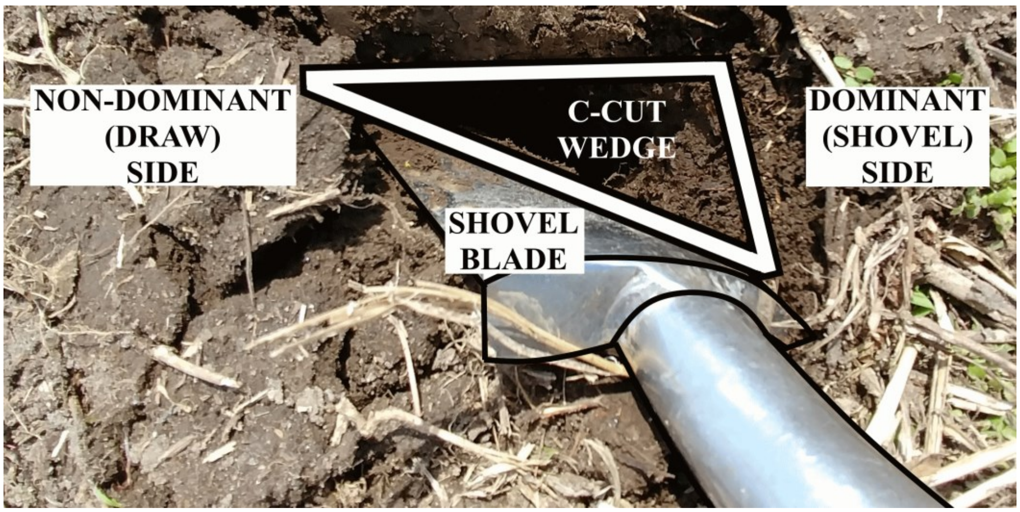

Figure 2-5. The wedge-shaped cavity created during a c-cut.

2.2.4.5 Seedling insertion.

The planter retrieves a seedling (if they do not already have one in hand) and holds the root plug in parallel with their extended fingers. They bend over and insert the plug into the hole by cupping the plug against the back of the shovel blade and sliding it across the blade from the wide end of the hole to the narrow end. When the seedling is fixed into the corner of the hole with the plug oriented vertically, the planter removes both their hand and their shovel from the hole.

2.2.4.6 Soil compaction.

The planter compresses the soil loosened during cavity creation around the seedling to close the hole. This practice can be performed using any of the hand, boot, or shovel, but boot closures are the most common in Ontario. As the planter stands from inserting the seedling, they step forward and use the sole of their boot to compress the soil. The planter must ensure that the plug is completely covered, no air pockets remain around the roots, the tree is not secured too loosely in the ground, and they have not damaged the seedling. Once the hole is completely closed, the planting cycle is complete, and the planter proceeds to the next microsite.

2.3 THE PHYSICAL DEMANDS OF TREE PLANTING

2.3.1 Cardiovascular

Tree planting is an occupation characterised by high levels of physical exertion interspersed with infrequent and brief rest periods. Canadian tree planters are generally piecework contractors (i.e. compensated on a per-tree basis) who work for approximately 6-25 cents per tree. Tree prices are typically higher in British Columbia and Alberta than Ontario and Quebec and differ between companies and contracts. Low per-tree prices require a high production rate for a planter to earn a substantial amount of money. As such, pay structure may be the motivation behind piecework planters both spending 80-85% of their day planting and maintaining approximately 60% of their age-predicted maximal heart rate across an entire workday (Hodges & Kennedy, 2011). This is about 35% of their maximal oxygen uptake (VO_2max) (Swain et al., 1994), and equal to the suggested upper general tolerance limit of 30-35% VO_2max for 8-hour shifts of mixed physical labour shifts (Jørgensen, 1985). Experienced planters can maintain a higher working pace (trees/hour) than inexperienced planters, without an associated increase in working heart rate (Hodges & Kennedy, 2011).

2.3.2 Fatigue

Workplace fatigue is multi-dimensional and can involve neuromuscular, metabolic, and mental components, in addition to further mechanisms (Yung, 2016). However, in the context of tree planting MSDs, neuromuscular fatigue is of greater focus. Tree planters experience acute neuromuscular fatigue daily, marked by elevated serum enzyme activity (lactate dehydrogenase, creatine kinase, and aspartame transaminase), and the effects of this fatigue accumulate as the season progresses (Roberts, 2002; Robinson et al., 1993; Trites et al., 1993). This resultant cumulative fatigue may also be due in part to lengthy portal-to-portal time, infrequent breaks, poor sleeping conditions, insufficient ratio of work to rest days (Williamson & Friswell, 2013). In combination, these factors may not allow planters to fully recover from one day of work to the next. Thus, not only do planters maintain a strenuous work pace throughout the workday, but they also do so while experiencing cumulative fatigue that is likely to persist through the end of their season. This cumulative fatigue can lead to immunosuppression and expose the planter to a higher risk of injury and illness over the course of the season (Jones et al., 2017).

2.3.3 Posture

Awkward sustained and repetitive postures are commonly associated with workplace MSDs and injuries, though other risk factors such as force may be of greater importance in the consideration of MSDs. Posture modulates how force is transmitted through bodily tissues (Wells et al., 2004), with non-neutral postures likely to lead to more injurious transmission of forces in the body. Tree planting requires planters to move their body into non-neutral postures repetitively, and thus they may be at an increased risk of sustaining a posture-related injury at some point during their planting career.

2.3.3.1 Trunk posture.

More than 50% of a planter's workday may be spent in trunk flexion greater than 45° (Upjohn et al., 2008), with maximal trunk flexion reaching upwards of 130° from vertical (Slot, Shackles, & Dumas, 2010). The mean amplitude probability distribution function (APDF) values of trunk flexion angle at the 10th, 50th, and 90th percentiles do not change significantly across the work day (Upjohn et al., 2008), suggesting that the gross mechanics requiring these extreme trunk postures are constrained by the task itself. Trunk rotation during seedling insertion is related to tool length and handle type, with short-shafted D handle shovels requiring trunk rotation more frequently (78.2% of observed planting cycles) than long-shafted staff handle shovels (52.5% of observations) (Giguère et al., 1993). Maximum draw-side trunk rotation (>53°) is greater than shovel-side trunk rotation (>42°) (Slot, Shackles, & Dumas, 2010), a difference that is likely due to the movement required to draw a seedling from the trigger bag.

2.3.3.2 Lower limb posture.

Little research has been done on lower limb kinematics during tree planting. Slot (2009) documented lower limb posture during 10 trials each of three loading conditions: (1) seedlings evenly distributed in their bags, (2) seedlings solely in the draw-side bag, and (3) seedlings solely in the shovel-side bag. Participants were 20 experienced planters recruited from a university population, and all were right-hand dominant planters.

Average hip flexion angles during planting peaked during maximum trunk flexion (shovel-side ~ 100°, draw-side > 80°). The shovel-side hip was adducted (~15°) and the draw-side hip was abducted (~20°) at maximum trunk flexion, while abduction and adduction angles were less than 10° through the rest of the planting cycle. Apart from the draw-side hip at maximal trunk flexion (15° of internal rotation), internal and external rotation were less than 10° in both hips.

Average knee flexion angles approached 50° (shovel-side) to 70° (draw-side) at maximal trunk flexion. Except for the shovel-side knee at maximal trunk flexion (~10° of adduction), abduction and adduction were less than 6° in both knees. Internal and external rotation were less than 10° in both knees.

On average, shovel-side ankle flexion remained somewhat neutral through the planting cycle, while the draw-side ankle reached approximately 15° of plantarflexion during maximum trunk flexion. Both ankles were everted throughout the planting cycle (shovel-side < 10°, draw-side < 5°. Except for shovel impact (external rotation ~9°), shovel-side ankle rotation was neutral, while the draw-side ankle was externally rotated (> 10°) through the entire cycle.

In summary, Slot's work (2009) found that the greatest non-neutral lower limb postures were experienced at maximal trunk flexion, correlating to seedling insertion, and the shovel-side loaded condition produced lower limb postures that were the furthest from neutral of all three conditions. However, this study was conducted in a sandbox in a laboratory setting and the results may not be generalizable to production in the field, as planters are unlikely to be put to work in an environment with a clear approach and level surface. Lower limb posture during planting appears to be used as a tool for balance maintenance (Giguère et al., 1993), and thus the repeatability documented in a laboratory setting may not be attainable in the field, as posture is likely modified for each individual planting cycle to accommodate for terrain differences between microsites. Thus, study of lower limb posture, in examination of a potential relationship to planter injury, may be better left to field study to ensure that the postures captured are representative of those experienced daily by planters.

2.3.3.3 Elbow and forearm posture.

A study of tree planters in a field setting (Slot, Shackles, & Dumas, 2010) documented elbow and forearm angles during planting cycles (Table 2-2). Small differences, some of which were significant, were observed in shovel-side elbow flexion and forearm pronation and draw-side forearm pronation depending on bag-loading condition.

Table 2-2. 50th and 90th percentile APDF values of elbow flexion and forearm pronation angles during planting cycles (Data from Slot, Shackles, & Dumas, 2010).

	Elbow Flexion		**Forearm Pronation**
	50^{th} percentile	*90^{th} percentile*	*50^{th} percentile*
Shovel Side	50°	< 70°	~100°
Draw Side	36°	> 60°	105°

2.3.3.4 Wrist posture.

Postural changes in the shovel-side wrist with respect to the forearm during a single planting task have previously been described (Denbeigh et al., 2013) in relation to four reference events: Event 1 – Shovel reaches peak height, Event 2 – Shovel impacts ground, Event 3 – Trunk reaches maximum flexion, and Event 4 – Planter returns to upright posture (Figure 2-6; excerpted from Denbeigh et al., 2013). The shovel-side wrist begins to extend as the planter bends to plant a seedling and reaches maximum extension (<45°) just prior to tree insertion. Simultaneously, the shovel-side wrist fluctuates between ulnar and radial deviation, experiencing greater maximum ulnar deviation (>25°)

than radial deviation (10-15°) (Slot, Shackles, & Dumas, 2010). Forearm rotation remains relatively neutral throughout the cycle.

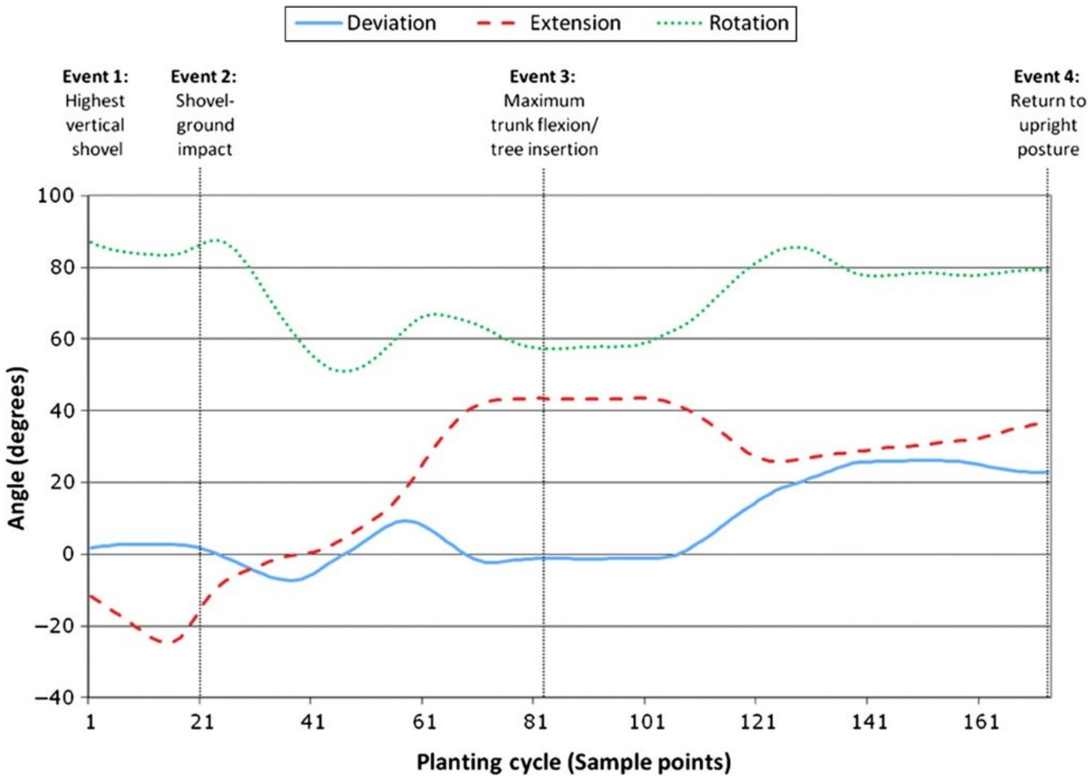

Figure 2-6. Deviation, extension, and rotation angles at the wrist during a full planting cycle. Ulnar deviation, extension, and pronation angles are positive, with 0° of rotation representing full supination. All angles are angle of the hand relative to the forearm. (n = 1, evenly loaded condition, 50Hz collection frequency). Excerpted from Denbeigh et al. (2013).

In a field study of 20 planters using their own shovels (length = 71.8 ± 4.6cm) to bag out 449 ± 52.5 seedlings over an average of two hours, Slot and colleagues (2010) found small differences, some of which were significant, in shovel-side wrist postures depending on bag-loading condition. However, multiple datasets in the symmetrical and asymmetrical carriage conditions were incomplete due to the challenges inherent in data collection in the field. Members of the same lab (Denbeigh et al., 2013) were unable to replicate these results in a laboratory setting in a study of 18 planters using a provided shovel (length = 95cm) to complete 30 isolated planting cycles, suggesting that there may be an effect of shovel length or fatigue on bag-loading condition-dependent wrist posture.

To the best of the author's knowledge no studies have examined draw-side wrist posture during tree planting.

2.3.3.5 Summary.

Research demonstrates that the act of tree planting requires extreme sustained repetitive non-neutral postures in the trunk and shovel-side wrist, putting planters at a high risk of sustaining posture-related injuries in the workplace. The potential negative implications of these extreme and repeated postures will be explored in Section 2.4, when injury risk factors in tree planters are discussed.

2.3.4 Forces

Although high bone-on-bone forces in all joints are well known to increase injury risk, little research has been done in the examination of these forces in tree planting populations. The research that had been done has focused mainly on wrist joint forces, likely because loading at the wrist has been suggested as a significant source of pain in tree planters (Slot & Dumas, 2010). In addition to their previously discussed examination of wrist postures, Denbeigh and colleagues (2013) used a shovel instrumented with strain gauges to examine forces at the wrist during the planting movement. Though the researchers collected shovel impact forces and used these values to compute resultant joint reaction forces (JRFs) with inverse dynamics, they failed to report the impact values themselves. Additionally, the use of inverse dynamics in motion analysis can result in error in the calculated movement characteristics (Hatze, 2002) and JRFs are not true bone-on-bone forces as they do not include muscle force. Thus, the JRFs reported in this paper do not provide much insight into injury risk during tree planting.

In a research study examining the effects of a novel wrist brace on wrist posture and joint stiffness in tree planters, Sheahan and colleagues (2017) reported mean shovel-ground impact forces of ~194 N. However, the shovel used in this study was instrumented with a load cell, which did not change the length of the shovel shaft but added 0.68kg to the mass of the shovel. Given that the average mass of the Hiballer Stainless Steel Spade used in this study is 1.47kg (Bushpro Supplies Inc., n.d.-b), this was a 46% increase in shovel mass, which would cause a similar increase the shovel's potential and kinetic energy and thus increase the force of impact. Adjusting for this increased mass gives an approximate shovel-ground impact force of 130N, a substantial force for the small muscles of the hand and forearm to experience at the high rate of repetition inherent in tree planting. The combination of high force and high repetition is a common injury risk factor and thus is a major area of concern in the health of tree planters.

2.3.5 Muscle Activation

The repetition of the planting cycle and the short work-to-rest ratio required to attain a high level of production are both likely to place a high level of demand on planters' muscles. However, to the best of the author's knowledge only three studies have examined muscle activation in tree planters during planting activities.

In a pilot study to develop guidelines for the reduction of tree planter injury, Kinney and colleagues (2006) measured forearm muscle activity during planting activities in five planters, all of whom had at least two seasons of planting experience. Four of the participants were right-hand dominant and one was left-hand dominant, and thus the data were labelled as shovel- or draw-side as opposed to right- or left-side prior to analysis. sEMG was collected bilaterally from four forearm muscles (flexor pollicis longus (FPL), flexor digitorum superficialis (FDS), flexor carpi radialis (FCR), and extensor carpi radialis (ECR)) during a single bag-out (approximately 45 minutes) in a field setting. Collection frequency was not reported.

The sEMG signals were smoothed with a 100ms moving window root mean square (RMS) and normalized to MVCs performed at the beginning of the planting session. However, the researchers neglected to report how these MVCs were conducted, which draws into question whether the reference contractions were true MVCs. The sEMG amplitude was expressed as a percentage of MVC. An example sEMG recording of a single planting cycle showed high levels of activity in the shovel-side muscles during cavity creation (~30-60% MVC) and in the draw-side muscles during seedling insertion (~25-80% MVC), though it is unclear whether the activity levels seen in this single recording were representative of those observed in the study as a whole.

A muscular effort period measure, defined by the researchers as the level of muscle activity during the recording, was assessed by measuring the amount of time each muscle was active at three muscle activity intensities (low (< 10% MVC), moderate (10-35% MVC), or high (> 35% MVC), though no rationale was presented in-text as to why these thresholds were selected. Figure 2-7 shows an example analysis of one planter during a 45 second recording, during which muscle activity was low or moderate for much of the time. The shovel-side ECR was active at a high intensity for 24% of the recording; however, the sample size and examined time frame are too small to draw any meaningful conclusions.

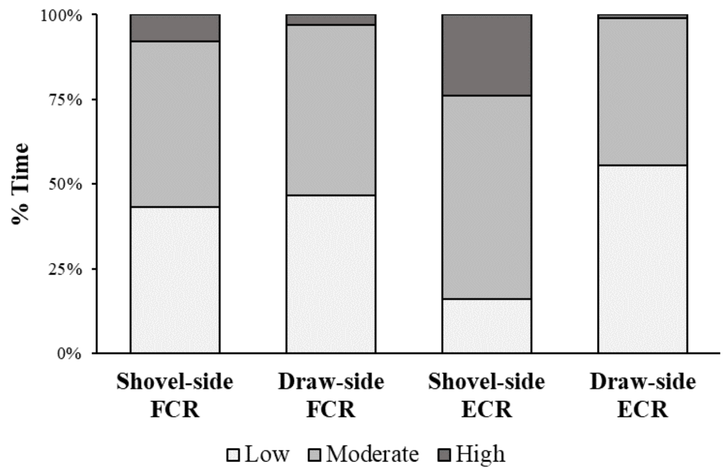

Figure 2-7. Muscular effort period measure of time spent at low, moderate, and high intensity levels of muscular effort as a percent of total planting time. n = 1, 45 second recording. Low: < 10% MVC, moderate: 10-35% MVC, high: > 35% MVC. Figure adapted from Kinney et al. (2006).

Muscular effort was calculated for all sEMG data and averaged across the five participants. The first and last five minutes of the data were analyzed separately to examine the effects of fatigue on the level of muscular effort. The shovel-side FPL, FDS, and FCR all had an increase in time spent at high intensity and a decrease in time spent at low intensity from the beginning to the end of the planting session, consistent with expected fatigue patterns of increasing muscular effort as compensation for a reduction in force generating capacity. The shovel-side ECR had a decreased time at high intensity and an increased time at low intensity, though the magnitude of these changes was not as substantial as those observed in the other three muscles. The generalizability of this study to tree planters at large is limited by the small sample size. Also due to the recruitment constraint requiring participants to have at least two seasons of experience these results may not be representative of those that would be observed in a novice population.

Sheahan and colleagues (2017) examined the effects of a novel wrist brace, designed specifically for tree planters, on wrist posture and joint stiffness. Twenty participants, who had at least one season of planting experience and were either right-hand dominant or ambidextrous planters, were recruited from a university population. In a laboratory setting, participants completed 10 individual planting trials while wearing the brace and 10 trials without the brace, resetting between each trial. The order of the braced and non-braced conditions was block-randomized. The researchers collected sEMG from six forearm muscles (FDS, extensor digitorum (ED), flexor carpi ulnaris (FCU), FCR, extensor carpi ulnaris (ECU), and ECR). This sEMG was used to estimate the stiffness of the wrist joint. Isometric maximum voluntary reference contractions (flexion, extension, radial and ulnar deviations) were produced while participants maximally gripped a fixed 3.8cm cylinder, and sEMG was normalized to the average of a 25ms window surrounding the peak signal of the reference MVC.

Differences in outcome measures between the conditions were examined using paired t-tests. No statistically significant differences were reported in muscle activity between the conditions, though a non-significant increase was seen in muscle activity from the non-braced condition to the braced condition in all muscles but ECR (Figure 2-8, excerpted from Sheahan et al., 2017). Mean muscle activity levels ranged from approximately 30-60% of maximum across all muscles and both conditions, a relatively high activation level given the repetition inherent in planting work. Similar activation levels (30-60%) during repeated tasks in other industries have been linked to increased incidence of musculoskeletal symptoms (Hanvold et al., 2013; Johnston et al., 2008).

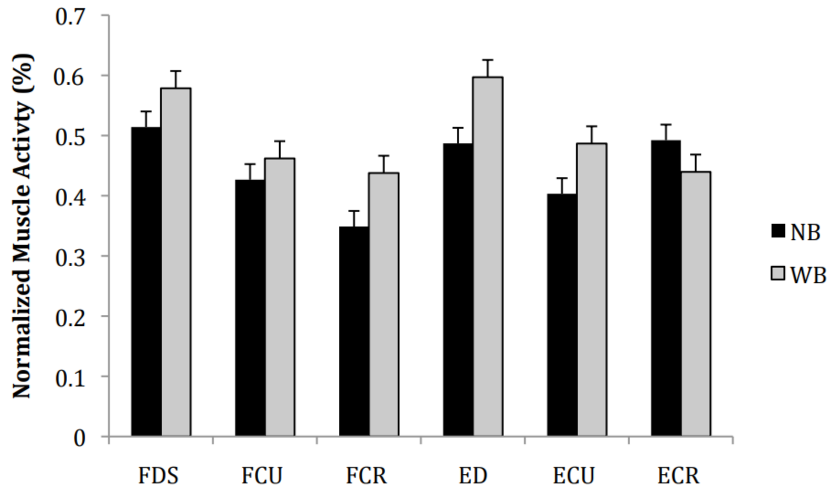

Figure 2-8. Mean activity (with standard error bars) of muscles at shovel impact for participants in non-braced (NB) and braced (WB) conditions. Excerpted from Sheahan et al. (2017).

As detailed above, a major limitation of this study was the instrumentation of the shovel with the load cell, which increased the shovel mass by 46%. This increase in mass is likely to have caused an associated increase in muscle activity above what would be seen if using an unmodified shovel. Further examination of muscle activity in forearm musculature while planting with an unmodified shovel would aid in better understanding of the muscular demands of tree planting.

In a study of 14 male hand planters in the Southeastern United States, Granzow and colleagues (2018) collected continuous sEMG bilaterally from the upper trapezius and anterior deltoid during a single workday. Participants were all right-hand dominant and planted with a T-handled dibble bar in their right hand. Participants performed three 15-second submaximal isometric reference contractions with 2kg weights in each hand for each muscle prior to the workday. The sEMG data were sampled at 1000 Hz and the raw signals were converted to RMS amplitudes using a 100-sample moving window with an overlap of 50 samples. The mean RMS amplitude of the middle 10 seconds of each reference contraction was calculated, and the average of these three values was taken for each muscle. The RMS sEMG amplitudes during the workday were expressed as a percentage of the average RMS sEMG amplitude observed during the reference contractions.

The metrics examined included a global index of muscular load calculated by taking the mean amplitude of the normalized RMS signal for each muscle across the entire recording, frequency of gaps in muscular activity (gaps/minute, gaps defined as any period of muscular activity below 5% of muscular load for at least 0.25s), muscular rest (summed duration of all gaps as a percentage of total time), and 10th, 50th, and 90th percentile APDF values of muscle activation during the observation period as a percentage of muscular load. The study had a high rate of sEMG data loss (resultant sample sizes – upper trapezius: right (shovel-side) n = 11, left (draw-side) n = 10; anterior deltoid: right (shovel-side) n = 8, left (draw-side) n = 10).

The average recording length was 433.9 ± 88 minutes, 75.8% of which was comprised of planting and 24.2% of which was comprised of non-planting tasks, including loading planting bags, carrying boxes of seedlings, and a lunch break. Muscle activity was greater in the right (shovel-side) arm than the left (draw-side) arm across all summary metrics, through the entire day, and during both planting and non-planting activities (Granzow et al., 2018). Muscle activity was also typically higher during planting than during non-planting activities, but non-planting tasks still displayed relatively high levels of activity in the upper trapezius muscles, likely as a result of the physical intensity of those tasks (ex. carrying boxes of seedlings to locations inaccessible by vehicles) and the limited opportunity available for rest (< 20.8% of shift time across all conditions in the left upper trapezius and <14.8% across all conditions in the right upper trapezius).

The participants in this study were all male seasonal foreign workers of a mean age (26.9 ± 6.0 years) that is greater than typically observed in study populations in Canada. The workers also earned hourly wages as opposed to piecework, limiting the generalizability of this study to typical Canadian hand planters. The implement used in this study was a T-handle dibble bar, which requires a different strategy of hole-cutting than the C-cut, and the study occurred in environmental conditions typical to the Southeastern United States and likely different from those experienced by Canadian hand planters. Both tool and environment differences are likely to alter the physical demands of the planting task examined, and thus the muscle activation patterns and amplitudes observed in this study may not be representative of those experienced by Canadian hand planters. Another limitation was the small sample size, which was made even smaller by the data lost during collection. However, this study is valuable as the first published examination of muscle activation in planters in the field and provides a starting point for the evaluation of the physical demands faced by hand planters through the lens of muscle activity.

2.4 TREE PLANTING AND MUSCULOSKELETAL DISORDERS

2.4.1 Introduction

Da Costa and Vieira (2010) define MSDs as "injuries or dysfunctions affecting muscles, bones, nerves, tendons, ligaments, joints, cartilages, and spinal discs". Common risk factors that impose biomechanical stress on a worker, and thus may contribute to the development of work-related MSDs, include inadequate rest periods, excessive task repetition, high forces, excessive non-neutral postures, contact stresses, and vibration. These risk factors are all inherent to the task of hand planting in its current form.

From 2009 to 2018, workers in British Columbia in the *703016 – Tree Planting or Cone Picking* classification unit made 999 total time-loss claims to WorkSafeBC, an annual injury rate of approximately 8.45%, or almost four times the provincial average (WorkSafeBC, 2020). Previous research has reported an even greater injury rate of around 22% of planters during a single planting season (Roberts, 2009), and 50% to 90% of planters over their careers (Giguère et al., 1993; Lyons, 2001; Smith, 1987).

This disparity in expected versus reported injuries may be due to underreporting of workplace MSDs, a practice common in North America (Luckhaupt & Calvert, 2010; Stock et al., 2014) and among young workers (Tucker et al., 2014), populations vulnerable to employer retaliation (Wilmsen et al., 2015), and low-wage or temporary workers (Azaroff et al., 2002). In support of this hypothesis, in a survey of 72 tree planters of which 76% reported having been injured because of planting, 58% did not consult a doctor and 48% took no time off from work (Lyons, 2001).

Of the time-loss claims made to WorkSafeBC from 2014 to 2018, over 55% were MSDs and over 30% were related to either repetitive motion (17.0%) or over-exertion (14.9%) (WorkSafeBC, 2020). Approximately 20% (20.9%) of claims were made for injuries to the wrist, fingers, and hand, and 12.8% for injuries to the back. Close to 50% (46.8%) of claims were made for strain, either back strain (12.6%) or other strains (34.2%), while a further 11.1% were attributed to tendinitis or tenosynovitis.

Planting injuries occur most frequently during the first two weeks and final two weeks of a season (WorkSafeBC, 2006), likely as a result of increased physical demands and inexperience or lack of conditioning in the former case and onset of injury resulting from cumulative trauma in the latter. Lyons (2001) posited that approximately 80% of tree planting injuries could be classified as “chronic”, though no time range was given for this definition, and upper extremity MSDs are so common amongst tree planters that specific vernacular has been developed to describe certain sets of symptoms, including the ‘claw’ (pain and stiffness in the wrist and fingers that worsens as the season progresses, resulting in flexed fingers when the hand is relaxed), ‘planter’s elbow’ (medial epicondylitis), and ‘tendo’ (general term for joint, tendon, and ligament disorders).

MSD symptoms can include weakness, clumsiness, and loss of range of motion, but musculoskeletal pain is the complaint most tracked amongst tree planters. The areas in which pain is most reported are planters’ feet, wrists, and backs, and the severity of this pain increases as the season progresses (Slot and Dumas, 2010, Slot, Shackle, & Dumas, 2010). Foot pain is an MSD symptom that has been well-documented in working populations that spend a substantial amount of working time walking (Reed et al., 2014), an attribute of tree planting that would be difficult to modify. Both back (Xu et al., 1997) and upper extremity (Rempel et al., 1992) pain are closely associated with repetitive work and other MSD risk factors present in tree planting, but the underlying cause of these symptoms may be more open to ergonomic intervention and modification.

2.4.2 Pain Incidence in Tree Planters

2.4.2.1 Back pain.

Back pain is a frequent complaint amongst tree planters. In a population of 118 planters (which excluded a population subset of 14), average reported non-zero pre-season musculoskeletal pain (scale from 0-10, with 0 indicating no pain and 10 indicating severe pain) was 2.9 ± 2.1 in the upper back (36% frequency), 3.4 ± 2.0 in the mid-back (30% frequency), and 3.6 ± 2.0 in the lower back (40% frequency) (Slot & Dumas, 2010). End of season scores for the population were unavailable due to lack of reporting and worker attrition. In the population subset (n = 14), 0% of whom reported pain in any area in the pre-season, there was a significant increase in pain reported in the upper (3.2 ± 1.8, n = 9), mid (3.6 ± 2.5, n = 8) and lower (3.3 ± 2.6, n = 10) back from pre-season to end of season.

In a study conducted during the final three weeks of a nine week season (n = 20), reported pain was 3.0 ± 1.7 in the upper back (n = 8), 3.3 ± 2.0 in the mid back (n = 13) and 3.3 ± 1.9 in the lower back (n = 16) (Slot, Shackles, & Dumas, 2010). Reported symptoms in the mid back were significantly greater (p = .02) in planters who unloaded their trees symmetrically (n = 10) than in those who unloaded their trees asymmetrically (n = 10), which is unexpected in the context that workers appear to compensate for asymmetric loads by making postural adjustments to the contralateral side of the applied load (Slot, 2009), and that asymmetric loading causes increased stress and pressure in the intervertebral disc (Steffen et al., 1998).

2.4.2.2 Wrist pain.

Anecdotal evidence suggests that the most frequent planting MSDs suffered by tree planters are overuse conditions of the shovel-side upper extremity, including De Quervain's tenosynovitis (inflammation of the tendons at the base of the thumb), planter's elbow (medial epicondylitis), carpal tunnel syndrome, and 'the claw' (stenosing tenosynovitis, or 'trigger finger'). However, previous research (Slot & Dumas, 2010; Slot, Shackles, & Dumas, 2010) reported pain statistics by left and right sides of the body, as opposed to shovel and draw side. Approximately 10% of planters operate their shovel with their left hand and 15% operate their shovel ambidextrously (Slot & Dumas, 2010), and thus this manner of reporting makes it difficult to determine whether there is a difference in pain incidence between shovel and draw side.

In a population subset of 14 planters, 0% of whom reported pain in any area in the pre-season, Slot and Dumas (2010) reported a significant increase in frequency and severity of reported non-zero end-of-season musculoskeletal pain (scale from 0-10, with 0 indicating no pain and 10 indicating severe pain) in both the right (front of: 4.7 ± 2.8, n = 7; back of : 3.1 ± 2.2, n = 7) and left (front of: 5.0 ± 3.5, n = 5; back of: 4.0 ± 3.0, n = 5) wrists, and the right (4.5 ± 3.0, n = 6) and left (3.0 ± 2.6, n = 6) fingers.

2.4.2.3 Summary.

The increase in both frequency and severity of subjective pain observed in the back and wrists/fingers suggests that tree planters are unable to recover completely from aches and pains that occur during the season. These lingering pains may be harbingers of underlying MSDs and increased injury risk.

2.4.3 Existing Interventions

Multiple guidelines for the prevention and reduction of planting injuries have been published by both worker compensation boards (Bell, 1993; Stjernberg & Kinney, 2007; WorkSafeBC, 2006) and planting companies (Brinkman & Associates Reforestation Ltd., 2015; Summit Reforestation and Forest Management Ltd., 2014). These are often distributed to incoming planters upon their hiring, though they may not be required reading prior to beginning work. The free-of-charge pre-season training program *Fit to Plant* (Roberts, 2004), developed by Selkirk professor Delia Roberts based on previous findings (Roberts, 2002), decreased injury rates from 22% to less than 5% when instituted at companies working on Weyerhauser Company contracts (Roberts, 2009). It is unclear whether this was a direct effect of the program itself or of an associated change in company culture, or an issue of underreporting. Slot and Dumas (2010) reported that 90% of planters (n = 118) who responded to their survey had a level of pre-season physical activity classified as 'high', as determined using the International Physical Activity Questionnaire. However, the researchers found no correlation between pre-season physical activity level and musculoskeletal symptom development over the course of the season in a population subset of 14 planters.

Some tree planting companies are beginning to employ physical and occupational therapists and ergonomics consultants to provide their employees with greater healthcare support. As an example, following research indicating that prophylactic taping of the shovel-side thumb decreased the rate of De Quervain's tenosynovitis (Western Forestry Contractors' Association, 2017), Brinkman Reforestation has required all first- and second-year planters to have their shovel-side hand taped during the first few shifts of the season (Workplace Safety North, 2019). Workers at companies without these support staff and educational programs have been known to turn to self-prescribed prophylactic supports, including wrist braces, elbow compression sleeves, and self-taping. Commercially available prophylactic supports may not be able to withstand the duress of planting, and a wrist brace designed specifically for tree planting showed no clear net benefit when examined in previous research (Sheahan et al., 2017).

Equipment modification is probably the most common intervention amongst tree planters and at the same time is the intervention least likely to be overseen by someone with ergonomic experience. Anecdotally, planting bag modification is uncommon in novice populations, and bags are typically not modified with ergonomic benefits in mind. Shovel modification appears anecdotally to be the most frequent equipment adjustment made, though a majority of the focus seems to be put on shortening the shaft and twisting the handle relative to the blade while little thought is given to handle choice, which appears to be somewhat of a case of 'one-size-fits-all'. Handle choices beyond the stock handle are difficult to acquire during the season and may be an afterthought for planters. Ergo D and Oval D handles are marketed as handles designed to put a planter's hand in a more natural position than the Comfort D and Standard D handles do, but anecdotally planters feel that these handles may simply transfer load to the ulnar side of the hand and increase injury risk (Denbeigh et al, 2013).

The Pottiputki, developed in Finland in the 1970s, is a hollow planting tube of 90cm length with a beak at the end that creates a planting hole when operated with a pedal (Björkemar Construction & Consulting [BCC], n.d.). The tree is slid down the tube and the hole closed with the planter's foot. This tool would likely reduce the need for lumbar flexion and would allow for muscular demands on the upper limb to be shared equally. However, the tube is specific to the diameter of the seedling plug, with larger plugs requiring the purchase of larger tubes, which weigh between 1.5-2.4 times as much as the typical planting spade and costs approximately four times as much (BCC, n.d.). It is also difficult to use in overgrown or technically demanding land (Barry, 1975), may predispose workers to develop hand and wrist injuries due to wrist posture at the point of impact (Oliver & Rickards, 1995), and the planting cycle takes significantly longer per tree than other common tools (Scarratt & Ketcheson, 1974). Resultantly, the Pottiputki is regarded as not well-suited to planting conditions and worker requirements in Canada and has thus never reached widespread usage in the Canadian planting community.

Though ergonomic and educational interventions are available, these interventions have not entered widespread practice in the industry and may not fully address potential injury risks. As a result, worker injury rate remains high, and room for improvement in interventions exists.

2.4.4 Hypothesized Causes of Tree Planting Pain and MSDs

Low back pain is significantly predictive of lost work time in both the short- and long-term (Morken et al., 2003), while employees frequently work through upper extremity symptoms and let them go unreported (Pransky et al., 1999). Identifying the specific factors underlying both pain and pathologies may help direct ergonomic interventions in tree planting tasks. Non-neutral postures, high forces, and repetitive movements have been well-documented to cause pathologies in both the wrist (Rettig, 2001) and back (Kelsey et al., 1984; Punnett et al., 1991), and thus are risk factors that should be of primary concern when designing these interventions.

The interaction between force and repetition in many cases of MSD incidence may indicate an underlying fatigue-failure mechanism (Gallagher & Heberger, 2013). The American Society for Testing and Materials (ASTM) defines fatigue failure as:

> "…the process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point (or points) and that may culminate in cracks or complete fracture after a sufficient number of fluctuations." (ASTM, 2000)

This pattern of failure is present in a variety of MSDs, including tendinitis, epicondylitis, low back disorders, and wrist and hand disorders (Gallagher & Heberger, 2013). The impact of repetitive activities on fatigue failure appears to depend on the forces imposed on musculoskeletal tissues, with higher forces producing higher stresses and thus causing failure after a smaller number of repetitions than lower forces (Gallagher & Schall, 2017). If sEMG is used as an indirect surrogate for muscle stress, the levels of muscle activity observed in previous work (Granzow et al., 2018; Kinney et al., 2006; Sheahan et al., 2017), in combination with the repetition rate inherent to tree planting, may help to explain the high rate of MSD incidence in the planting population.

Repetitive extreme trunk postures are likely primary contributors to back pain and MSD incidence in tree planters. As previously discussed, planters spend a substantial portion of their day in trunk flexion greater than 45° (Upjohn et al., 2008), with maximal trunk flexion reaching upwards of 130° from vertical (Slot, Shackles, & Dumas, 2010). Frequent bending or twisting is a risk factor for occurrence of low back pain (Xu et al., 1997) and other back disorders (Punnett et al., 1991), and has been shown to lead to decreased compressive spinal strength *in vitro* (Gunning et al., 2001). Additionally, prolonged time in levels of deep trunk flexion leads to the flexion-relaxation response, resulting in a decrease in lower back muscle activity and an associated increase in demand on passive tissues, which can cause injury (Behm et al., 2006).

The added mass of loaded planting bags may heighten the negative impact of repetitive extreme trunk postures on back health. The *Minimum Safety Guidelines for Tree Planters* manual (Bell, 1993) advocates for a maximum bag mass of 10-15kg. More recently, Stjernberg and Kinney (2007) recommended a maximum sustained bag mass of 15% of body mass, with maximum loads of no more than 20% allowable if the planter is planting steadily and decreasing the load. However, the more trees a planter carries per bag up, the higher the ratio of time they spend in planting tasks versus non-planting tasks, and thus the more time they spend making money. In a study of ten male planters with an average of 4 ± 2.2 seasons of experience, the planters who had the highest average planting rates bagged up a significantly heavier load than planters with lower production rates (Roberts, 2002). Bag loads in this study averaged $32\% \pm 5\%$ of body mass (range 21% - 39%), loads far greater than those recommended by Stjernberg and Kinney (2007). In vitro research has shown that highly repetitive flexion and extension with even slight flexion and extension moments can cause herniation and disc failure (Adams & Hutton, 1985; Callaghan & McGill, 2001). While the majority of planting bag weight is supported at the planter's hips, the moments of the loaded bags may be sufficient to cause similar MSDs in planters.

In the case of the wrist and forearm, the combination of grasping and fluctuating wrist flexion/extension, and deviation seen throughout the planting cycle may put stress on the median nerve and tendons of wrist flexors and extensors, as both wrist flexors and extensors have been shown to be active during gripping tasks (Snijders et al., 1987). This increase in loading may give rise to an associated increase in carpal tunnel pressure (Keir et al., 1997), may in turn give rise to MSDs and pain of the wrist.

The wrist and hand experience high forces during shovel impact. The application of external forces on the palm can lead to reduced circulation in the fingers (Griffin et al., 2006), compression and damage of tissues, and increased carpal tunnel pressure (Cobb et al., 1995), and has been linked to hand and wrist disorders (Kothari, 1999; Silverstein et al., 1987). Workers who have loads greater than 4kg applied to the palm are at a greater risk of injury than those who experience smaller loads, and this risk is heightened even further if the task is repeated more frequently than once every 15 seconds (Silverstein et al., 1987). Though the exact load experienced at the hand and wrist during shovel impact is unclear, the force on the shovel itself is far greater than 4kg and likely puts planters at an elevated risk of force-related injury relative to workers who experience lower forces in their work.

There is a significant association between repetitiveness of work and upper extremity MSDs (Latko et al., 1999). Cyclical loading of tendons has been shown to cause microtears in tendon tissue in in vitro research (Nakama et al., 2005), and can result in overuse disorders such as tendinopathy (Kahn & Cook, 2003). Cyclical work with duty cycles shorter than 30s is strongly linked to development of wrist and forearm MSDs (Kilbom, 1994), and high duty cycles (30s work:10s rest) in forearm muscles have also been shown to increase sEMG fatigue indicators in forearm flexors and extensors (Hägg & Milerad, 1997). The duty cycle of planting, with a planting cycle performed approximately every 11 seconds, is thus liable to increase risk of upper extremity injury and cause substantial fatigue in forearm muscles over the course of a planting shift.

Non-neutral postures, high forces, and repetitive motion are MSD risk factors that are common to tree planting tasks and which put tree planters at an increased risk of sustaining a workplace injury. Due to the piecework nature of the task, planters decide their own duty cycle, and thus the repetition factor of the work is difficult to modify. While interventions have been proposed to limit non-neutral postures and high forces, planter injury rates remain high. Examining sEMG in tree planters more closely may help give rise to ergonomic and instructional interventions that decrease injury risk from a muscle activation and muscle fatigue standpoint.

2.4.5 Use of sEMG to Examine Muscle Activation in MSD Development

As previously stated, little research has examined muscle activation during tree planting tasks. The research completed has shown high levels of muscle activity in shovel-side forearm muscles (Kinney et al., 2006; Sheahan et al., 2017), as well as the upper trapezius and anterior deltoid (Granzow et al., 2018). Granzow and colleagues (2018) suggested collection of back sEMG as the next step in examination of muscle activation during planting tasks, and there is a paucity of muscle activation research in the draw-side upper extremity despite injury incidence rates similar to those seen in the shovel-side upper extremity.

Surface EMG can be used to evaluate muscle strain exposure during working tasks (Jonsson, 1982). The APDFs of these resultant signals can be used to determine the profile of this muscular load. The amplitude probability at a given %MVC is the probability that muscle activation is equal to or less than that %MVC, and thus can be expressed as the fraction of the total task duration that muscle activation is equal to or less than that %MVC. Jonsson (1978) suggests two limit values for tasks of an hour or more in length at the static load level (10^{th} percentile APDF), the mean load level (50^{th} percentile APDF), and the peak load level (90^{th} percentile APDF). The recommended limit value is the level of muscular load that should not be exceeded during the task (static: ≤ 2% MVC; mean: ≤ 10% MVC; peak: ≤ 50% MVC), while the upper limit value is the level of muscular load that should not be exceeded under any circumstances (static: ≤ 5% MVC; mean: ≤ 14% MVC; peak: ≤ 70% MVC). These limits can be used to analyze the APDFs obtained during working tasks; if the calculated APDF for a specific load level exceeds one of these limits, then the work should be considered too strenuous at that level.

Muscle activation of the lower and upper back and shoulders has previously been suggested to have a relationship with incidence of low back pain in the healthcare industry. Iliocostalis lumborum sEMG was used to investigate the relationship between injury indicators and sEMG measures in 32 care aides across eight Intermediate Care facilities in British Columbia (Village et al., 2005). Cumulative and peak spinal compression, as estimated by applying a compression normalization factor to mean sEMG values, were significantly correlated with facility-specific lost-time injury rate and MSD injury rate ($p < .01$), though mean lumbar sEMG values themselves were not reported. In examination of muscle activation during patient transfer tasks (Keir & MacDonell, 2004), during which low back pain is of great concern, average sEMG in the erector spinae reached upwards of 25% of MVC in novice participants. Novice participants were found to have higher normalized mean and peak erector spinae activity and lower normalized mean and peak greater trapezius and latissimus dorsi activation than experienced participants ($p < .05$ for most tasks), suggesting that participants with more task experience may use techniques to protect the spine by transferring more load to the upper back and shoulders. These findings suggest that back and shoulder sEMG may be of use in the examination of tree planting tasks and potential lower back injury risk of novice planters.

Tree planters spend a substantial portion of their working day planting, and thus also spend a substantial portion of their day gripping the handle of their shovel. Hägg & Milerad (1997) examined forearm fatigue during intermittent gripping work at 25% of MVC in the FDS, ED, FCU, ECR brevis, and ECR longus during three different duty cycles (10s work:10s rest, 20:10, and 30:10) lasting approximately twenty minutes. Significant signs of fatigue were seen in at least two of the extensor muscles during all duty cycles ($p < .05$), but were seen in the flexor muscles only during the 30:10 cycle, suggesting that both the contribution of wrist extensors and the distribution of fatigue in the forearm during gripping may be of importance in upper extremity MSDs.

Wrist posture has also been suggested as influencing muscle loading during gripping. Mogk & Keir (2003) examined muscle activation in the FCR, FCU, FDS, ECR, ECU, and ED communis during handgrip efforts (5/50/70/100% MVC, 50N) at different combinations of wrist (flexion/neutral/extension) and forearm (pronation/neutral/supination) postures. Extensor activity as a percentage of maximum was typically larger than flexor activity during the low-force efforts, with flexor activity only exceeding extensor activity in some postures at 70-100% of MVC. This suggests that the level of extensor muscle activity needed to maintain neutral wrist posture during low-force grip efforts, such as holding a shovel handle or a tree seedling, may have a greater role than flexor activation in pain and MSD development in the forearm.

Levels of muscle activation in the back and upper extremity have been suggested as underlying factors in development of back and upper extremity pain and MSD in prior research. There is a dearth of research into muscle activation in the back and draw-side upper extremity during planting tasks, as well as an incomplete examination of the shovel-side upper extremity, and thus these areas were the focus of this study. The aim was to collect surface electromyography (sEMG) from novice participants during simulated planting tasks in order to describe the muscle activation seen in the back and upper extremity during tree planting and to determine whether the muscle activation observed might contribute to the common planter complaints of pain, discomfort, and injury.

Research Question: What muscle activation amplitudes are observed in the trunk and upper extremity during tree planting tasks in a novice population?

CHAPTER 3: METHODOLOGY

3.1 PARTICIPANTS

Twenty-one subjects were recruited from the university student population using convenience sampling. Twenty subjects (10 male, 10 female) completed both sessions of planting (Table 3-1), while one subject dropped out following completion of the familiarization session due to lack of time to complete the collection session. All participants were novice to the task of tree planting and had no musculoskeletal injuries or impairments that would preclude safe participation in the study.

Table 3-1. Participant characteristics.

	All (n = 20)	**Female (n = 10)**	**Male (n = 10)**
Age	23.8 ± 4.18 years	22.0 ± 1.73 years	25.6 ± 5.04 years
Height	171.6 ± 8.51 cm	165.0 ± 4.67 cm	178.1 ± 6.11 cm
Weight	74.7 ± 14.73 kg	68.3 ± 16.12 kg	81.2 ± 9.53 kg
BMI	25.3 ± 4.16 kg/m^2	25.0 ± 5.48 kg/m^2	25.5 ± 2.13 kg/m^2
Handedness	18 right, 2 left	10 right	8 right, 2 left
15% of body mass (# of trees in bags)	11.2 ± 2.21 kg (134 ± 34 trees)	10.2 ± 2.41 kg (119 ± 36 trees)	12.2 ± 1.42 kg (150 ± 24 trees)

3.2 INSTRUMENTATION

All participants used the same unmodified D-handle shovel (Bushpro Stainless Steel Speed Spade, Bushpro Supplies Inc., Vernon, Canada; length from top of handle to tip of blade = 85.9cm, mass = 1.5kg, handle circumference = 10.0cm) and set of planting bags (Bushpro 3 Bucket Design planting bags, Bushpro Supplies Inc., Vernon, Canada) (Figure 3-1). The shovel was fitted with the stock Comfort-D handle. The placement of the three buckets on the hip belt of the bag remained consistent between participants. The bags were adjusted such that the hip belt sat comfortably at the participant's waist and the shoulder harness supported the weight of the bags without restricting movement. The shovel and the bags used in this study are the same as those novice planters would use when planting in the field.

Figure 3-1. Planting equipment. (A) shovel, (B) front view of bags, (B) side view of bags, (C) rear view of bags.

Participants were filmed and muscle activation and acceleration of the planting shovel were recorded during planting trials. A high-speed camera (EX-ZR1000 digital camera; Casio Computer Co., Ltd., Norderstedt, Germany) was used to record the planting sessions at a frame rate of 120Hz.

The sEMG was collected using a 16-channel wireless system (Trigno™ Wireless EMG System; Delsys Inc., Boston, MA) at a fixed sampling rate of 2000Hz. Active Trigno sensors (common mode rejection ratio >80dB, gain 1000, band-pass filter 20Hz – 450Hz) were used. The sensor sites were shaved, abraded, and swabbed with rubbing alcohol prior to sensor application to reduce noise. Specific adhesive interfaces (Trigno™ Sensor Adhesive; Delsys Inc., Boston, MA) were used to affix the sensors (four bar contacts [5mm x 1mm], 99.9% Ag, 7.5mm inter-electrode spacing, Trigno™ Wireless

EMG Sensor; Delsys Inc., Boston, MA) to the participant's skin. An adhesive spray (Tuf-Skin® Taping Base; Cramer Products Inc., Gardner, KS) was applied to the area surrounding the sensor, and the sensor was further secured with self-adhesive tape (Hypafix® Dressing Retention Tape; BSN Medical Canada, Laval, QC).

The sEMG was recorded bilaterally from six muscle pairs, the selection of which was directed by previous injury research (Slot & Dumas, 2010) and recommendations (Granzow et al., 2018): (a) common muscle body of forearm extensor group, (b) common muscle body of forearm flexor group, (c) erector spinae, (d) upper trapezius, (e) rectus abdominus, and (f) external obliques. The sEMG sensors were positioned as per Criswell (2011). All sEMG signals were bandpass filtered (20Hz – 450Hz) in real time during data collection.

Shovel acceleration was recorded using the same type of wireless sensor as used for sEMG collection (Trigno™ Wireless EMG Sensor; Delsys Inc., Boston, MA), as the sensors incorporated both EMG electrodes and an accelerometer. This sensor, which was capable of recording three dimensional linear acceleration, was calibrated per manufacturer guidelines and attached to the shovel with the x-axis lying parallel to the shaft and positive up. Tri-axial acceleration data was collected at a fixed frequency of 148.1Hz. Acceleration data was used to determine the time point at which the shovel reached peak height. A reflective marker was also affixed to the side of the shovel handle to track its position more accurately in the video recordings.

3.3 EXPERIMENTAL PROCEDURES

Participants completed two sessions of two hours in length on consecutive days. The first day consisted of a familiarization session and the second day of a data collection session. All sessions occurred in the Biomechanics Laboratory in the Physical Education building at Memorial University of Newfoundland.

The planting tasks were conducted in a specially-constructed wooden box (length: 2m, width: 1m, depth: 0.3m) lined with tarpaulin and filled with a mixture of soil, sand, and gravel that the author, an experienced tree planter, judged to be representative of soil quality in Northern Ontario (Figure 3-2). This medium was reset after each planting cycle to ensure that it was adequately compressed.

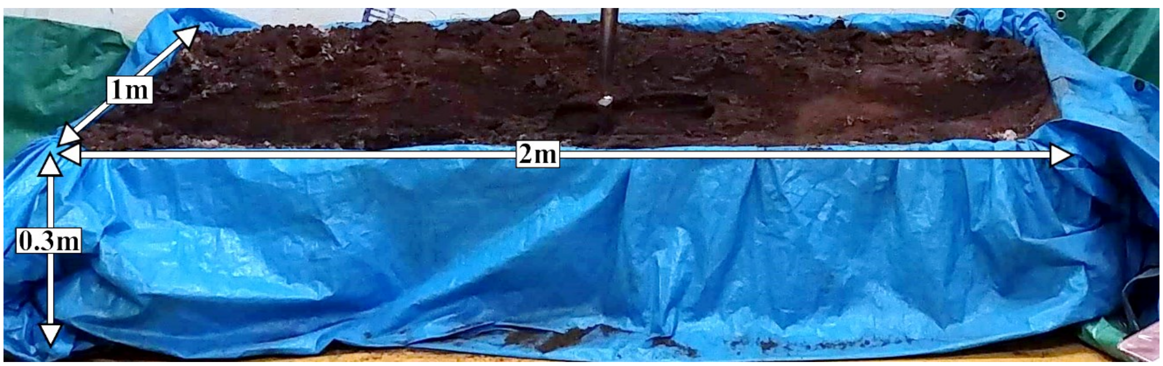

Figure 3-2. Specially-constructed box filled with planting medium.

3.3.1 Familiarization Session

Prior to the familiarization session, participants completed a Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent form. Participants then completed a general warmup of two minutes of cycling at 70 rpm, 1kp on a stationary bike, followed by a specific warmup adapted from recommendations made by Stjernberg and Kinney (2007), which included stretches of the plantar flexors, hamstrings, quadriceps, back, shoulders, and wrists.

Following this warmup, each participant practiced the movements required for MVC of the muscles of interest against manual resistance applied by the research team (Holmes et al., 2015; Vera-Garcia et al., 2010). These contractions are outlined in

Appendix A. They completed two contractions per muscle, or until they were comfortable with the movement and MVC production. Participants were then introduced to the equipment that they would use during the study (planting bags and shovel).

Participants were instructed in planting technique by the author, a tree planter who has planted approximately 250 thousand trees in Northern Ontario over the course of their planting career. The author described and demonstrated each component of a successful plant. Instruction was standardized across participants. Participants were fitted with empty planting bags and practiced each component of a plant individually before combining the components into the complete planting motion. The author evaluated participant competency based on the quality of their trees, as outlined in the Planting Quality Inspection Manual FS 704 (2012). Examined planting faults included: improper plug placement, exposed plug, tree not straight, tree too loose, tree too shallow, and tree too deep. The length of time spent practicing task components individually varied depending on ability; participants who had more difficulty learning a component performed more repetitions until they could demonstrate the component properly.

Once participants showed consistent quality of planted trees as per the Planting Quality Inspection Manual guidelines, they were deemed competent and their planting bags were loaded with 15% of their body mass, per the recommendations of Stjernberg and Kinney (2007). Participants then completed fifty planting cycles (Figure 3-3). A rest of approximately twenty seconds was taken between each planting cycle, during which time the participant returned to the starting position and the author removed the planted tree, reset the planting medium, and provided technique feedback where required. Once participants had completed fifty plants the familiarization session ended. Participants were booked to return to the lab for data collection within two days of the familiarization session.

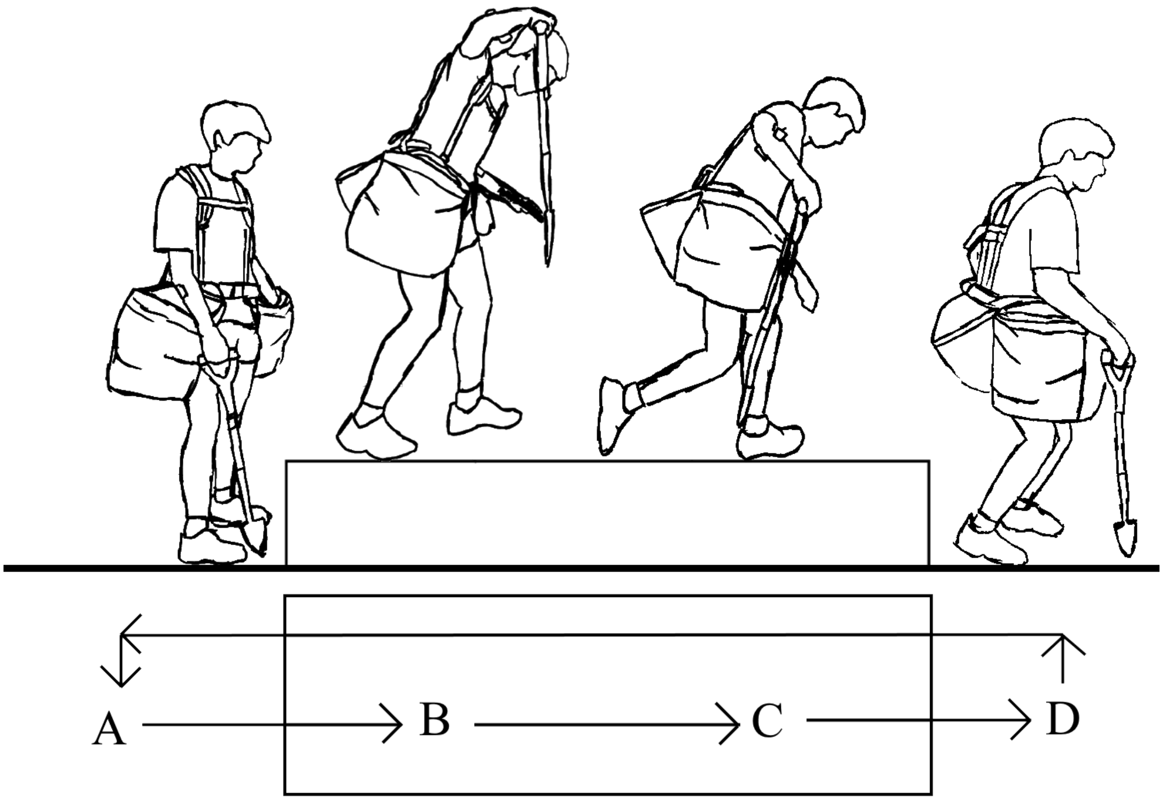

Figure 3-3. Experimental setup. Participants began standing in front of the box (Position A). They stepped up into the box with their non-dominant leg, then took two steps forward, ending in a split stance with their non-dominant leg forward. They raised their dominant hand and shovel and drove the shovel blade into the ground, then performed a C-cut to create a hole into which they inserted a seedling with their non-dominant hand (Position B). When the seedling was inserted, they removed the shovel and used their dominant foot to close the hole. They then returned to an upright posture and took a step with their non-dominant leg (Position C), before stepping off the box (Position D). They then walked back across the box to the starting position (Position A).

3.3.2 Collection Session

Prior to beginning planting data collection, participants were prepared for collection of sEMG as described above. Once the sEMG signal quality was verified by visual inspection, participants completed the previously outlined general and specific warmups. Participants then followed the MVC protocol as practiced during the familiarization session.

Participants were fitted with loaded planting bags. They then practiced up to 10 planting cycles and received technique feedback from the author. Once the author was satisfied that participant performance met the Planting Quality Inspection Manual guidelines, they moved on to the data collection procedure.

During data collection, each participant completed at least 20 trials, each consisting of a single planting cycle. If the author felt planting quality was unacceptable or sEMG or shovel acceleration quality were poor, these trials were noted, and an additional trial was added to the end of the protocol to replace each poor trial. No feedback regarding planting technique was provided once data collection had begun. Approximately 20 seconds of rest was taken between trials to provide the research team with adequate time to reset the collection equipment and the planting medium.

3.4 DATA PROCESSING AND ANALYSIS

Due to the limitations in the data collection technology used, a method was needed to synchronize the video data with the sEMG data. This was done using the accelerometer data, which was collected simultaneous to the sEMG data on the same system and as such the two datasets were synchronous. The acceleration data were unfiltered, and x-axis (superioinferior) acceleration was double-integrated to determine the time point at which the vertical displacement of the sensor affixed to the shovel handle was greatest, and thus the time point at which the shovel handle reached peak height when raised prior to cavity creation. Video files were visually inspected in Kinovea (Version 0.8.15) to determine the frame at which the marker on the shovel handle reached peak height. These peak height time points in the acceleration data and video files were used to synchronize the video to the sEMG. Some estimation was introduced in this step due to the differences in sampling rates between the video (120Hz), and the accelerometer (148.1Hz). All estimates were rounded to the next nearest frame number.

The video data was then used to break the planting motion into six phases based on time points identified in previous work (Slot, Shackles, & Dumas, 2010; Denbeigh et al., 2013). These phases were defined using the following time points (Figure 3-4): beginning of shovel raise, peak shovel height, shovel impact, greatest anterior displacement of shovel handle, greatest posterior displacement of shovel handle, removal of shovel from cavity, and return to upright posture. The specific planting phases defined by these time points are outlined in Table 3-2.

Table 3-2. Descriptions of planting phases.

	Description	**Beginning of Phase**	**End of Phase**
Phase 1	Shovel raise	Beginning of superior motion of shovel	Peak shovel height
Phase 2	Shovel insertion	Peak shovel height	Shovel impact
Phase 3	Anterior motion portion of c-cut	Shovel impact	Peak anterior displacement of shovel handle
Phase 4	Cavity creation portion of c-cut	Peak anterior displacement of shovel handle	Peak posterior displacement of shovel handle
Phase 5	Seedling insertion/shovel removal	Peak posterior displacement of shovel handle	Complete removal of shovel from cavity
Phase 6	Return to standing	Complete removal of shovel from cavity	Return to upright posture

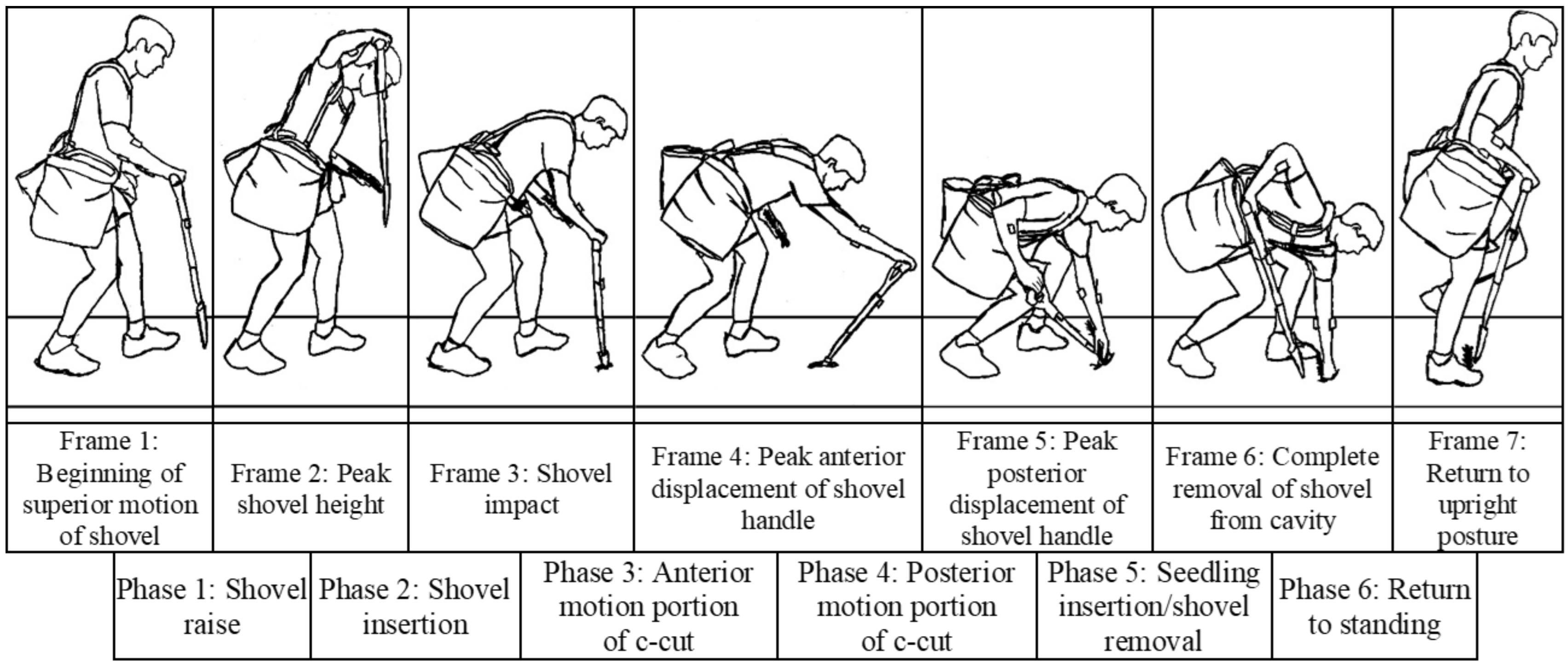

Figure 3-4. Time points used to segment the planting motion into six phases: beginning of shovel raise, peak shovel height, shovel impact, greatest anterior displacement of shovel handle, greatest posterior displacement of shovel handle, removal of shovel from cavity, and return to upright posture.

The sEMG signals were visually inspected for each trial and muscle, and trials where there was persistent drop-out, non-existent signal, or noise that obscured the physiological signal were removed from analysis of that muscle. Following data cleaning, the bias was removed from all sEMG signals and signals were full-wave rectified.

Prior to amplitude calculation each sEMG signal was normalized to the peak of the MVC trials for each muscle as per Burden (2010). The RMS of the MVC data was calculated using a 100ms moving window, and the maximum activation for each muscle was determined through examination of the resultant RMS signal. Division of trial sEMG data by these values yielded sEMG data expressed as a percentage of the maximum EMG amplitude observed during the MVC. This amplitude normalized sEMG was then used to calculate two amplitude measures – RMS and integrated EMG (iEMG). Both were calculated for each of the six planting phases. The trapezoid rule was used to determine iEMG for each of the six phases of planting.

In addition to activation amplitude, APDFs of the RMS sEMG data were calculated as per Jonsson (1982) for the 10^{th} (%MVC that sEMG is at or below for 10% of task time), 50^{th} (%MVC that sEMG is at or below for 50% of task time), and 90^{th} (%MVC that sEMG is at or below for 90% of task time) percentiles using a custom Excel VBA script. The APDF summary statistics for each muscle were averaged across all trials and subjects.

A muscular effort period measure was also used to determine the amount of time spent at each of three intensity levels: low (<10% MVC), moderate (10-35% MVC), and high (>35% MVC). These bins were the same as those used in previous analysis of sEMG during planting (Kinney, 2006), and appear to be arbitrarily defined. To determine the muscular effort period measure, amplitude-normalized sEMG were windowed from the start of Phase 1 to the end of Phase 6, and each data point was classified into one of the three bins indicated above. The percentage of time spend at each contraction level was then determined for each individual planting trial and these muscular effort period measures were averaged across all subjects to create a group average muscular effort period measure for each muscle.

The APDF and muscular effort period measures give similar insights, with only slight differences in manner of calculation. The APDF measure was included due to its frequency of usage in the literature. The muscular effort period measure is unlikely to be particularly robust but was included to facilitate comparison to previous literature (Kinney, 2006).

In addition to the above methods used to quantify muscle activation, linear envelope (LE) sEMG was also determined for the purpose of producing a time-series representation of the data. Amplitude-normalized sEMG was used in the calculation of LE sEMG. Data were windowed from the start of Phase 1 to the end of Phase 6. Data were time-normalized to 100% of the planting cycle, using a total of four time windows: 0-9% (Phase 1 of planting cycle); 10 – 17% (Phase 2 of the planting cycle); 18 – 51% (Phases 3 and 4 of the planting cycle); 52 – 100% (Phases 5 and 6 of the planting cycle). The timing used for each of these bins was based on the average phase duration, across all participants, observed during data collection. The time-normalized trials were then ensemble averaged across all subjects to create a group ensemble average for each muscle.

3.5 STATISTICAL ANALYSIS

As this study was exploratory in nature and meant to provide a description of muscle activation levels during tree planting, only descriptive statistics were determined, Mean and standard deviation of RMS and iEMG data were calculated using IBM SPSS Statistics (Version 23.0; IBM Corp., Armonk, NY).

CHAPTER 4: RESULTS

4.1 DATA EXCLUSION

Participants required an average of 25 ± 3 attempts to achieve 20 trials of acceptable quality plants (min: 21, max: 32). Despite the efforts made to ensure signal quality, a substantial amount of data degradation occurred during the study. Most of this degradation ensued due to disruption to the electrode-skin interface because of contact between the electrodes and planting bags. The shoulder straps interfered with upper trapezius signal quality, the hip belt interfered with erector spinae, rectus abdominus, and external obliques signal quality, and the electrodes on the draw-side forearm rubbed against the planting bag throughout the motion. Loss of signal quality from the shovel-side forearm electrodes appeared to occur due to the force of shovel impact, which in some instances created considerable skin movement artefact that could not be removed with signal processing. Degradation due to electrode-skin interface disruption manifested as either noise that obscured physiological signals or complete dropout of signal. Further data were removed due to electrode malfunction. The data that had to be excluded from analysis of each muscle are outlined in Table 4-1. All rectus abdominus and external obliques data were removed from analysis due to persistent poor quality of sEMG signal. As the study was of an exploratory nature, the arbitrary decision was made to present results for muscles with at least 80 trials of acceptable data quality (20% of total trials). Although the cut-off was chosen somewhat arbitrarily, this cut-off represented an average of, at minimum, 15 of 20 trials kept for six or more subjects, as indicated in Table 4-1. As such, we were somewhat confident that the data provided strong insight into the activation of these muscles within the subset of participants that were included in the analysis. Despite the amount of data lost, it was felt that what remained was still an important component in the description of muscle activation during tree planting.

Table 4-1. Summary of data excluded from EMG analyses due to poor signal quality. Total trials for each muscle: 400. n = number of participants represented in included data; Avg trials = average number of trials / participant that were deemed acceptable for inclusion in analysis. Shovel-side musculature is dominant and draw-side musculature is non-dominant.

	Good	Noise	Drop Out	Equip. Fault	% Kept	*n* Kept	Avg trials	Muscle Kept?
Sh. Wrist Extensors	352	39	1	8	88.0%	20/20	18 ± 4	Yes
Dr. Wrist Extensors	360	11	29	0	90.0%	20/20	18 ± 3	Yes
Sh. Wrist Flexors	329	63	8	0	82.3%	18/20	18 ± 4	Yes
Dr. Wrist Flexors	342	48	10	0	85.5%	19/20	18 ± 4	Yes
Sh. Upper Trapezius	227	166	6	1	56.8%	12/20	19 ± 2	Yes
Dr. Upper Trapezius	169	218	13	0	44.3%	11/20	15 ± 5	Yes
Sh. Erector Spinae	159	240	1	0	39.8%	8/20	20 ± 0	Yes
Dr. Erector Spinae	90	278	32	0	22.5%	6/20	15 ± 6	Yes
Sh. Rectus Abdominus	40	359	1	0	10.0%	4/20	10 ± 6	No
Dr. Rectus Abdominus	76	316	8	0	19.0%	5/20	15 ± 6	No
Sh. External Obliques	38	336	6	20	9.5%	3/20	15 ± 6	No
Dr. External Obliques	26	196	178	0	6.5%	2/20	13 ± 3	No

4.2 PHASE TIMING

Prior to a detailed review of the sEMG results, it is important to examine phase length to provide context to sEMG amplitudes, as the vast majority of the sEMG data is reported as a function of phase. All 400 trials collected were used in analysis of phase timing, as phase length was dependent solely on video analysis and not on sEMG signal quality. The average length of the planting cycle was 5.2 ± 0.9 seconds. The shortest phase length occurred during shovel insertion (Phase 2), while the longest phase length occurred during return to upright posture following seedling insertion (Phase 6) (Figure 4-1).

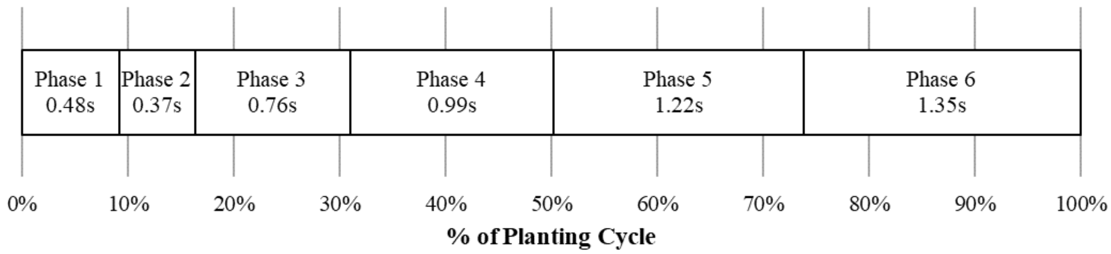

Figure 4-1. Average length (in seconds) of each phase of planting cycle. (n = 400). Phases: (1) shovel raise, (2) shovel insertion, (3) anterior motion portion of c-cut, (4) cavity creation portion of c-cut, (5) tree insertion/shovel removal, and (6) return to standing.

4.3 EMG

Descriptive statistics for iEMG and RMS by phase are shown in Figure 4-2 and Figure 4-3 respectively. Muscle activity in the shovel-side musculature was typically greater than in the draw-side during Phases 1-4, while activity in the draw-side musculature was typically greater than that in the shovel-side during Phases 5 and 6.

The ensemble average LE sEMG for each muscle are shown in Figure 4-4. The draw-side wrist extensor and flexor groups had similar timing in activation patterns, most prominently during Phases 5 and 6. The shovel-side forearm musculature had similar activation patterns during Phase 2. Activation of the shovel-side upper trapezius was highest during Phase 1, with secondary peaks in activation during Phase 2 and Phases 5 and 6. Draw-side upper trapezius activation appeared to be relatively consistent throughout the motion. Both erector spinae had approximately the same level of activation during Phases 1-4, while the shovel-side erector spinae showed a more sustained level of activation during Phases 5 and 6.

Descriptive statistics for APDF values are provided in Table 4-2. The dominant wrist extensors exceeded 5% of MVC at the 10^{th} percentile APDF and 10% of MVC at the 50th percentile APDF, while activity of all muscles was below 30% of MVC for 90% of the planting cycle.

Muscular effort period measure statistics for each muscle are shown in Figure 4-5. All muscles had activation level of 10% or greater for at least 24% of the planting cycle, with the shovel-side wrist extensors (59%), shovel-side erector spinae (45%), and draw-side wrist extensors (43%) spending the largest proportions of the planting cycle at an activation level of 10% of MVC or greater.

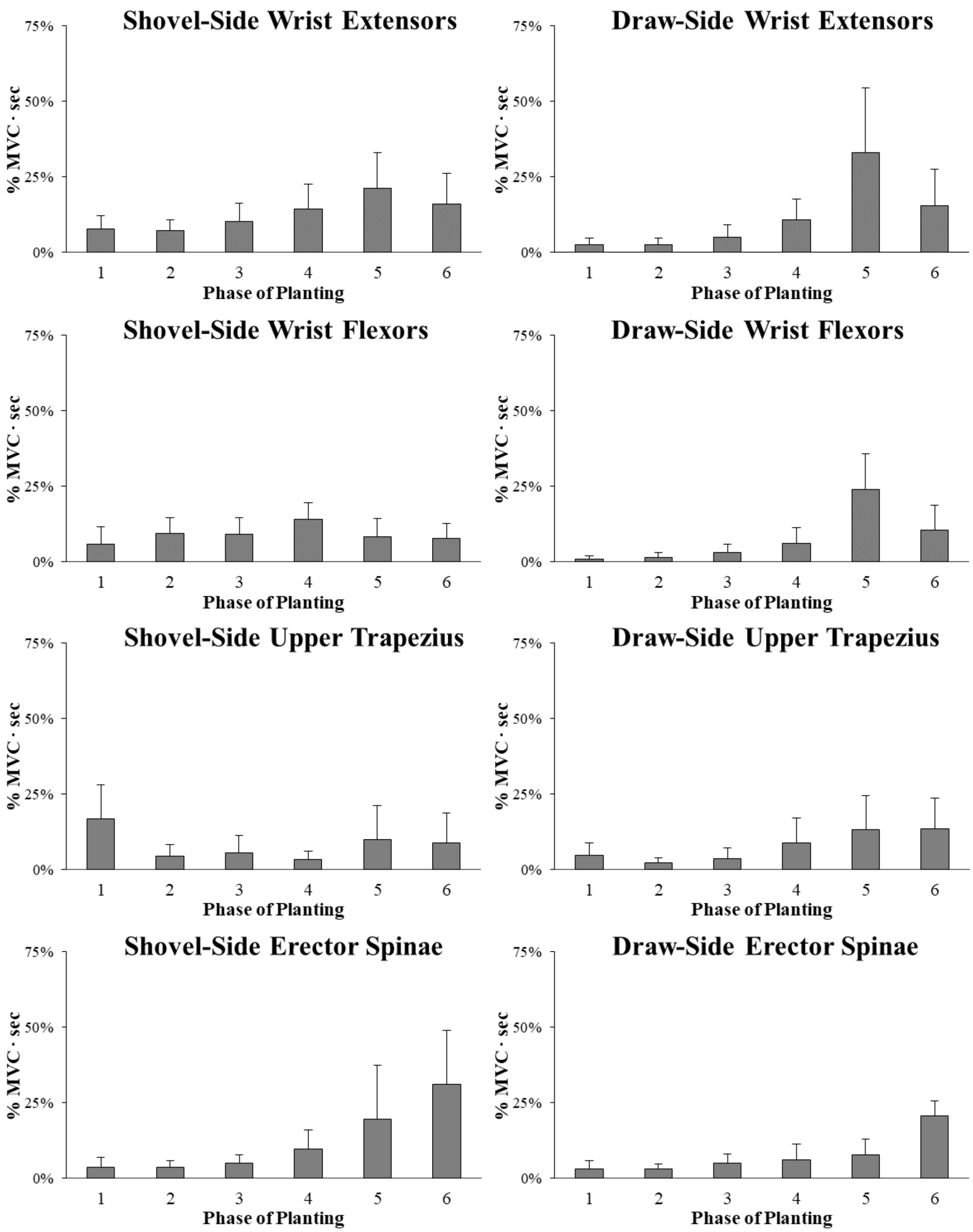

Figure 4-2. Integrated sEMG by planting phase. Phases: (1) shovel raise, (2) shovel insertion, (3) anterior motion portion of c-cut, (4) cavity creation portion of c-cut, (5) tree insertion/shovel removal, and (6) return to standing. Shovel-side musculature is dominant and draw-side musculature is non-dominant.

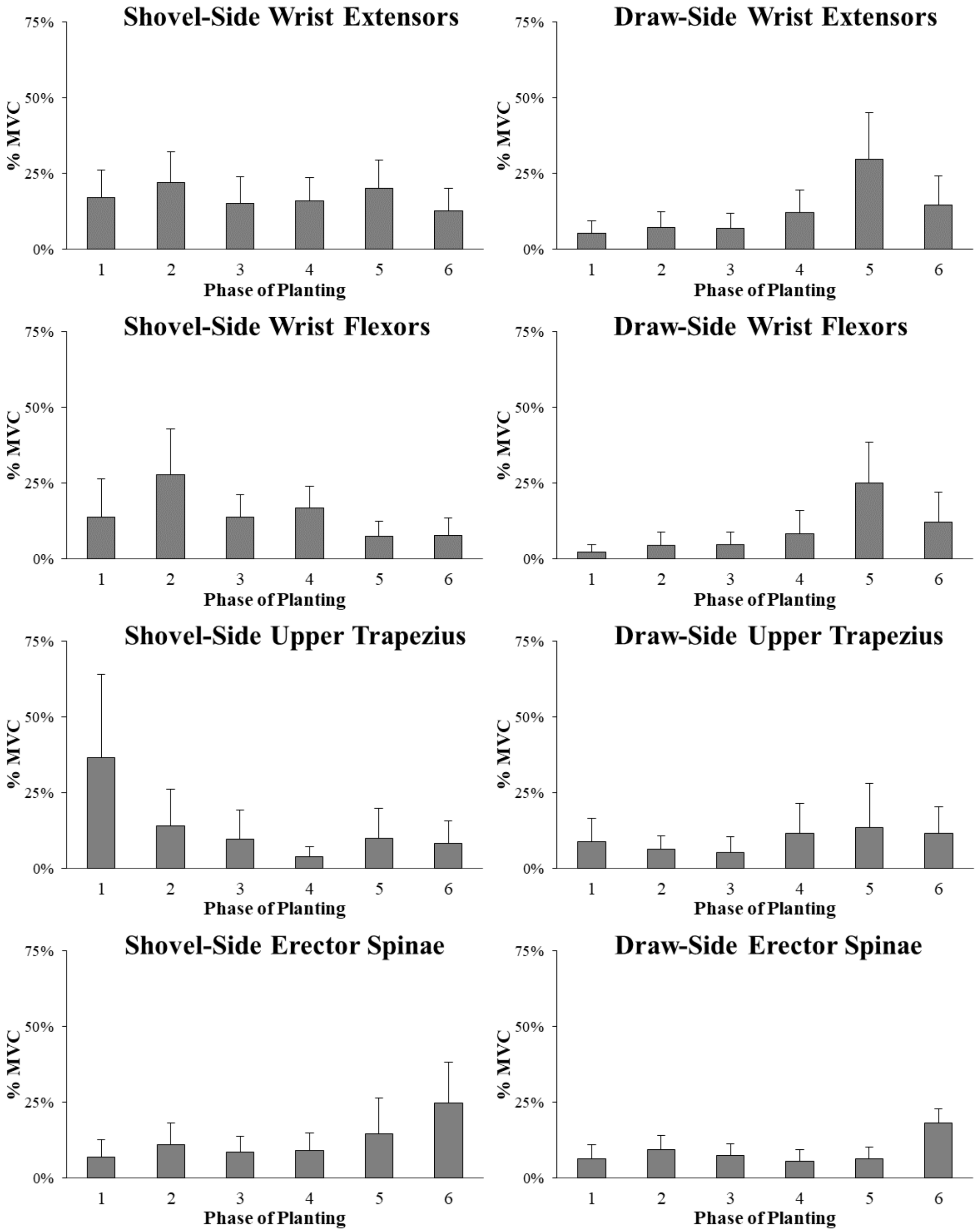

Figure 4-3. RMS sEMG by planting phase. Phases: (1) shovel raise, (2) shovel insertion, (3) anterior motion portion of c-cut, (4) cavity creation portion of c-cut, (5) tree insertion/shovel removal, and (6) return to standing. Shovel-side musculature is dominant and draw-side musculature is non-dominant.

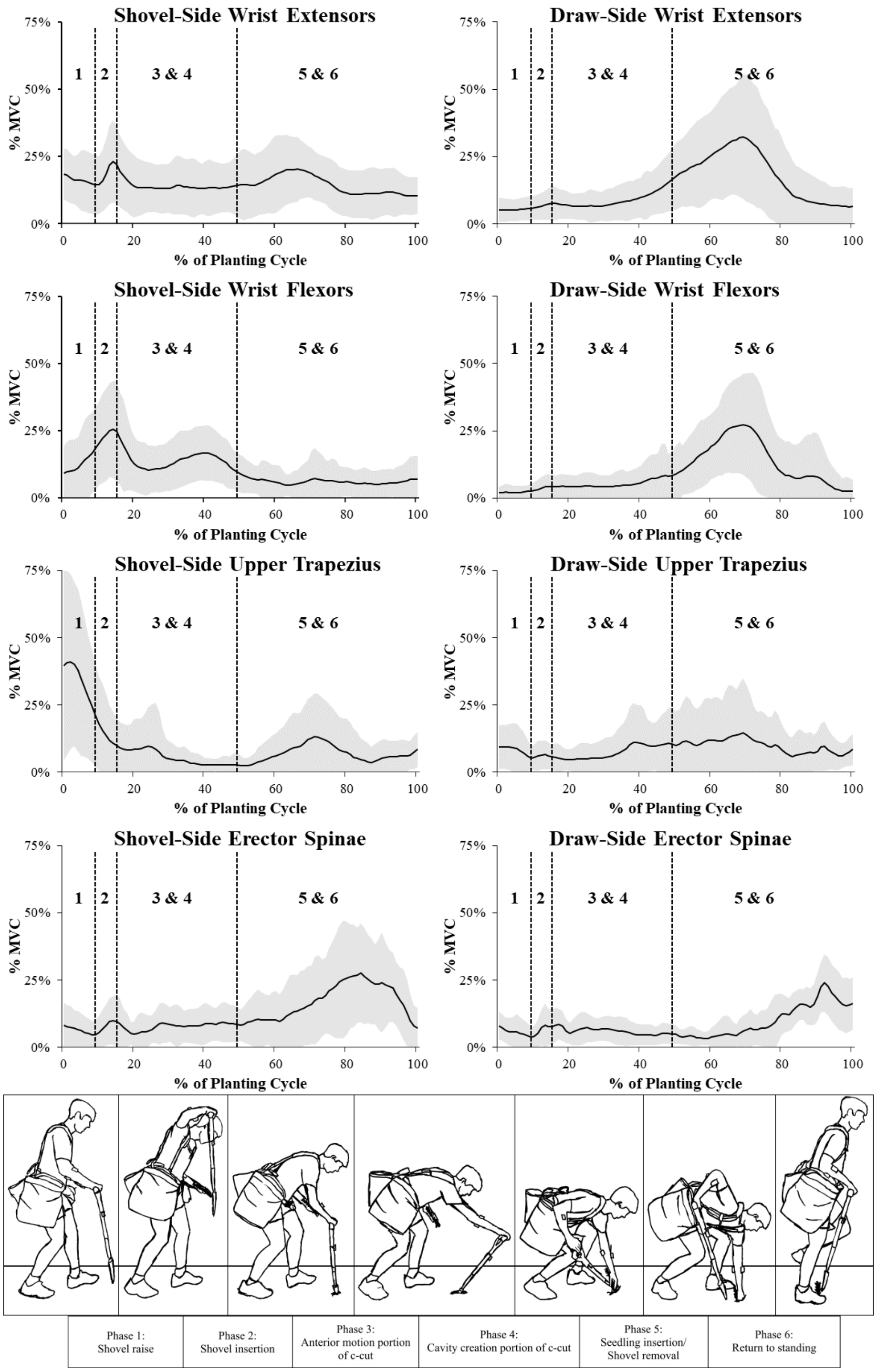

Figure 4-4. Ensemble average linear envelope of planting cycle sEMG. Data were time-normalized in four windows, as indicated by vertical dashed lines: Phase 1 (0-9% of cycle), Phase 2 (10-17% of cycle), Phases 3 & 4 (18-51% of cycle), and Phases 5 & 6 (52-100% of cycle). Shovel-side musculature is dominant and draw-side musculature is non-dominant.

Table 4-2. Descriptive statistics for APDF by muscle at the 10th, 50th, and 90th percentiles. Shovel-side musculature is dominant and draw-side musculature is non-dominant.

	10th percentile (% MVC)	**50th percentile (% MVC)**	**90th percentile (% MVC)**
Shovel-side Wrist Extensors	5.4 ± 3.05	12.5 ± 5.56	27.2 ± 9.75
Draw-side Wrist Extensors	3.3 ± 2.87	8.1 ± 4.16	31.9 ± 15.81
Shovel-side Wrist Flexors	2.4 ± 1.88	7.1 ± 3.24	24.2 ± 9.74
Draw-side Wrist Flexors	1.2 ± 1.42	4.2 ± 3.11	26.1 ± 11.20
Shovel-side Upper Trapezius	1.5 ± 1.19	4.3 ± 3.48	26.0 ± 16.92
Draw-side Upper Trapezius	2.4 ± 1.57	5.7 ± 3.62	19.6 ± 14.76
Shovel-side Erector Spinae	2.3 ± 1.54	9.8 ± 6.24	27.2 ± 15.03
Draw-side Erector Spinae	1.5 ± 0.97	5.2 ± 2.61	18.7 ± 4.10

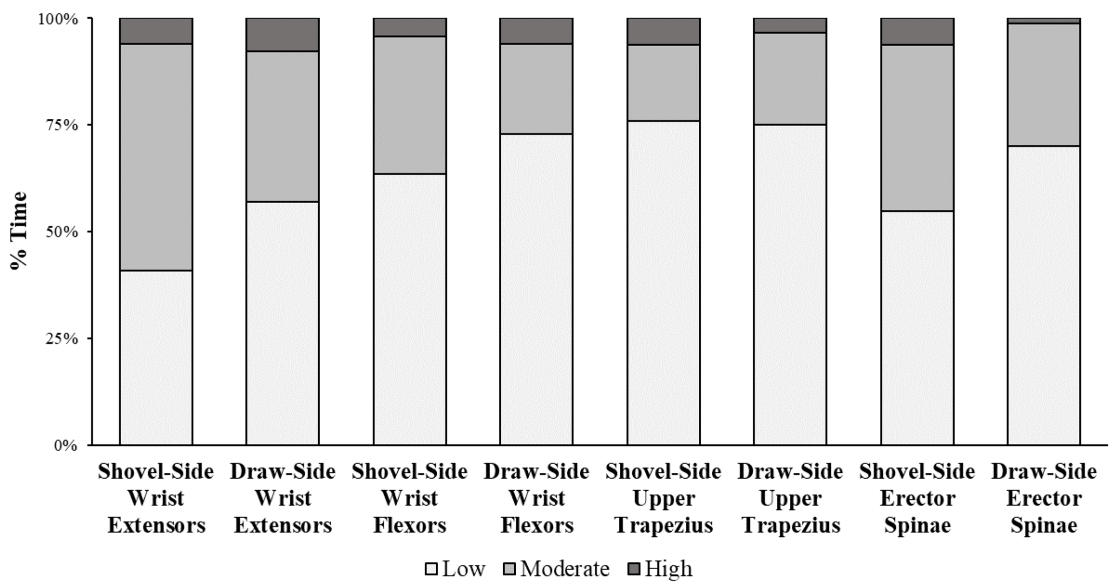

Figure 4-5. Muscular effort period measure of time spent at low, moderate, and high intensity levels of muscular effort as a percentage of total planting time. Low: < 10% MVC, moderate: 10-35% MVC, high: > 35% MVC. Shovel-side musculature is dominant and draw-side musculature is non-dominant.

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

Tree planting is physiologically strenuous work (Hodges and Kennedy, 2011; Roberts, 2002) with a high rate of injury (Giguère et al., 1993; Lyons, 2001; Roberts, 2009; Smith, 1987). However, the relationship between muscle activation and tree planter injury is not generally well-defined and previous research has focused solely on experienced planters (Granzow et al, 2018; Kinney, 2006; Sheahan et al., 2017). The objective of the current study was to quantify muscle activation in novice tree planters during a simulated planting task. This data was then discussed in the context of threshold limit values to explore how the muscle activation observed might suggest causal mechanisms for the common planter complaints of pain, discomfort, and injury.

Muscle activation in the shovel-side musculature was generally greater than in the draw-side during Phases 1-4, while activation in the draw-side musculature was generally greater than in the shovel-side during Phases 5 and 6 (Figure 4-3). Results of APDF analysis indicated that persistent low-level static exertions (10th percentile APDF of greater than 2% MVC) were observed in the shovel-side wrist flexors and extensors and erector spinae, as well as in the draw-side wrist extensors and upper trapezius (Table 4-2). Additionally, although peak activation was not explicitly quantified, the linear envelope data showed maximum activations of approximately 25% MVC in all shovel-side musculature and in the draw-side forearm musculature (Figure 4-4). Persistent low-level muscle activation, high peak exertions, and high impact forces are ergonomic risk factors that contribute to fatigue, physiological damage of muscle groups, and development of pain and MSDs (McGill, 1997). Thus, the study findings support the existing theory that persistent muscle activation may play a role in the high rate of injury present in this population.

5.2 MUSCLE ACTIVATION AMPLITUDES IN TREE PLANTERS

The results gathered in the current study are generally consistent with those presented in previous research. It is important to note, however, that these similarities relate only to the relative activation between muscles and not the absolute activation magnitude. The magnitude discrepancies can likely be explained by differences in the mass of the planting implements used in studies. Shovel-side forearm muscle activation was highest during shovel insertion (Phase 2) (Figure 4-2, Figure 4-3), but the activation levels observed were lower than the approximate range of 35-50% MVC in forearm muscles at the instant of peak shovel-ground impact noted by Sheahan and colleagues (2017). This disparity may be attributable to the modifications made to the shovel used during the Sheahan et al. study, as a segment of the shaft was removed and replaced with a load cell. The load cell increased the mass of the shovel by approximately 45%, and this increased mass would result in increased muscular demand and activation.

Activation in the draw-side forearm musculature was highest during tree insertion (~25% MVC, Phase 5) (Figure 4-3). Similarly, Kinney and colleagues (2006) observed high muscle activation levels in the draw-side FCR and ECR during tree insertion by veteran planters in a field setting, with activation reaching upwards of 50% MVC in both muscles during a single representative cycle. The specific methodology that was used to measure the MVCs is unclear, and the viability of a comparison of muscle activation amplitudes between ideal soil conditions in a lab setting and undisclosed field conditions is questionable.

The mean RMS (Figure 4-3) and 90th percentile APDF (Table 4-2) observed in the upper trapezius were substantially lower than those reported by Granzow and colleagues (2018) in both the shovel-side (56.7% global index of muscular load, 90th percentile APDF = 122.5% RVE) and draw-side (43.7% global index of muscular load, 90th percentile APDF = 94.8% RVE) musculature during planting. However, the reference contractions that Granzow and colleagues used for normalization were submaximal, indicating that the reported muscular loads likely overstate the actual activation level. Additionally, the dibble bar planting tool used in this study typically weighs 3-5kg, more than twice the 1.5kg mass of the shovel used both in the present study and by most Canadian planters.

5.3 INJURY MECHANISMS IN TREE PLANTERS

As described in detailed in Chapter 2, there are three likely underlying mechanisms for the high injury rates observed in tree planters: persistent low-level exertions, peak activation levels, and high impact forces.

5.3.1 Persistent Low-Level Exertions

Muscle contractions exert force on anatomical structures, and persistent exertion without periods of rest is liable to cause injury to these structures. Jonsson (1978) suggested that for work lasting longer than an hour the average static load (10th percentile of APDF) should not exceed 2% of MVC and, in the event that it did so, must never be allowed to surpass 5% of MVC.

In the current work, the shovel-side wrist extensors (10th percentile APDF = 5.4% MVC) exceeded both limits, while the shovel-side wrist flexors (10th percentile APDF = 2.4% MVC) and the draw-side wrist extensors (10th percentile APDF = 3.3% MVC) exceeded the lower limit (Table 4-2). The persistent activation evident in the shovel-side forearm musculature is likely due to the role of these muscles in shovel positioning and wrist posture. Throughout the motion, the wrist flexors are used to grip the shovel handle and the wrist extensors oppose gravity to maintain a neutral wrist posture under the load of the shovel. More granularly, the muscles likely produce the cycle of wrist flexion through extension that occurs during the events of shovel insertion and creation of the c-cut (Denbeigh et al., 2013). The persistent activation of the draw-side wrist extensors may be due to their role in the radial deviation at the wrist required to ensure the proper alignment of the seedling pod when the tree is inserted into the hole. These persistent low-level exertions of forearm musculature may contribute to the moderate levels of musculoskeletal pain planters experience in the wrists, fingers, and forearms (Slot & Dumas, 2010).

The shovel-side erector spinae (10^{th} percentile APDF = 2.3% MVC) exceeded the lower limit set by Jonsson (1978) (Table 4-2). The shovel-side erector spinae showed a greater amount of persistent low-level activation than the draw-side, which may be due to their likely role in controlling lateral flexion to the draw-side during tree insertion (Figure 4-3 and Table 4-2). Trunk angles during planting are restricted by the bounds of the task itself and thus do not change over the course of a planting day (Upjohn et al., 2008). As the workday progresses and muscles fatigue, maintaining these postures would require increased levels of muscle activation. The persistent low-level activation observed in the erector spinae in the current study is thus likely to become progressively greater in order to meet the postural demands set by the constraints of the planting task, potentially contributing to the moderate levels of back pain frequently reported by planters (Slot & Dumas, 2010).

5.3.2 Peak Activation Levels

Per the recommendations of Jonsson (1978) for work performed for longer than an hour, peak levels (90^{th} percentile of APDF) should not exceed 50% of MVC and must not surpass 70% of MVC. None of the musculature examined exceeded 35% of MVC at the 90^{th} percentile of APDF (Table 4-2), though the shovel-side upper trapezius and erector spinae and all forearm musculature had RMS activation levels greater than 20% of MVC (Figure 4-3). Based on the literature (Jonsson, 1978) these contraction levels are not likely to be substantial enough to exceed fatigue tolerances and cause acute injury.

More recently, Sonne and colleagues (2015) examined the relationship between fatigue and recovery in the hand and wrist. Surface EMG in the studies was collected during submaximal isometric handgrips at varying percentages of MVC and 15 seconds in length, followed by a 3 second maximal exertion and a 3 second rest period before the cycle repeated. The results indicated that, during tasks that repeatedly expose a muscle to increased activation, the demands that have previously been put on that muscle will affect the rate of fatigue accumulation and cause decreases in maximal force production. The experimental protocols resemble both the intermittent activation patterns observed in the current study (Figure 4-4) and the average planting cycle length, and thus an argument can be made that the peak activation levels observed here (Table 4-2) may understate the actual levels of fatigue that might occur as a planting day progresses. Experienced workers may plant an average 3000 trees every workday (Trites et al., 1993) for a nine week season consisting of around 45 working days (Slot & Dumas, 2010), resulting in a production level of 135 thousand trees in a single season. These repeated loads would cause tissue fatigue, reducing both the tissue failure tolerance and the margin of safety for load application (McGill, 1997). As the tissue fatigues over time due to the high rate of repetition inherent in planting, the levels of activation observed in the current study may reach sub-acute injury thresholds.

5.3.3 Activation at Shovel Impact

Although shovel impact forces were not measured in this study, discussion of injury risk in tree planting populations is not complete without considering this mechanism. The force with which the shovel blade impacts the planting medium during shovel insertion is substantial (Sheahan et al., 2017), and a similarly large level of muscle activation is likely required to control the associated change in wrist posture. Application of force, both internal and external, especially during high levels of muscle activation and changing postures, can lead to pain and injury. In the current study, the shovel-side wrist extensor and flexor musculature co-contracted during shovel insertion (Figure 4-4) with the likely role of maintaining shovel positioning and wrist posture. Their activation levels reached peaks of approximately 20-25% MVC just prior to shovel impact, the point of the planting cycle at which the wrist transitions from flexion to extension (Denbeigh et al., 2013). The wrist flexors are thus acting eccentrically at a high level of activation during the change in wrist posture caused by the force of shovel insertion. The microtrauma accumulated due to these repeated eccentric contractions of the wrist flexors under force application can lead to medial epicondylitis (Ciccotti et al., 2004), which is common enough among tree planters that they refer to it colloquially as 'planter's elbow'. It may also be an underlying cause of the moderate levels of musculoskeletal pain reported by planters in their wrists and forearms (Slot & Dumas, 2010).

5.4 CONSIDERATIONS FOR INJURY PREVENTION

There is no direct relationship between the muscle activations observed in this research and injury incidence in tree planting populations. However, this data does generate potential hypotheses for mechanisms that elevate injury risk in tree planters, and it would be remiss to not discuss these hypotheses in the context of ergonomic and instructional strategies for injury prevention. Ergonomic recommendations for mediation of the injury mechanisms outlined above are well-documented. High impact forces can be alleviated using engineering controls such as modifications to equipment (Westgaard & Winkel, 1997). Administrative controls like job rotation (Padula et al., 2017) can be instituted as strategies to control MSD development occurring because of high-repetitive work, though the effect of these recommendations on MSD development is not always clear-cut (Leider et al., 2015).

However, the nature of tree planting makes it difficult to institute those ergonomic interventions more commonly recommended in other employment areas. Job rotation is not a practical suggestion, as the task of tree planting is simple and direct: plant a tree, repeat. There are no other tasks between which it would be feasible for employees to rotate. Exploration of ergonomic modifications to existing equipment may provide an avenue for decreased injury risk; though the Pottiputki is not well-suited to Canadian planting, perhaps other novel designs could be conceived of to meet the present need.

Despite being piecework, unlike many other cyclic tasks tree planting is not controlled by daily production targets and has no upper cap on task repetition. Any lengthening of the task cycle would decrease the number of trees planted and consequently decrease earnings. Attempts to impose a task cycle length would be reliant on groups of young workers valuing their future health over their current income. Increasing tree prices to ameliorate the wage losses that would accompany decreased task repetition may bring workers to value health less in the face of greater potential income and only exacerbate the issue.

Replacement of piecework models of compensation with hourly rates would allow planters to operate at a pace that is less likely to contribute to injury. This change would have to be instituted on an industry-wide scale. Given the constraints of the planting seasons and the operating costs of planting camps, however, individual companies have little incentive to switch to an hourly compensation rate, as it would come with an associated decrease in production. Previous research in tree planting has shown that piecework compensation results in a 20% increase in production over fixed wages (Shearer, 2004). Additionally, planters themselves would be averse to this compensation structure unless hourly wages were high enough to meet the expectations set by their production during piecework. Thus, the gap between the production expectations of companies and the health and wellbeing expectations of planters is not likely to be easily bridged by changing the compensation structure. Labour movements spearheaded by representative bodies like the Tree Workers' Industrial Group (TWIG; a tree planter advocacy group established in 2018) may give tree planters more of a voice in industry decision-making and help to address these concerns.

Work practice controls such as training on proper work technique may reduce risk of MSD development (Karsh et al., 2001). Anecdotally, current tree planter training is typically limited to the first few weeks of a worker's first season and technique is not addressed further unless the worker raises concerns or sustains an injury. Employment of biomechanists to observe planters in the field throughout the season and provide on-the-job cues, training, and recommendations engineering controls like equipment modification is a potential solution for decreasing risk of injury. This would allow for early identification of problem areas through direct supervision of planters with a trained eye. Additionally, the involvement of workers in participatory ergonomics programs may positively influence injury rates (Rivilis et al., 2008).

5.5 STRENGTHS AND LIMITATIONS

This study is unique in that, as far as the author is aware, it is the first study of tree planting sEMG to examine novice participants, phasic draw-side forearm activation, forearm activation while using an unmodified shovel, and erector spinae activation, though representation of participants in erector spinae data was limited. Additionally, this study is the first to examine upper trapezius sEMG during tree planting relative to a maximal reference contraction, and while using the shovel type most common in Canada.

There are several limitations to this work that must be addressed. A substantial amount of data had to be excluded due to high levels of degradation. Causes of degradation included disruption of electrode adhesion due to contact with the planting bags and the force of shovel impact, electrode malfunction, and complete loss of channels. This resulted in complete removal of two of the muscle pairs studied and decreases confidence in the generalizability of the upper trapezius and erector spinae data presented herein due to the limited number of participants represented. The 20% cut-off for inclusion of data was decided somewhat arbitrarily, and thus data from the muscles with less representation may not necessarily be indicative of muscle activation that would be present in a wider population, though the remaining data is a strong representation of the participants included in the analysis.

Though best efforts were made to accurately represent soil conditions, there are a multitude of other conditions likely to impact muscle activation of tree planters in the field that are difficult to replicate in a laboratory environment, including navigation of obstacles, variable soil quality and density, and variations in terrain. These unstable conditions are likely to increase the demands on torso musculature (Anderson & Behm, 2005; Behm et al., 2005), and thus the levels of erector spinae activity observed in this work may be less than would be expected in the field.

The c-cut, though somewhat common in Ontario, is not the only hole cutting method in use, and even veteran planters that use the c-cut method are likely to have modified and abbreviated it. These differences in technique may require modified activation patterns in the forearm musculature to those observed here, though activation levels would likely be similar. The manner of hole-closing demanded by a contract or land type would also place differing stresses on the planter; where boot closes were used in this study due to their prevalence in Ontario planting, hand closing and shovel closing of holes would place demands on forearm and shoulder musculature beyond those observed in this work.

The weight loaded into the planting bags was selected based on BC Ministry of Forests recommendations (Bell, 1993), but the recommended loads are much lower than actual loads observed in the field (Slot, Shackles, & Dumas, 2010). Additionally, constraints of conducting the task in laboratory required discrete individual trials, removing the erector spinae and upper trapezius activation that would likely occur during a planter's search for their next microsite. Thus, the activation levels reported in the erector spinae and upper trapezius are likely underestimates of the levels produced by planters in the field who take heavier bag-ups and perform in longer bouts.

Participants were untrained, and generally had no prior knowledge of the physical demands of tree planting. As novices, their techniques likely differed substantially from those that experienced planters would develop over time and repetition of the planting task, which would impact the muscle activation observed. To test this hypothesis, the researcher completed 80 planting trials and compared their planting cycle length and phase timing to the results collected from the novice participants. These comparisons showed a substantial difference in length of planting cycle (Appendix B), with the experienced planting cycles taking an average of 39% of the time required for the novice planting cycles. Differences in relative phase length were also apparent. Thus, the muscle activation levels observed in this study are not likely to be representative of those present in a population of experienced planters.

The study only examined muscle activation in twenty trials, which, accounting for practice trials conducted prior to collection, were at most the participant's fortieth repetition of the planting motion. Planting pace was restricted by the time required for removal of the planted tree and compression of the disturbed soil, brief qualitative evaluation of sEMG tracing, recording of trial numbers, and resetting recording equipment. These time constraints forced a slower pace between planting cycles than would be typical in the field, though the timing of the planting cycle itself was unaffected. As a result, fatigue effects on muscle activation during planting could not be examined, though there is the presumption that percentage of activation relative to a reference MVC would increase as a planting day progressed (Behm, 2004).

The time points used to break the planting motion down into phases were based primarily on shovel positioning. As the specific timing of draw-side movement relative to shovel-side motion appeared to be somewhat inconsistent between both trials and participants, the standard deviations observed in draw-side sEMG measures tended to be greater than those of shovel-side muscles. These issues with timing may have obfuscated the actual muscle activation patterns of the draw-side muscles, especially in the draw-side upper trapezius (Figure 4-4). Additionally, despite the use of adhesive interfaces, adhesive spray, and tape, the intensity of the planting movement and interaction between the sEMG sensors and the planting bags caused substantial data loss in the upper trapezius and erector spinae. As such, care should be taken in the interpretation of the findings reported for these muscles.

5.6 FUTURE DIRECTIONS

Further research in tree planting involving the concurrent collection of sEMG, kinematics, and kinetics would allow for a more complete overview of the interaction of muscle activity, posture, and forces during planting tasks. Inclusion of both experienced and novice participants in such research could provide for better understanding of the differences in muscular demands in the two populations. Additionally, more specific investigation of the interaction between the activation of forearm musculature and grip type and force may reveal more specific areas in which ergonomic interventions can be made. Qualitative analysis of ensemble average linear envelope sEMG (Figure 4-4) indicates periods of co-contraction in the shovel-side forearm musculature during shovel insertion (Phase 2) and in the draw-side forearm musculature during tree insertion/shovel removal (Phase 5). These are both phases during which the relevant wrist must be stabilized during a period of force application and thus may have a high potential for contribution to injury incidence.

Adjustments to typical methodology for sEMG collection are also necessary to ensure data quality in future examination of tree planting. To this point, collection of tree planting sEMG has used active electrodes. In the current study, difficulty was noted in maintaining the interface between skin and wireless active electrode. This seemed to be due in part to the bulk of the electrodes, which caused the tape used to secure them to meet the skin at an oblique angle. Tape adhesion was put under stress during participant movement and was typically unable to withstand perturbations, especially with the addition of sweat and abrasion from the planting bags. The wired active electrodes used by Granzow and colleagues (2018) have a lower profile than those used in the current study and may be more easily secured, though the researchers did note some data loss. The use of passive electrodes would restrict collection to a laboratory setting and likely require custom cable lengths, and care would need to be taken to avoid movement artefact.

Better coverings for wireless active electrodes may also increase the quality of the electrode-skin interface. Electrode application to the upper trapezius, forearms, erector spinae, and abdominal muscles could be improved with the application of a base layer of self-adhesive dressing retention tape beneath a strip of high-strength rigid strapping tape, which would increase the security of the interface while preventing the skin irritation that would be likely to arise with the application of a strapping tape alone. Another option for the forearms could be the application of self-adherent cohesive tape encircling the entire limb, both securing the electrode and allowing for some stretch of the tape to occur during muscle contraction.

5.7 CONCLUSION

The current study aimed to address a gap in the literature surrounding the work demands experienced by tree planters, specifically examination of muscle activation of the back and upper extremity in novice participants, which was collected during a simulated tree planting task. As far as the author is aware, this is the first study of tree planting sEMG to examine novice participants, phasic draw-side forearm activation, and forearm activation while using an unmodified shovel. The results support the existing theory that persistent muscle activation may play a role in the high rate of injury present in this population. The use of traditional ergonomic recommendations to decrease the likelihood of injury may not be practical given the nature of the task, and changes in compensation models may be necessary to decrease injury risk. Further studies should consider collecting sEMG, kinematics, and kinetics concurrently. This would allow for a more complete overview of the interaction of muscle activity, posture, and forces during tree planting tasks and provide a broader base upon which to make specific recommendations for the decrease of injury incidence in tree planting populations.

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Appendix A: MVC PROTOCOLS

Table A-1. MVC protocols for normalization of sEMG. All MVCs were performed twice and each repetition lasted four to five seconds.

Muscle	Unilateral or Bilateral	Protocol
Wrist Extensors	Unilateral	Sitting, forearm neutral, hand in a fist, wrist extension against manual resistance
Wrist Flexors	Unilateral	Sitting, forearm pronated, hand in a fist, wrist flexion against manual resistance
Upper Trapezius	Bilateral	Sitting, arms vertical along sides of body, bilateral elevation against manual resistance applied to shoulders
Erector Spinae	Bilateral	Prone, lower body restrained, trunk horizontally cantilevered over end of table, arms crossed on chest, extension of trunk against manual resistance applied to shoulders
Rectus Abdominus	Unilateral	Sit-up position with knees flexed and feet restrained, arms crossed on chest, flexion against manual resistance applied to trunk
External Obliques	Unilateral	Side-lying position, knees flexed and lower limb restrained, arms crossed in front of body, side-bend against manual resistance applied to shoulder and arm

Appendix B: TIMING DIFFERENCES BETWEEN NOVICE AND EXPERIENCED PLANTERS

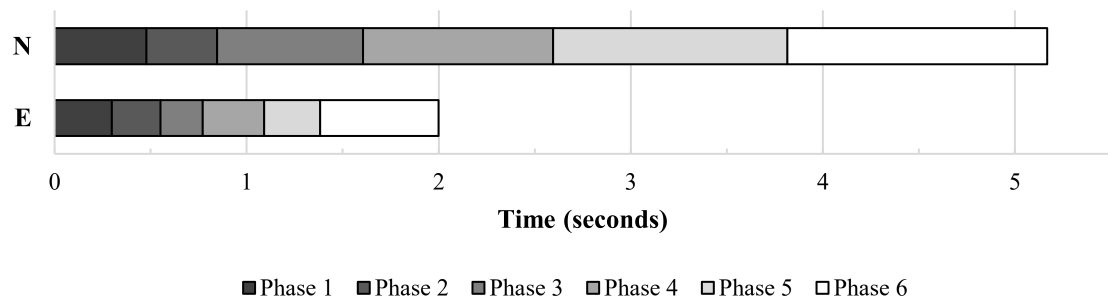

Figure B-1. Length in seconds of the average planting cycle for novice (N; n = 20, 400 trials) and experienced (E; n = 1, 80 trials) participants.

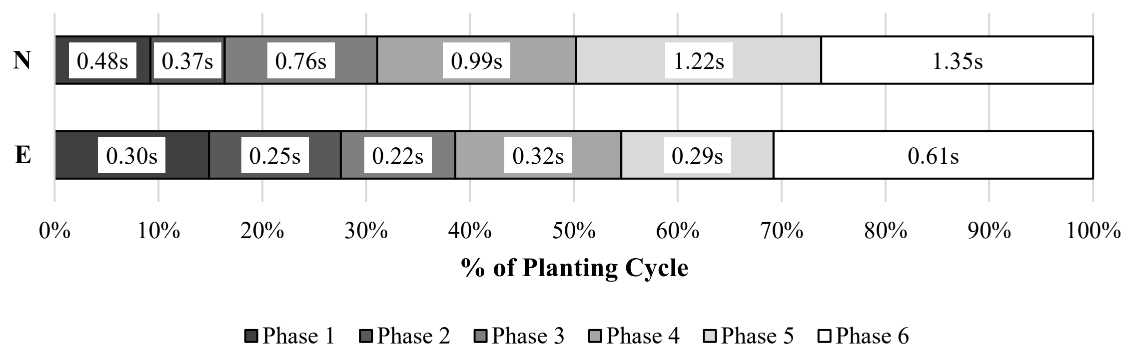

Figure B-2. Length of planting phases as a percentage of total planting cycle for novice (N; n = 20, 400 trials) and experienced (E; n = 1, 80 trials) participants.