An investigation of biomechanical signals and their contribution to joint action during team lifting

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TITLE: An investigation of biomechanical signals and their contribution to joint action during a team lifting task

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Abstract

Team lifting is required in many workplaces, particularly where heavy and awkward lifts are prevalent. Despite the known risk factors associated with team lifting, it remains under researched, with almost no 4-person lifting studies. The purpose of this thesis was to investigate how members of a 4-person team coordinate their actions during a lifting task that involved an unexpected release from a single team member. It involved a novel approach to investigating the mechanisms associated with joint action and whether these mechanisms may alert the remaining lifters that a release is imminent, where the goal was to elicit an unexpected response from the group. Data collected for a previous team lifting study was used. Six groups of four male participants (n = 24) performed 30 lifts with a constructed 60 kg lifting apparatus designed to transition between a rectangular (2 x 4 ft or 61 x 122 cm) and a square (2 x 2 ft or 61 x 61 cm) configuration. A total of 8 trials (4 per configuration) were designated as "drop trials". Vertical force at the hands and right-side electromyography (EMG) of the biceps brachii (BB), anterior deltoid (AD), upper trapezius (UT), and the lumbar erector spinae (LES) was collected for each participant. Means and standard deviation of vertical force was compared from the pre-drop phase for both drop and non-drop (lift) trials. No significant differences were found between drop and non-drop trials during the pre-drop phase. A comparison of time to peak force and time to peak muscle activity was performed for lifters adjacent to the release position. These times were compared against a 25 to 150 ms window to determine whether the muscle activity was considered reflexive or anticipatory to the dropped load. A small proportion of the peak muscle activity values were considered anticipatory (6 BB and 2 LES), suggesting that while it is possible for the dropper to disguise the release, perhaps joint action provides insight to the other lifters. The complex mechanisms that support joint action, their connection to biomechanics and their role in team lifting warrants further research in order to determine how large of a role they might play.

Keywords: Team lifting, joint action, vertical force, electromyography, coordination

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1.0 Introduction

Heavy and awkward lifting is highly prevalent in the workplace. While the physical demands associated with individual lifting relate to known risk factors for low back musculoskeletal injuries, team lifting remains relatively unstudied. The masonry trade has concerns regarding workers lifting heavy and awkward stone slabs (Masonry and Allied Trades Labour Management Committee, Infrastructure for Health and Safety Association, Personal communication). These stone slabs can range from 100 to 150 kg, requiring a team of up to 4 lifters. It is expected that there is greater potential for impaired coordination between workers during 4-member lifts, especially in the presence of worksite obstacles (Visser et al., 2015). It is not uncommon for a team member to lose control and release the load being lifted, resulting in a sudden, asymmetrical increase in load distribution that may disproportionally increase risk for injury among remaining workers.

In our original study (Craig et al., 2021 abstract in Appendix A), biomechanical demands were quantified during 4-member team lifts to determine how demands may be altered with a single-member load release ("drop"). To build upon the limited research available, we quantified changes in muscular activity of the upper limb and low back, forces at the hand, and load distribution. In teams of 4, participants lifted a constructed 60 kg slab total of 30 times. The slab was designed to transition from 2 x 2 ft. (61 cm x 61 cm) to 2 x 4 ft. (61 cm x 122 cm). Each team completed 15 lifts with each load shape with each participant being randomly assigned a "drop" trial for each of the load dimensions. The participant assigned the load release was termed the "dropper" and other lifter locations were described in reference to this position. We found that the shape of the load resulted in different individual lifter demands before and after a release. Additionally, due to load shape, lifters adjacent to the drop location experienced a significant increase in force at the hand and wrist, while the lifter located opposite the dropper experienced a decrease in force. A full abstract depicting the findings can be found in Appendix A.

Musculoskeletal disorders (MSDs) are characterized as injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs (Centers for Disease Control and Prevention, USA). Workplace-related MSDs pertain to conditions in which the work environment and execution of work greatly contribute to the condition/injury, and/or the condition persists or worsens due to the work conditions. With masonry workers tending to report a high prevalence of workplace MSDs (Entzel et al., 2007), interventions may be put in place to reduce these numbers such as, changes to materials, work equipment, or safer workplace practices and strategies. As the majority of loads workers are required to lift are above the 23 kg recommended limit for single workers outlined by NIOSH (National Institute of Occupational Safety and Health, USA), the use of lifting teams is a common strategy (Waters et al., 1993). However, with each additional lifter comes an extra set of variables, further complicating the task. As coordination amongst team members is integral to safety and task performance, it essential to develop a deeper understanding of how a group of lifters interact.

The coordination of multiple people acting together to perform a task is referred to as joint action (Sebanz et al., 2006; van der Wel, 2011; Vesper et al., 2011, 2017). Joint action typically requires precise coordination of actions in space and time between individuals (Sebanz et al., 2006; Vesper et al., 2011; Vesper et al., 2017). There are a few proposed mechanisms attributed to successful joint action such as, mental representation in joint action, sharing sensory information, and general mechanisms supporting coordination (Vesper et al., 2017). However, the mechanism of interest for the current study are those supporting joint action coordination. Joint action coordination refers to instances where two or more actors coordinate their actions under real time constraints whether they intended to or not (van der Wel, 2011).

While the concept of people working together to accomplish a common goal is nothing new, only recently have advances been made in investigating perception and action of humans in teams. Furthermore, the literature has focused on how humans interact to accomplish a task successfully, rather than how underlying joint action mechanisms may inhibit the desired outcome. Humans intentionally make themselves more predictable during teamwork by decreasing the variability of their actions in order to improve coordination (Vesper et al., 2011). Most of the literature surrounding joint lifting currently only involves virtual lifting tasks (Bosga & Meulenbroek, 2007; Isenhower et al., 2010; Newman-Norlund et al., 2010; Masumoto & Inui, 2013). But do these underlying mechanisms translate to accidents or mishaps during team lifts?

As masonry workers tend to report a higher prevalence of workplace musculoskeletal disorders (Entzel et al., 2007), it is imperative to have a firm understanding of how to make team lifting safer. It is questionable whether effort and loads are shared equally among team members. Additionally, while people commonly make their actions more predictable during teamwork (Vesper et al., 2011), it is not known whether this is true during an unexpected load release. By investigating team lifting dynamics in addition to underlying coordination mechanisms associated with joint action, we can develop a greater understanding of how lifters interact as a group.

2.0 Literature Review

2.1 Team Lifting

Lifting in industry is associated with risk factors for upper limb and low back MSDs such as, forceful exertions, repetitive movements, and awkward postures. As a result of this, it is important to determine safe single person and team lifting capacities in order to create safe workplace guidelines. While a variety of guidelines, advisory standards, legislation addressing manual materials handling (MMH) does exist, it is vast and dependent on a number of conditions (Mital et al., 1993). NIOSH developed a recommended weight limit equation to aid in determining safe lifting weights (Waters et al., 1993). While these resources are valuable for determining safe workplace practices, some caution should be taken as they have not been revised for 29 years and have been considered overly conservative (Potvin, 2014).

Barrett and Dennis (2005) noted that few studies exist that focus on the biomechanics of team lifting and those that do often only focus on 2-person conditions. A list of lifting studies and their methodological features can be found in Table 1. Some 4-person trials do exist however, most of these were performed by a single research group and use military personnel, which may not be a reasonable representation of the general population. This is particularly concerning, as heavy load lifting is often performed with an inadequate number of workers as observed during field studies (Visser et al., 2014).

The field study by Visser and colleagues (2014) established work demands and workloads among ironworkers performing concrete reinforcement work. In accordance with the Dutch Labour Inspectorate, workers were expected to lift a maximum of 25 kg solo, and were to work in pairs for loads of 50 kg and teams of 4 for loads of up to 100 kg. Despite these recommendations from the Dutch Labour Inspectorate, every ironworker violated the 25 kg maximum load. The use of an adequate number of lifters for heavier loads may seem the ideal solution, however factors other than the load mass often influence the decisions made by workers in the construction industry (Visser et al., 2014). As the use of appropriate team sizes or mechanical lifting devices are not always an option for a variety of reasons (terrain, physical space, and cost), it is imperative to understand the implications of lifting.

The effect of team size and sex on maximal lifting capacity has long been the focus of studies (Karwowski, 1988; Rice et al., 1995; Sharp et al., 1993a,b). While findings are conflicting from these studies, they do aid in understanding what is happening during team lifting. There is debate as to whether it is the weaker team member or the stronger team member that determines the load (Karwowski, 1988; Rice et al., 1995), however Sharp and colleagues (1993a) found that in lifts involving mixed-gender teams, the stronger individuals allowed weaker individuals to lift a heavier load. This is important because assuming that the load was distributed equally amongst the lifters, the weakest lifter in the group would be required to lift more than their 1-repetition maximum (1-RM) deadlift. Sharp and colleagues (1993a) used military personnel in their study to determine maximum team lifting capacity as a function of team size. To determine this, Sharp and colleagues (1993a) determined 1-RM for individuals and teams of 2, 3, and 4 lifters. From these values, they determined what percentage of the sum of the individual lifts were achieved as a team (Sharp et al., 1993a). Military personnel may not be a good representation of the whole in terms of strength, as their physical careers may result in higher strength percentile. However, determining that mixed-gender teams allow female team members to lift more than their 1-RM is important in understanding possible mechanisms of injury involved with team lifting.

While the general focus of much of the team lifting research is similar, the methodology has varied widely. Much of the team lifting research focuses on lifting capacity and allowable weight limits (Karwowski, 1988; Sharp et al., 1993a,b; Sharp et al., 1995; Rice et al., 1995), however they have differing protocols and populations. Sharp and colleagues (1993a,b; 1995; Rice et al., 1995) recruited military personnel to assess lifting capacity, while others used university aged students (Karwowski, 1988; Lee, 2004). Additionally, studies examining other aspects of lifting used construction populations such as ironworkers (Visser et al., 2015). Comparison of lifting capacity studies is complicated by lifting apparatuses used and task demands. Sharp and colleagues (1993a,b) and Rice and colleagues (1995) used a lifting apparatus made from contemporary weightlifting bars, while Karwowski (1988) and Sharp and colleagues (1995) created a box with handles. While both devices provide valuable data on lifting capacity, reported lifting capacity is likely dependent on lifting device characteristics. Specifically, this is necessary when participant lifting capacity is determined using a weight bar, as it provides participants optimal body position and grip and coupling may be enhanced via bar diameter and knurl. Furthermore, while using a box may be more representative of most industrial lifting, it may pose as a disadvantage for lifters, as the shape does not allow for optimal body position. The box may get in the way of the lifter's knees, thus placing them in an awkward position for lifting, potentially leading to decreased ability to generate strength.

As might be expected, there are differences between maximal lifting capacity when comparing modified weightlifting bars and boxes (Table 1). For example, individual 1-RM measures from studies involving a bar (Sharp et al., 1993a,b; Rice et al., 1995) were more than double that those using a box (Karwowski, 1988; Sharp et al., 1995). With males lifting a mean of 137.4 kg and females lifting a mean of 82.7 kg across the studies using bars, when compared to the male and female lifts using a box of 63.5 kg and 38.8 kg respectively, it is clear that a participants ability to lift loads can be dependent upon what they are lifting (Karwowski, 1988; Sharp et al., 1993a,b; Sharp et al., 1995; Rice et al., 1995). Moreover, when comparing military vs. non-military populations, maximal individual lifts were 59.0 ± 5.5 kg and 42.0 ± 5.8 kg for male and female non-military participants (respectively), while military participants lifted 67.9 ± 11.5 kg and 35.6 ± 6.4 for males and females (Karwowski et al., 1988; Sharp et al., 1995). However, the values for the military population involve not only a lift, but also a 7.2 m carry (Sharp et al., 1995). This is the closest comparison of the military vs. non-military populations, as the other studies used a bar rather than a box as a lifting device.

Furthermore, there are discrepancies between instructions provided to participants in terms of how to lift. In some of the studies, participants are permitted autonomy in how they would like to lift (Dennis & Barrett, 2002; Sharp et al., 1995; Dennis & Barrett, 2003a,b), while others included a training program prior to beginning the formal experiment (Sharp et al., 1993a; Lee 2004). While allowing participants freedom in lifting style may not directly affect overall loads lifted, it does allow for variability between studies. In addition, some trials were excluded from experiments if proper bent-knee, flat back deadlift form was not adhered to (Sharp et al., 1993a,b). Improper form resulted in the termination of a trial, where the last successful load lifted was recorded, meaning that the team or individuals may have been able to lift a larger load than recorded if form was not a factor (Sharp et al., 1993a,b).

Table 1. A comparison of lifting capacities determined using a bar versus a box from previous studies. Note: (M) males, (F) females, (MG) mixed gender teams, (Mil) military participants, (Civ) civilian participants.

Reference	Participants	Origin and destination of team lift	Object Lifted	Lifting Capacity (kg)			
				Individual	2-Person Teams	3-Person Teams	4-Person Teams
Karwowski (1988)	6 (M) 6 (F) Civ	Floor to bench (89 cm)	Box	(M) 59.0 ± 5.5 (F) 42.0 ± 5.8	(M) 105.7 ± 13.5 (F) 76.7 ± 8.2	n/a	n/a
Sharp et al. (1993a)	23 (M) 17 (F) Mil	Floor to knuckle height of shortest member	Bar	(M) 137.0 ± 22.1 (F) 84.7 ± 14.2	(M) 252.9 ± 32.8 (F) 155.8 ± 15.7 (MG) 183.5 ± 24.1	(M) 345.1 ± 39.5 (F) 214.6 ± 17.6 (MG) 262.3 ± 33.5	(M) 493.2 ± 65.3 (F) 307.7 ± 31.4 (MG) 397.3 ± 37.1
Sharp et al. (1993b)	11 (M) 10 (F) Mil	Floor to knuckle height of shortest member	Bar	(M) 138.2 ± 23.0 (F) 78.8 ± 8.9	n/a	(M) 345.1 ± 39.5 (F) 214.6 ± 17.6 (1M2F) 244.3 ± 19.1 (2M1F) 280.3 ± 35.4	n/a
Rice et al. (1995)	23 (M) 17 (F) Mil	Floor to knuckle height of shortest member	Bar	(M) 137.0 ± 22.1 (F) 84.7 ± 14.2	(M) 252.9 ± 32.8 (F) 155.8 ± 15.7	n/a	n/a
Sharp et al. (1995)	12 (M) 9 (F) Mil	Floor to knuckle height + 7.2m carry to a 132 cm platform	Box	(M) 67.9 ± 11.5 (F) 35.6 ± 6.4	(M) 125.2 ± 19.1 (F) 64.1 ± 5.9 (MG) 86.6 ± 13.5	n/a	n/a

Sharp and colleagues (1993a) made use of 4-person team lifting, however their objective was to determine lifting capacity as a function of team size. Thus, they were interested in the percentage of 1-RM each individual would contribute to a successful lift, rather than the biomechanical ramifications involved with four people lifting together

(Sharp et al., 1993a). While determining maximal lifting capacity of teams and the effects of the number of lifters has on capacity may be important, there is a need to evaluate the loads on muscles and each lifter using various biological signals to determine individual and coordinated actions during a lift. Additionally, without knowledge of load distribution during team lifting it is possible that weaker members may be bearing greater loads, potentially putting them at greater risk for injury. There is a need for studies looking at coordinated lifting using force and electromyography (EMG) to analyze possible outcomes from a potential load release during team lifting and to determine which tissues are being adversely loaded during such an event.

2.2 Joint Action

Joint action is defined as two or more persons coordinating their actions to accomplish a shared outcome or change in their environment (Bosga & Meulenbroek, 2007; Masumoto & Inui, 2013; Sebanz et al., 2006; van der Wel, 2011; Vesper et al., 2011; Vesper et al., 2017). As people rarely act individually, joint action research has become a topic of interest in multiple person interactions. A number of theories exist to explain how joint action works. Joint action can refer to anything from two people sharing a conversation to a pair of jugglers passing balls back and forth (Bosga & Meulenbroek, 2007; Masumoto & Inui, 2013; Sebanz et al., 2006; van der Wel, 2011; Vesper et al., 2011; Vesper et al., 2017). Often, successful completion of joint action requires co-actors to precisely coordinate their actions in time and space (Masumoto & Inui, 2013; Vesper et al., 2011). A variety of methods exist for people to coordinate their actions such as, visual, auditory, and haptic information, with each method being preferred dependent upon the task (Vesper et al., 2011). Certain tasks may require that co-actors continuously adapt their actions in order to successfully complete their joint task, for example, when two people are carrying a heavy couch, they need to coordinate the forces they apply to either end (Vesper et al., 2011). However, while lifting and carrying is a common example of joint action, minimal research exists that involves joint lifting and is most often virtual.

There are two established mechanisms explaining temporal coordination (Masumoto & Inui, 2013). The first mechanism is the dynamical systems approach, which has shown that two actors performing a rhythmical task while being able to see one another, may fall into the same rhythm, this is called entrainment (Masumoto & Inui, 2013; Vesper et al., 2011). However, as this can happen between individuals spontaneously with no plan to coordinate their actions, it cannot account for how individuals adjust their actions to another's in order to achieve a common goal (Masumoto & Inui, 2013). Secondly, some literature has provided information on how individuals adjust their actions to match another person's during non-rhythmic tasks (Masumoto & Inui, 2013; Sebanz et al., 2006; Vesper et al., 2010; Vesper et al., 2011).

While much of the research on joint action strategies has employed continuous rhythmical tasks, little is known about how people coordinate their actions during non-rhythmic tasks or when continuous feedback is less available (Vesper et al., 2011). A common strategy used by co-actors to facilitate coordinating their actions is to reduce the variability of their actions in order to make themselves more predictable (Vesper et al., 2011). This is particularly important as, while more lifters are necessary to lift heavier loads, teams are otherwise at a disadvantage when comparing actions carried out by individuals (Bosga & Meulenbroek, 2007).

Vesper and colleagues (2011) found that, when comparing participants performing tasks that required close temporal coordination to individuals performing tasks next to one another, reduced variability and improved coordination was not observed in the individuals. This suggests that the reduction in variability of one's actions is a coordination strategy (Vesper et al., 2011).

While a number of strategies exist to facilitate joint action, seldom are they investigated in unison. For example, if two people are lifting and carrying a couch together. They not only produce complementary forces on the couch, but they must also walk in synchrony with one another (Masumoto & Inui, 2013). The current body of joint lifting literature is sparse. Furthermore, while the literature does investigate mechanisms that contribute to coordination during lifting (haptic coupling, redundant force contributions, embodied constraints, dynamics, and action-scaled invariance, and anatomical substrates), most of these studies use virtual lifting rather than actual lifting tasks (Bosga & Meulenbroek, 2007; Isenhower et al., 2010; Newman-Norlund et al., 2010; Masumoto & Inui, 2013). During these joint lifting tasks, participants are given a task that involves applying force to a load cell that provides them with visual feedback in order to complete the specific task (Bosga & Meulenbroek, 2007; Newman-Norlund et al., 2010; Masumoto & Inui, 2013). Furthermore, none of these studies aim to determine whether joint action coordination mechanisms aid lifters in creating a safe, team lift, but rather an efficient one.

Isenhower and colleagues (2010) did however use actual lifting in order to determine the physical and interpersonal constraints that afford cooperation during real world tasks. Using a simple lifting task of two co-actors moving wooden planks, they investigated how bodily constraints effect coordination strategies. Participants were paired based on arm-span (short arm-span, long arm-span, and mismatched arm-span pairs) and were tasked with moving wooden planks varying in size from one place to another. Planks were given to them in ascending, descending and random order based on length and participants were instructed to move the planks either individually or as a pair. Isenhower and colleagues (2010) found that the arm-span of the pair influenced at which plank length pairs switched from individual lifting to lifting as a pair. This is interesting as these findings suggest that anthropometrics should be considered when examining joint action coordination. However, this study does not include any biomechanical measures and the other studies mention only use virtual lifting, leaving a demand for a joint action study that combines actual lifting with biomechanical measures.

Using a virtual object passing task, Strachan and Torok (2020), explored the role task fairness plays in co-efficiency. In two experiments, participants were given the choice between symmetrical and asymmetrical object paths that lead to same end point. The symmetrical path overall required more movement cost but created an equal task distribution. While the asymmetrical path overall equated to a smaller movement cost, but required one partner to have an unfair portion of the task. Experiment 1 had participants incur individual movement costs to ensure maximal co-efficiency. Experiment 2 had the opposite, where participants had to force their partner to invest more effort than themselves and still found that people will sacrifice the fairness of an action in order to increase co-efficiency of an action. This means that, in order to reduce the movement costs associated with a task, regardless of who may receive a greater portion of the task load, participants will make that decision if it ultimately leads to greater efficiency (Strachan & Torok, 2020). It is essential to understand whether individuals would sacrifice fairness of a task when handling an actual load in order to maximize efficiency. In order to do so, actual lifting joint action research must be conducted in order to determine whether these mechanisms will supersede team safety over efficiency. Also, to determine further implications that may exist with the addition of more team members.

2.3 Biomechanics and Joint Action

The use of biomechanical variables to determine whether underlying mechanisms of joint action exist in situations that require an expected response is entirely novel. Therefore, it is necessary to determine whether or not joint action can be evaluated with detailed biomechanical variables, particularly during instances of quick reactions. Holmes and Keir (2012), used a framework that sorted muscle activity into either anticipatory or reflexive following sudden expected and unexpected perturbations based on the timing of the muscle activity. While they were not conducting their research on joint action, it is a useful framework to determine the timing of reactions to a perturbation in order to ascertain whether said reaction was anticipatory or reflexive. Holmes and Keir (2012) found that during trials involving a known perturbation, there was an increase in muscle activity prior to the perturbation. While this is not confirmation that biomechanical variables such as muscle activity can be used to evaluate mechanisms of joint action, it does indicate that it may be possible.

Additionally, as haptic coupling is a common strategy used to facilitate joint action, it is reasonable to believe that investigating force distribution during team lifting tasks is a feasible strategy to determine its role in joint action. Combining biomechanical variables such as muscle activity and force in conjunction with a classification structure to determine whether these variables are reflexive or anticipatory could be a viable option in determining joint action. However, as joint action is associated with cognition and coordination, specifically through continuous feedback during a task, it is important to determine whether the timing of these biomechanical variables is too short for the detection of joint action to be feasible.

2.4 Summary

Lifting in industry, while necessary, contributes to risk factors associated with MSDs. As loads are often heavier than should be handled by an individual lifter, team lifting is used. While team lifting research does exist, there are almost no studies of 4-person lifting. In conjunction with the demands associated with lifting, there is interest in how team members coordinate their actions with one another. As well, it is necessary to determine whether EMG and force outcomes can provide insight on how a team of lifters coordinate their actions. Joint action has become a popular topic of research, however despite the prevalence of lifting and related injuries, the only joint lifting research is virtual. Upon being approached by the IHSA about concerns with team lifting and injuries amongst their masons, we conducted a study on the biomechanical demands associated with 4-person lifting. The study involved the investigation of the individual implications of a single member dropped load during a 4-member team lifting task. We found that participant location relative to the dropper and load shape altered the force outcomes. Participants located to the left and right of the dropper experienced an increase in vertical force at the hand, while participants located opposite the dropper experienced a decrease in vertical force. Participants were instructed to make the release as unsuspecting as possible for remaining lifters. However, a known mechanism of joint action involves humans intentionally making their actions more predictable in order to better work together. Therefore, more research is needed in order to determine whether these underlying mechanisms will alert other lifters to a drop, despite intending it to be unsuspected.

3.0 Purpose & Hypotheses

3.1 Purpose

The aim of this thesis is to investigate how individuals work together during a four-person lifting task involving an unexpected release from a single team member. That is, do a lifter's biomechanical signals alert other lifters of an imminent release during a four-person lifting task where the goal is to elicit an unexpected response from a group following a load release?

Based on the original study on the mechanics, the specific questions are:

a. Do the lifter opposite the dropper's biological signals provide evidence to indicate coordination with the dropper?
b. Do any of the other lifters share a similar connection? If so, is there a specific coordination strategy?

3.2 Hypotheses

1) We hypothesized that, prior to a load release, the lifter responsible would indicate that a drop is imminent via an increase in biceps brachii activity, or an increase in vertical force. We expected that the dropper will alert the remaining lifters by way of a positive or negative change in these biomechanical signals.
2) Following these signals, it was expected that the lifter opposite the dropper will be alerted first via these mechanisms used to facilitate joint action coordination (visual feedback, increase in force, and/or increase muscle activity from the dropper). Furthermore, we thought that the lifter located

opposite the release position would exhibit an increase in biceps brachii activity and a decrease in vertical force lagging behind the dropper. Additionally, the remaining two lifters would exhibit an increase in activity of the biceps brachii and an increase in vertical force leading slightly before the lifter located opposite the dropper.

3) In addition, we hypothesized that the timing of lifters peak muscle activity in relation to their timing of peak force, would indicate that their muscle activity was anticipatory rather than reflexive to a load release.

4.0 Methods

4.1 Participants

These data were collected as part of a study on team lifting in summer 2019. Twenty-four male participants aged 18-35 participated (Table 2). Participants were free of lower back, hip, and upper limb injury/pain within the past 12 months. Participants were recruited in groups of 4 individuals to facilitate experimental sessions involving 4-member lifting teams. All participants signed an informed consent form before partaking in any trials (Appendix B). Ethics was approved by the McMaster Research Ethics Board before beginning any experiments.

Table 2. Participant characteristics: age (years), weight (kg), and height (cm) of participants per group. Overall mean and standard deviation of age, weight and height for each group. Individual participant data can be found in the appendices (Appendix C).

Group Number	Age (years)	Mass (kg)	Height (cm)
1	23.3 ± 1.0	95.6 ± 10.0	186.1 ± 5.5
2	23.3 ± 4.2	81.0 ± 7.2	183.0 ± 1.9
3	25.0 ± 3.5	91.3 ± 18.8	186.5 ± 4.6
4	21.0 ± 1.4	71.0 ± 6.2	179.0 ± 4.7
5	20.3 ± 1.5	73.8 ± 8.0	176.5 ± 6.0
6	21.5 ± 2.1	79.8 ± 3.3	186.3 ± 3.6
Overall Mean	22.4 ± 2.8	82.1 ± 12.7	182.9 ± 5.7

4.2 Experimental Protocol

Each 4-participant lifting team performed lifts with a 60 kg lifting apparatus. The experimental apparatus was constructed out of wood to hold appropriate weight and transitioned between a rectangle (2 x 4 ft or 61 cm x 122 cm) and a square configuration (2 x 2 ft or 61 cm x 61 cm) (Figure 1). Participants were positioned at each of the four corners, and performed a vertical lift from 51.5 cm above the floor to standing arm's length (Figure 2). The starting vertical height was implemented to facilitate adequate coupling and space for each participant. Each team performed 15 lifts of each configuration (30 total lifts) with 8 trials designated as "drop trials" (Figure 3). Each trial had a duration of no more than 13 seconds and participants were given 3 minutes of rest between trials to mitigate the effects of fatigue. Each participant was randomly assigned 2 release trials (1 per configuration). Lifters were unaware of which trials the other participants had been designated as their release trials. Prior to each trial, participants were shown a card that either said 'drop' or 'no drop' to inform them of whether it was their release trial or not. Verbal cues were given by the experimenter to coordinate timing of the lift, participants then lift and hold the load for 3 seconds. After the initial 3 seconds, participants were given a 5 second window to release their corner in order to obtain a proper sudden, unexpected response. The remaining 3 participants were then required to balance and hold the load for an additional 5 seconds. Upon completion of the trial, experimenters stepped in to assist in lowering the load back to the starting height. The remaining 22 trials were "no-drop" trials and were identical to the release trials with the exception that no release occurred.

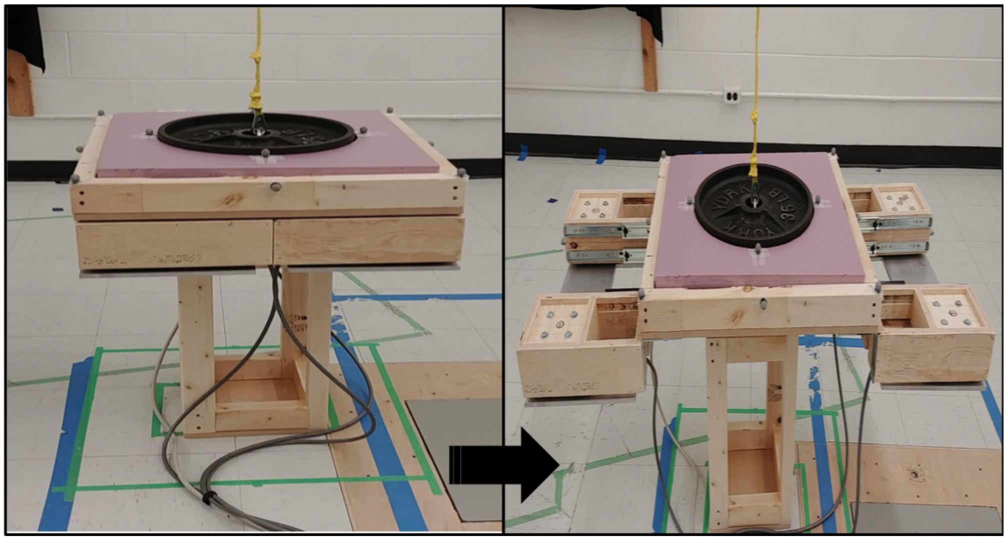

Figure 1. Constructed lifting apparatus in the 2x2 ft. configuration (Left) and transitioned to the 2x4 ft. configuration (Right).

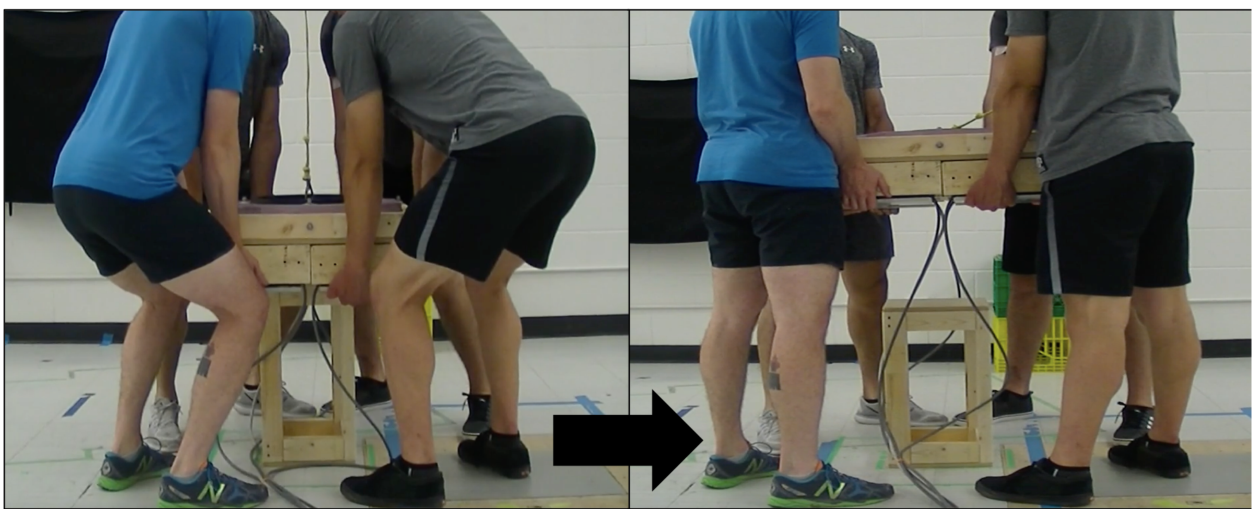

Figure 2. Participants are positioned at each of the four corners of the lifting apparatus performing a vertical lift from the 51.5cm starting height.

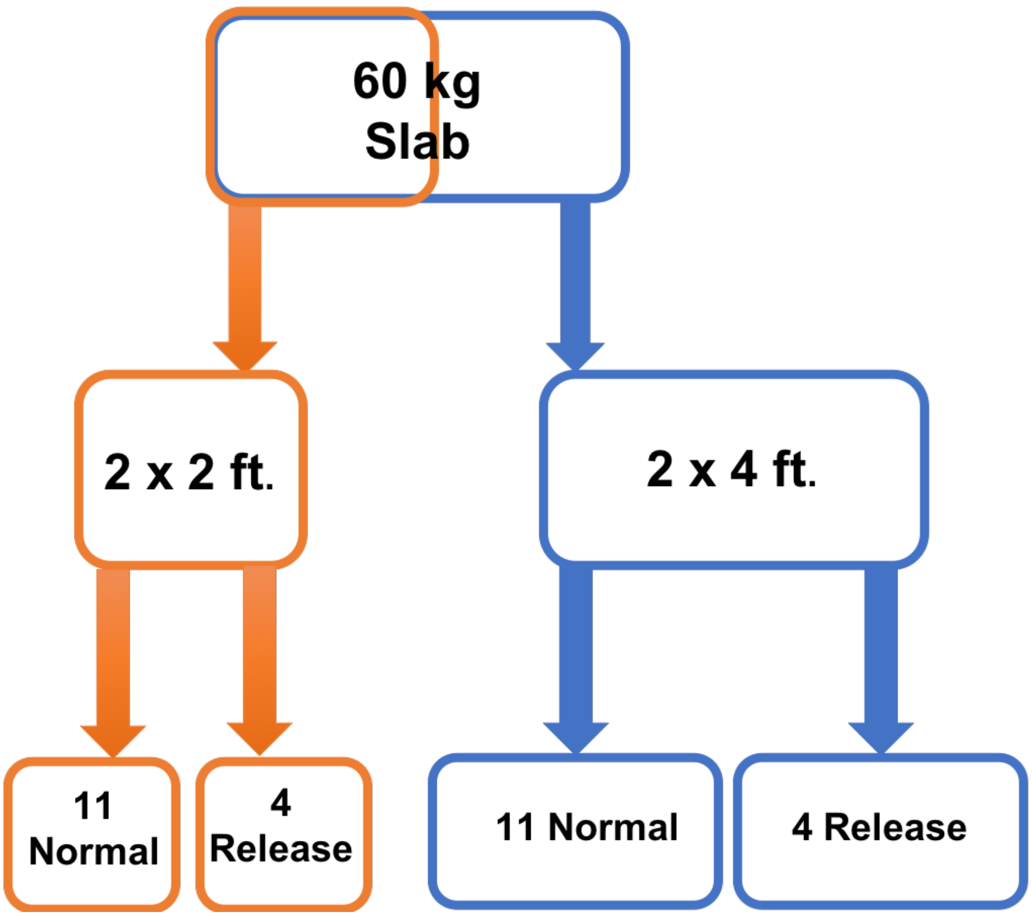

Figure 3. Visual representation of the study protocol for both configurations of the lifting apparatus.

4.3 Instrumentation

4.3.1 Motion Capture

An optical motion capture system with 12 cameras (Raptor-4, Motion Analysis Corporation, Rohnert Park, CA) and 12 reflective motion capture markers affixed to the lifting apparatus to motion slab orientation. Marker data was collected at 50 Hz.

4.3.2 Hand Forces

Tri-axial hand forces were collected using four 6-DOF load cells and amplifier (MiniAmp, MC3-1000, 2 MC3-500, MC3-100, AMTI, Watertown, MA, USA)(Figure 1).

A voltage range of ±10 V and 10 V excitation voltage was used. The lifting interface consisted of aluminum plates mounted to the underside of each load cell with no other connection to the apparatus, this provided participants a surface to place their hands during lifting trials. The vertical (z-axis) load was used to determine the total load held by each participant and the horizontal load components (x-axis and y-axis) were used to estimate shear load at the hands for each participant. Forces were collected at 1000 Hz (NI-USB 6229, Labview National Instruments, Austin, TX, U.S.A).

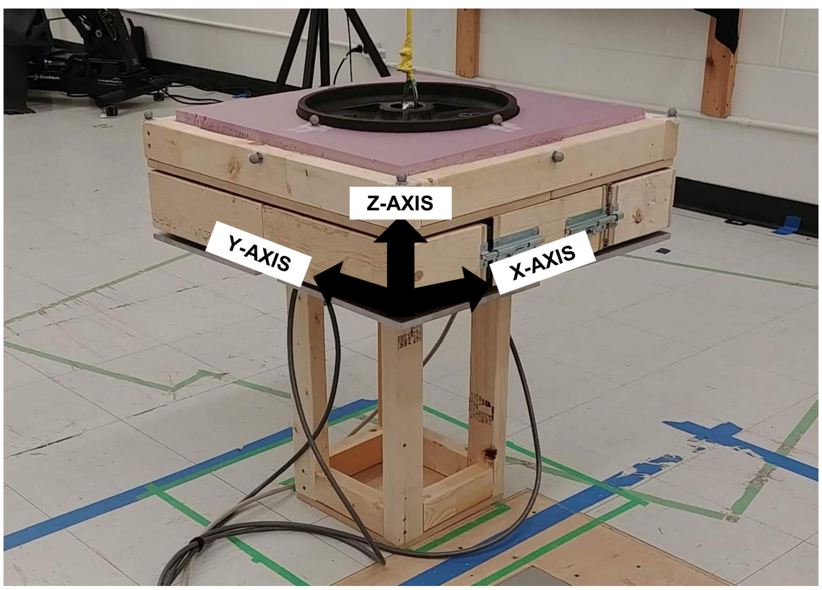

Figure 4. Depiction of the axis system of the load cells located in each of the four corners of the lifting apparatus.

4.3.3 Surface Electromyography

Each participant was instrumented with four surface electrodes total, over the right-side anterior deltoid (AD), biceps brachii (BB), lumbar erector spinae (LES; L3 vertebral level), and upper trapezius (UT)(Trigno, Delsys Incorporated, Natick, MA, USA). EMG signals were differentially amplified (CMRR = 115 dB @ 60Hz, input impedance $10^{12}\Omega$), band-pass filtered (10–1000 Hz), sampled at 1926 Hz. Prior to electrode placement, the skin was scrubbed with alcohol and shaved. Wireless surface electrodes were used and electrode placements were confirmed by palpation upon contraction. Electrodes were placed in the middle of the biceps brachii muscle (along the direction of the muscle fibres), roughly halfway between the elbow and shoulder. Electrodes for the anterior deltoid electrode were placed just distal to the lateral clavicle on the muscle belly. Electrodes for the upper trapezius were placed halfway between the spinous process of the seventh cervical vertebrae and the posterior tip of the acromion process. Lumbar erector spinae electrodes were placed on the muscle belly of the erector spinae at the third lumbar vertebral level. Following electrode placement, a series of maximum voluntary muscle-specific isometric exertions (MVEs) were performed for 10 seconds each. MVEs are necessary in order to normalize muscle activity for comparison between participants (Baggen et al., 2019). For the biceps brachii, participants performed resisted elbow flexion at 90°, seated in a chair with an experimenter providing resistance. For the anterior deltoid, participants performed resisted shoulder flexion, seated in a chair with an experimenter providing resistance. For the upper trapezius, participants performed resisted shoulder abduction and circumduction. This was done with participants laying face-down on a table, shoulder flexed to 90°, and thumb pointing towards the ground while an experimenter provided resistance to the arm. For the lumbar erector spinae, participants performed resisted trunk extension, while laying on a table with their torso over the edge of the table. Participants were asked to raise their torso until they were parallel to the floor, while an experimenter provided resistance. Quiet trials were recorded to determine the resting activation level (or bias) of each muscle. Surface EMG data was recorded at 1926 Hz.

4.4 Data Analysis

4.4.1 Lifting Phases

Six lifting phases were determined. Vertical position of the slab was defined using a centroid of slab using 4 motion capture markers positioned equidistant around the added load (Figure 5). Vertical position data of the slab was first smoothed using a 2nd order, dual pass, low pass Butterworth filter with a cut-off frequency of 10 Hz. The vertical position data was then differentiated to velocity. Velocity was then smoothed using a 2nd order, low-pass Butterworth filter with a cut-off frequency of 0.75 Hz to ensure that we only detected gross changes in velocity. As the phases either precede or follow a change in velocity (lift, drop, or lower), the major peaks of each phase were determined using the absolute velocity. For “drop” trials, 6 separate phases were determined. The timing of the phase 1 (Lift Phase) was determined using the initial peak recorded from the velocity of the initial lift and counting backward until the velocity was below of 0.1 m/s for 20 points (0.2 s). Phase 2 (4-Lifter Steady State) was determined using by counting forward from the initial lift velocity until the values were below 0.1 m/s. Phase 3a (Pre-Drop Phase) involved counting backward from the peak formed from the velocity associated with the load release. However, as we are interested in seeing whether there are any changes in force or EMG moments before the drop, we did not include a minimum value and counted backward 0.3 seconds from the velocity associated with the drop to ensure that we analyzed the appropriate window of time. Phase 3b (Catch Phase) is the catch portion immediately following the load release, thus the timing was determined to be just after the peak formed from the velocity of the drop was reached and as velocity began to decrease due to the lifters catching the slab. Additionally, peak vertical force corresponds with this. Phase 4 (3-Lifter Steady Phase) was determined using the peak formed from the velocity associated with the drop and counting forward until the velocity was below 0.1 m/s for 0.2 seconds. Phase 5 (Lower Phase) was determined using the final peak formed from the velocity associated with the lowering of the slab (Figure 6). By counting backward until the velocity was below 0.1 m/s for 0.2 seconds, we were able to determine the initiation of the lowering phase. For "no-drop" trials, only 3 phases (Phase Lift, Steady, and Lower) were present as there was no pre-drop, catch, or 3-person hold.

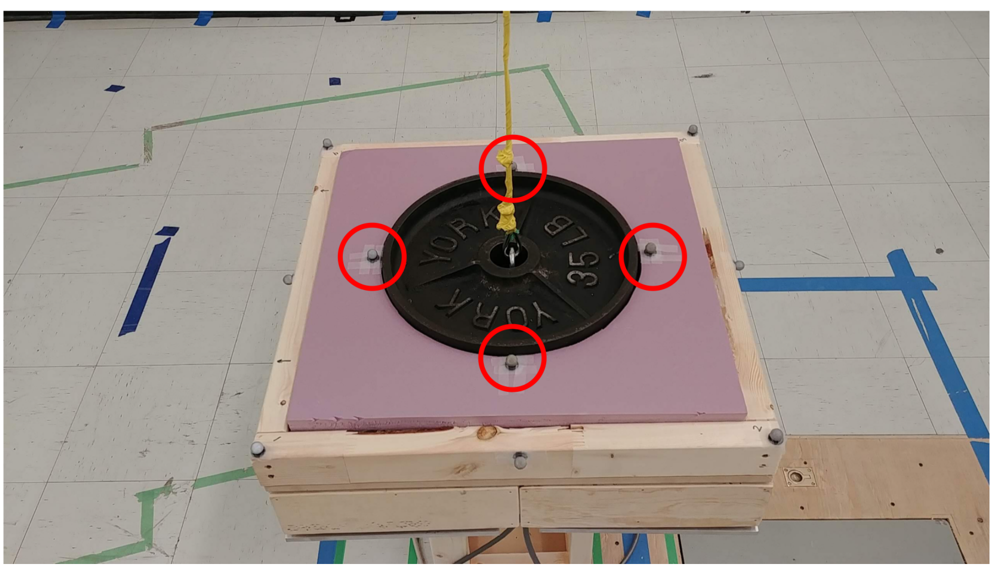

Figure 5. A depiction of the 4 reflective motion capture markers used to determine the centroid used for establishing the position of the slab.

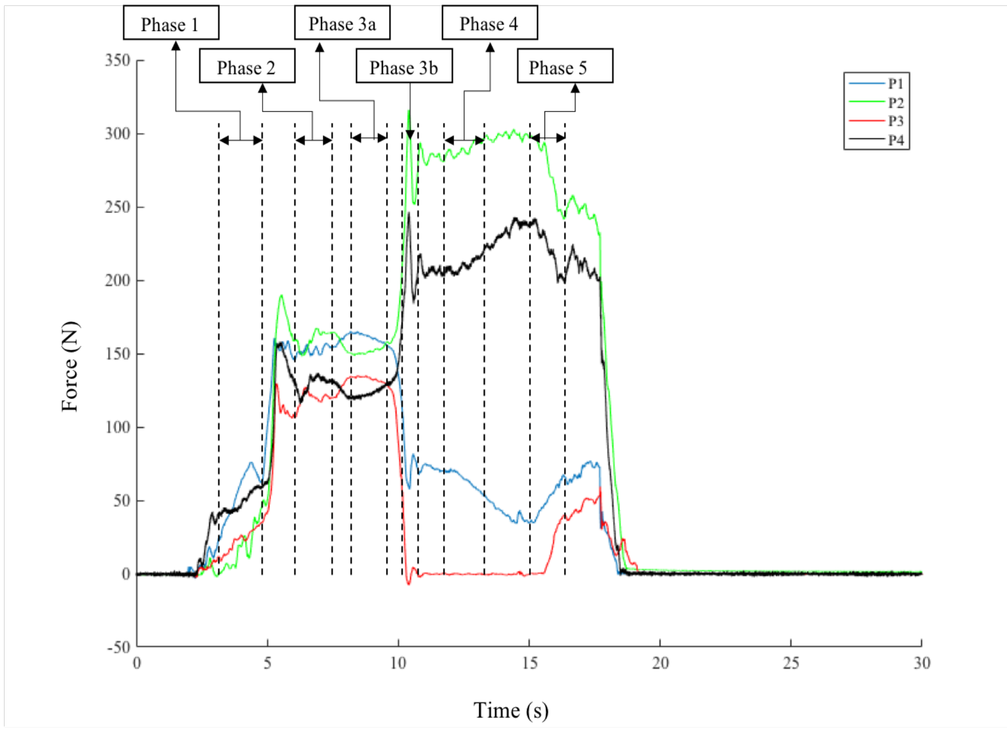

Figure 6. Visual of the 6 phases investigated for each release trial overlaid on the four participants vertical force traces, where P2 is the dropper, P1 and P3 are left and right of the dropper, and P4 is opposite the dropper. Phase 1: 3-second window prior to the top of lift, Phase 2: 3-second window prior to load release - 4 team members baseline, Phase 3a: 3-second window immediately before the load release, Phase 3b: the catch portion of the release, Phase 4: 3-second window following load stabilization by remaining 3 team members and, Phase 5: 3-second window immediately before the load was lowered.

4.4.2 EMG and Force

MVE and EMG trial data was full-wave rectified and a low pass Butterworth filter (single pass) with a cut-off frequency of 6 Hz was used. Resting muscle activity was subtracted from both MVE and lifting trial EMG data. Surface EMG was normalized to maximal voluntary excitation from MVE trials (normalized EMG = [trial EMG/MVE] x 100%). Mean and peak surface EMG values were calculated for each lift (release trials) during the 6 phases: (1) the lift phase, (2) the 4-lifter steady state phase, (3a) the pre-drop phase, (3b) the catch phase, (4) 3-lifter steady phase (i.e. forces from the handloads reach a steady-state), and (5) the lower phase (Figure 6). Analyzing the 6 windows allowed for evaluation of immediate and delayed load distribution responses to the sudden load release relative to baseline.

Hand forces were first converted to Newtons using the transducer sensitivity matrices provided by the manufacturer. The voltage range was ±10 V and the resolution was 16 bits. Any unloaded bias was removed to ensure that recorded data was a response to actual activity. Mean and peak vertical forces were calculated over the same six phases as EMG.

4.4.3 Statistical Analysis

Summary data (means and standard deviations) were calculated for all (EMG and force) dependent variables grouped by lifting apparatus configuration (2 dimensions: 2 x 4 ft., 2 x 2 ft.), participant location (3 non-release locations and dropper location), and phase of lift (Pre-drop, with 4 team members holding steadily at baseline and immediately post-drop with the remaining 3 team members holding steady) (independent variables). The 3 locations relative to the release location were used for subsequent analyses: opposite corner (O), right-edge adjacent corner (R), and left-edge adjacent corner (L) for the square configuration, and opposite (O), short-edge adjacent (SA), and long-edge adjacent (LA) for the rectangular configuration (Figure 7). Repeated measures ANOVAs were used to assess (1) lifting apparatus configuration, (2) participant location relative to dropper, and (3) phase of lift on each outcome measure of interest. The primary statistical effect of interest was the 3-way interaction between participant location, lifting phase, and apparatus configuration (i.e. determine which participant locations experience the greatest increase in biomechanical demands following the load release relative to baseline, and whether these demands were different depending on the configuration of the apparatus) and their effect on BB, AD, LES, and UT (%MVE), as well as vertical and resultant forces. Assumptions of normality and sphericity were verified as not being violated. An alpha value of 0.05 was set for each statistical procedure. Post-hoc testing was conducted using a t-test with Bonferroni's correction for multiple tests. Full tables showing post-hoc results can be found in the appendices (Appendix E).

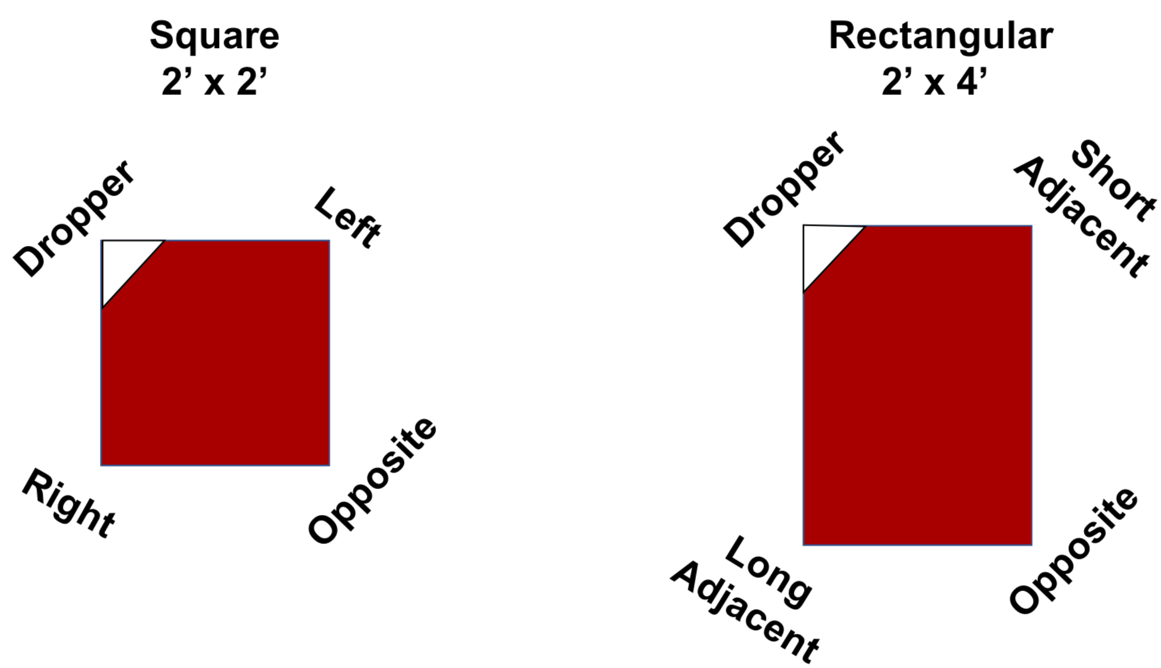

Figure 7. A visual representation of how lifter position was coded for data analysis for both the square configuration (left) and the rectangular configuration (right). All positions were coded in relation to the release position (dropper). The release position could be any of the four corners meaning that the short (SA) and long adjacent (LA) positions could be on either the left or right of the dropper.

4.4.4 No-Drop Trials

For each lifter, normal variability was analyzed by calculating the variance and standard deviation for all EMG (AD, BB, LES, and UT) and vertical force at the hands in what would be considered 3a based on timing. Means, standard deviation, and coefficient of variation were calculated for each measure.

4.4.5 Drop Trials

To determine whether there was a connection between the lifter opposite the dropper and the dropper themselves, phases 3a (pre-drop), 3b (catch phase), and 4 (3-lifter stabilization) were analyzed. For phase 3a (pre-drop phase), means and standard deviation were calculated for all measures. Furthermore, a cross-correlation analysis was conducted between the lifters and the dropper to determine a relationship in force production. The analysis of phase 3b (catch phase) included peak vertical force, peak percent MVE for all muscles, time to peak force and EMG, as well as a comparison of each participants time to peak force and time to peak EMG for the BB and LES. Means and standard deviation for all measures will be analysed for phase 4.

4.4.6 Time to Peak Force

To determine the time to peak force, we first needed to determine the timing of the initiation of the drop. The initiation of drop was determined during the pre-drop phase (phase 3), by looking for the dropper's force to decrease for 20 continuous frames and then taking the frame number from the first of the 20 frames. Following this, the peak force for the two lifters adjacent to the dropper needed to be established. This was accomplished by searching for the max value during the catch phase (phase 4) and the frame number associated with the value. Times (in seconds) were then calculated by taking the frame number of both the initiation of the drop and the peak force, and dividing by the force sampling rate (1000 Hz). Finally, the time it takes the adjacent lifters to reach peak force is subtracted from the time of the initiation of drop to figure out the time to peak force.

4.4.7 Time to Peak Muscle Activity

The time to peak muscle activity was calculated in the same manner as time to peak force. The initiation of drop time had previously been determined during the time to peak force. The frame number for the adjacent lifters peak muscle activity was calculated in the same way as the peak force, by taking the max value of both the BB and LES (UT and AD were excluded due to insignificant increases) and the associated frame number during the catch phase. Time (s) was then calculated by dividing the peak muscle activity frame numbers by the EMG sampling rate (1926 Hz). Finally, the time of peak muscle activity was subtracted from the initiation of drop time, in order to determine the time to peak muscle activity.

4.4.8 Time to Peak Force vs. Time to Peak Muscle Activity

We were interested in the differences in time to peak muscle activity and time to peak force to see whether muscle activity following the drop was reflexive or anticipatory. In order to do so, we subtracted the time to peak muscle activity (s) from the time to peak force (s). We then compared these times against the range of 0.025 s (25 ms) to 0.150 s (150 ms), which was considered the reflex time period. Any peak muscle activity reached prior to peak force or before 0.025 s following peak force was considered anticipatory.

4.4.9 Reflex vs. Anticipatory

In order to analyze timing of muscle activity following a drop, a reflex window was used of 25 to 150 ms (Figure 8) (adapted from Holmes & Keir, 2012). Any peak muscle activity that occurs before the 25 ms cut-off is considered as anticipatory of a coming perturbation. Where any peak muscle activity that is reached in the reflex window or following it is considered reflexive.

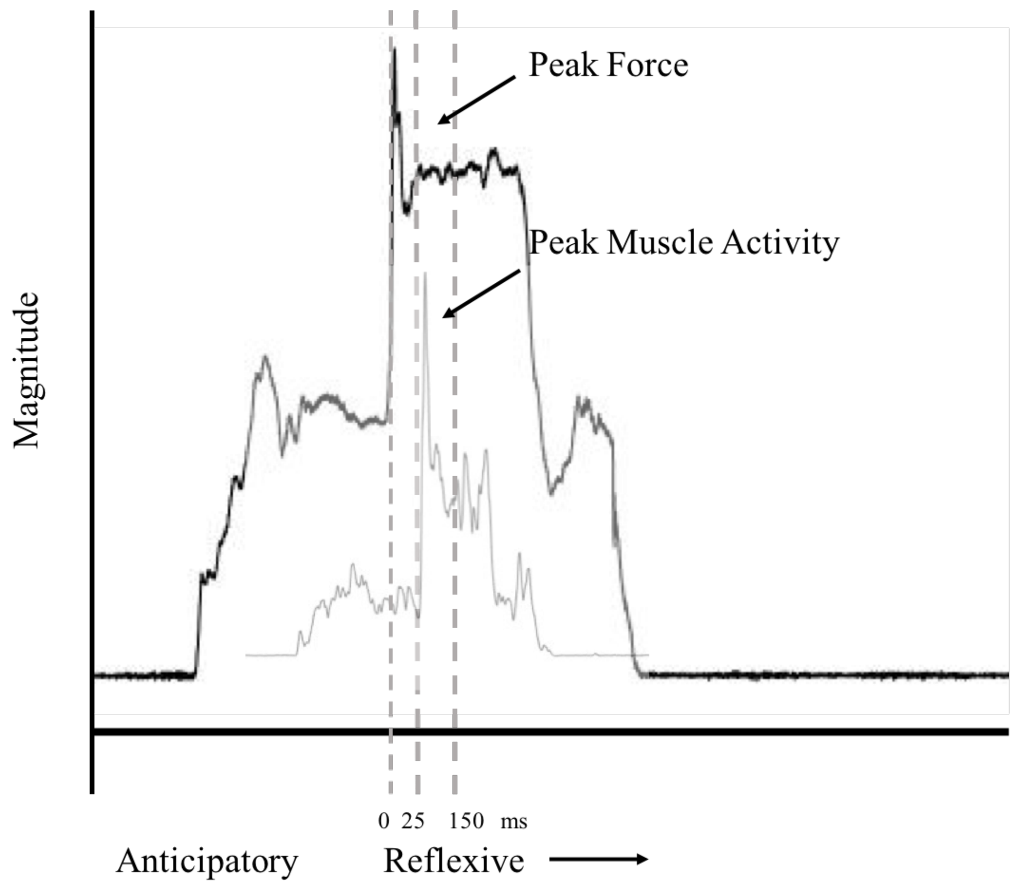

Figure 8. A visual representation of period of time used to determine whether muscle activity was anticipatory or reflexive following a load release. The top line is a force trace during a drop trial. The smaller trace underneath is a trace of muscle activity from the same drop trial. The firs dotted grey line represents the peak force time, the second dotted grey line represents the lower threshold of 25 ms, and the third dotted grey line represents the upper threshold of 150 ms. All peak muscle activity values reached before the 25 ms threshold were considered anticipatory. All peak muscle activity values reached following the 25 ms threshold were considered reflexive.

5.0 Results

5.1 Summary Data

Summary data was collected for both vertical force (Table 3) and muscle activity (Table 4) for all muscles. Means, standard deviation, and coefficient of variation was calculated and organized by lifter position for each configuration. Pre-drop and 3-lifter steady state lifting phases were used for comparison.

Table 3. Vertical force means (N), standard deviation (SD) and coefficient of variation (CoV) for both configurations (2 x 2 ft. and 2 x 4 ft.) organized by lifter position and lifting phase (pre-drop and 3-lifter steady state).

Position	Phase	Mean	SD	CoV	Mean	SD	CoV
		2 x 2			2 x 4		
Dropper	3a	126.2	32.0	25.3			
Opposite	3a	139.4	38.2	27.4			
Left	3a	136.0	29.4	21.6			
Right	3a	139.2	40.1	28.8			
Dropper	3a				112.6	22.4	20.0
Opposite	3a				123.1	32.0	25.8
Short Adj.	3a				161.3	31.0	19.0
Long Adj.	3a				159.9	32.6	20.4
Dropper	4	-2.6	7.5	-293.7			
Opposite	4	90.0	38.5	43.0			
Left	4	218.5	40.3	19.0			
Right	4	215.0	44.4	21.0			
Dropper	4				0.2	5.2	2795.4
Opposite	4				74.9	29.0	38.7
Short Adj.	4				253.2	62.0	24.5
Long Adj.	4				207.6	38.4	18.5

Table 4. Mean, standard deviation and coefficient of variation of muscle activity for all muscles for both configurations (2 x 2 ft. and 2 x 4 ft.) organized by lifter position and lifting phase (pre-drop and 3-lifter steady state).

Muscle	Position	Phase	Mean	SD	CoV	Mean	SD	CoV
				2 x 2			2 x 4	
Bicep	Dropper	3a	8.6	6.9	79.7			
	Opposite	3a	9.1	8.2	89.6			
	Left	3a	9.0	6.6	74.1			
	Right	3a	8.9	7.6	85.0			
	Dropper	3a				8.4	6.7	80.5
	Opposite	3a				8.5	6.2	72.1
	Short Adj.	3a				10.1	8.6	84.7
	Long Adj.	3a				9.5	7.9	82.9
	Dropper	4	0.4	0.8	205.4			
	Opposite	4	8.4	6.7	80.6			
	Left	4	23.7	19.0	80.4			
	Right	4	10.0	11.3	112.7			
	Dropper	4				1.4	3.0	222.9
	Opposite	4				6.2	4.8	78.4
	Short Adj.	4				17.8	16.4	92.4
	Long Adj.	4				16.8	18.2	108.6
Anterior Deltoid	Dropper	3a	1.0	1.6	164.6			
	Opposite	3a	0.6	1.0	160.0			
	Left	3a	0.7	1.1	157.4			
	Right	3a	0.4	0.5	129.8			
	Dropper	3a						
	Opposite	3a						
	Short Adj.	3a						
	Long Adj.	3a						
	Dropper	4	0.2	0.7	316.0			
	Opposite	4	1.6	1.9	120.5			
	Left	4	3.2	3.9	123.7			
	Right	4	0.6	0.7	117.2			
	Dropper	4				1.0	1.3	132.5
	Opposite	4				0.8	1.4	170.5
	Short Adj.	4				0.6	0.9	157.0
	Long Adj.	4				0.7	1.2	188.2
	Dropper	3a	5.0	8.0	162.6			
	Opposite	3a	5.0	9.9	198.1			
	Left	3a	4.9	7.7	155.7			
	Right	3a	4.9	7.5	152.3			
	Dropper	3a				5.2	7.0	135.0
	Opposite	3a				4.6	5.2	114.5

Upper Trapezius	Short Adj.	3a				5.2	8.9	172.6
	Long Adj.	3a				5.4	8.7	161.4
	Dropper	4	1.4	2.0	142.7			
	Opposite	4	4.3	7.4	173.4			
	Left	4	16.2	14.0	86.5			
	Right	4	5.6	8.4	148.5			
	Dropper	4				1.9	2.8	150.8
	Opposite	4				4.6	5.2	112.2
	Short Adj.	4				14.0	15.1	107.3
	Long Adj.	4				7.5	9.0	119.5
Lumbar Erector Spinae	Dropper	3a	10.5	6.7	63.6			
	Opposite	3a	10.9	8.8	80.9			
	Left	3a	10.7	8.1	75.6			
	Right	3a	10.6	7.7	72.7			
	Dropper	3a				9.0	5.9	65.2
	Opposite	3a				9.1	6.3	69.4
	Short Adj.	3a				10.7	7.7	71.7
	Long Adj.	3a				10.9	8.3	76.4
	Dropper	4	3.7	3.6	97.0			
	Opposite	4	9.4	6.8	72.7			
	Left	4	11.4	8.0	70.2			
	Right	4	17.4	9.9	56.6			
	Dropper	4				3.1	2.8	88.8
	Opposite	4				6.8	5.1	75.7
	Short Adj.	4				15.7	11.0	70.2
	Long Adj.	4				14.4	9.8	67.5

5.2 Vertical Force

During release trials, a significant interaction between lifting phase and position (Figure 9) ($F(3, 9) = 83.52$, $p<0.05$, $n_G^2 = 0.82$). Additionally, the position of lifters relative to the dropper had a significant main effect on vertical force ($F(3, 9) = 142.32$, $p<0.05$, $n_G^2 = 0.83$) for mean vertical force values for the square configuration (2 x 2 ft.). Prior to the drop, force distribution was relatively uniform amongst all lifters. While lifters positioned to the right and left of the dropper experienced a significantly greater increase in force (83 ± 44.4 and 76 ± 40.3 N respectively) following the drop, the lifter located opposite experienced a significant decrease in force (50 ± 38.5 N).

Additionally, for the rectangular configuration (2 x 4 ft.), a significant interaction between phase and position (Figure 10) ($F(3, 9) = 9.91$, $p<0.05$, $n_G^2 = 0.53$) and a main effect of position ($F(3, 9) = 29.25$, $p<0.05$, $n_G^2 = 0.77$) were observed for mean vertical force during release trials. In contrast to the square configuration, the force distribution during the pre-drop phase was not entirely uniform for the rectangular configuration, ranging from approximately 20-28 % of the load. While the long and short adjacent position lifters held more of the overall load prior to a release, they also experienced a significant increase in force following the drop. Additionally, the short adjacent lifter experienced a greater increase in force (92 ± 62.0 N) than the long adjacent lifter (48 ± 38.4 N) following the drop, while the opposite lifter experienced a 48 ± 29.0 N decrease in force.

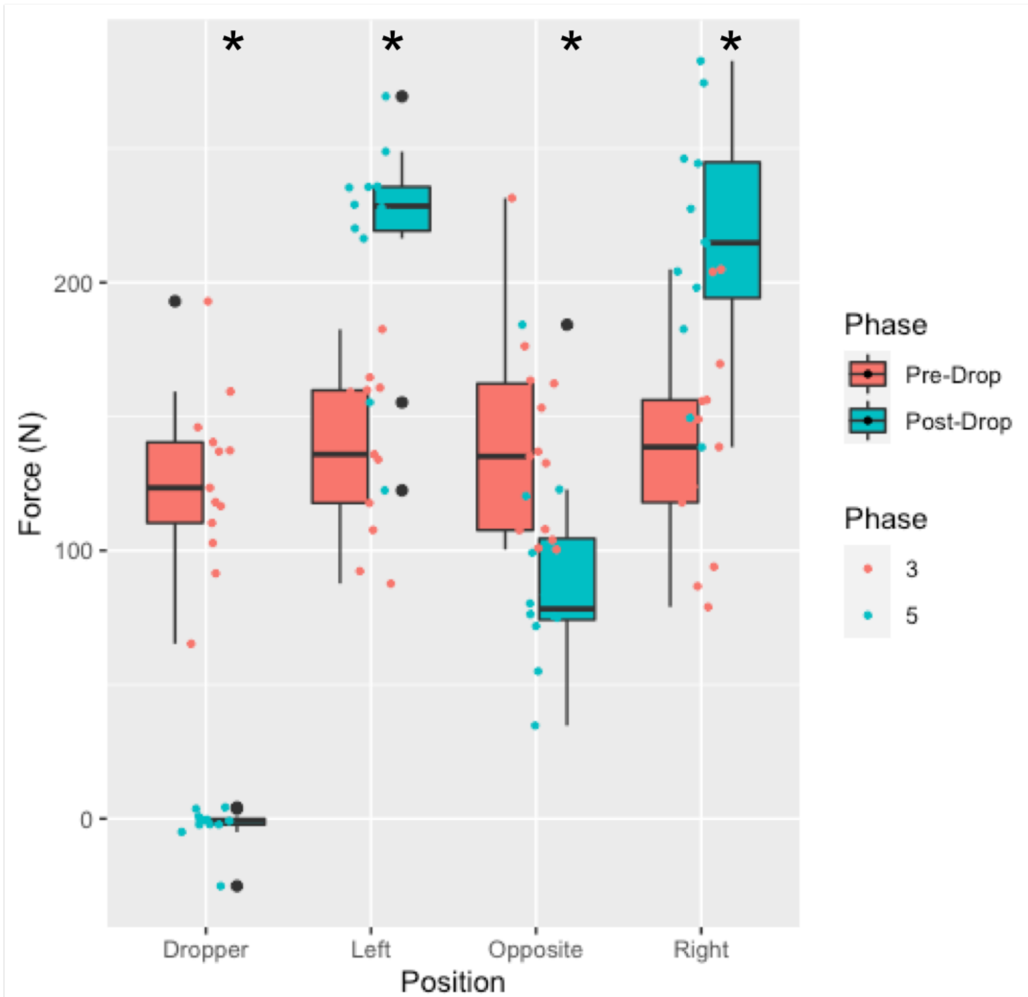

Figure 9. A box and whisker plot showing vertical force (N) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the square configuration (2 x 2 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in vertical force due to lifter position. Note the significant increase mean vertical force for the lifters to the left and right of the dropper and the decrease in mean vertical force for the opposite lifter.

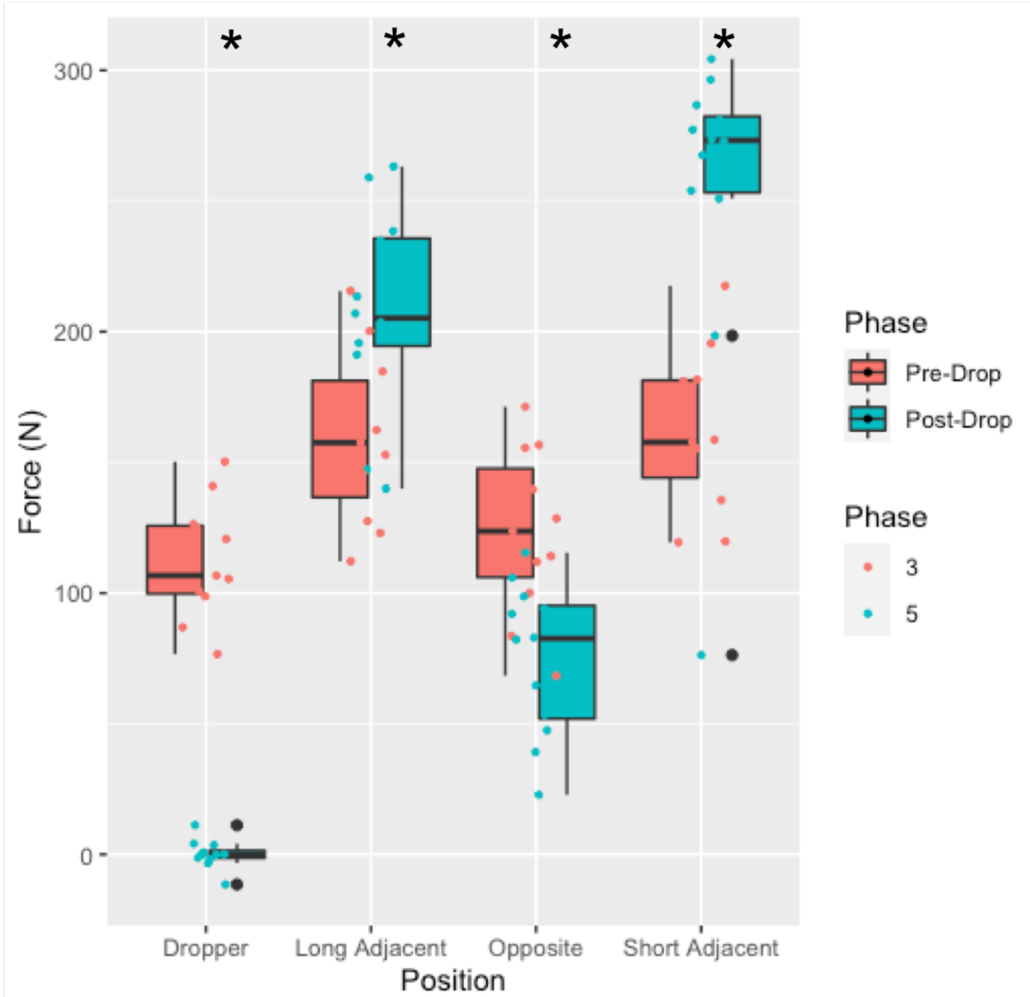

Figure 10. A box and whisker plot of vertical force (N) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the rectangular configuration (2 x 4 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in vertical force due to lifter position. Both long and short adjacent lifters experienced a significant increase in mean vertical force from phase 3a to phase 4, however the short adjacent lifter experienced a much greater increase. While the opposite lifter experienced a significant decrease in mean vertical force.

5.3 Muscle Activity

5.3.1 Biceps Brachii

During release trials, a significant interaction between lifting phase and lifter position ($F (3, 9) = 27.16$, $p<0.05$, $n_G^2 = 0.69$) and a significant main effect of lifter position on biceps brachii amplitude ($F (3, 9) = 46.95$, $p<0.05$, $n_G^2 = 0.71$) were observed for the square configuration. Similar to vertical force, prior to a drop, BB activity was relatively even amongst lifters (Figure 11). Following a drop, the lifter positioned to the right of the dropper experienced a significant increase in BB activation (15 %MVE).

During release trials for the rectangular configuration, a significant main effect of lifter position on biceps brachii amplitude was observed ($F (3, 9) = 3.92$, $p<0.05$, $n_G^2 = 0.40$). Similar to the square configuration pre-drop, the rectangular pre-drop BB activity was relatively uniform (Figure 12). Following the drop, while the long and short adjacent lifters did see increases in activation, they were not significantly different from the pre-drop phase. The significant main effect of position can be attributed to the difference between the dropper's BB activity in comparison to the short and long adjacent lifters during the post drop phase. BB activity post-drop had considerably more variability for the adjacent lifters.

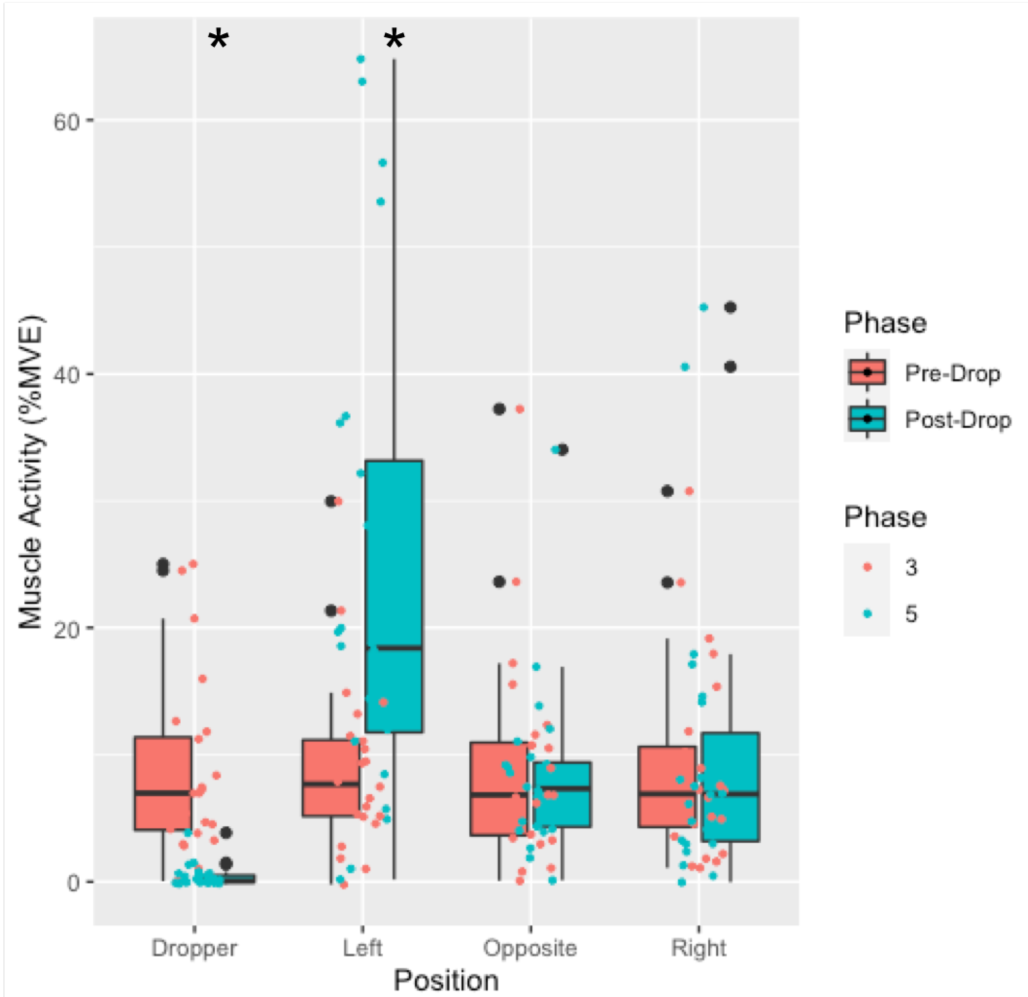

Figure 11. A box and whisker plot of amplitude of the Biceps Brachii muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the square configuration (2 x 2 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in BB activity due to lifter position. The lifter to the left of the dropper experienced a significant increase in BB muscle activity from phase 3a to phase 4.

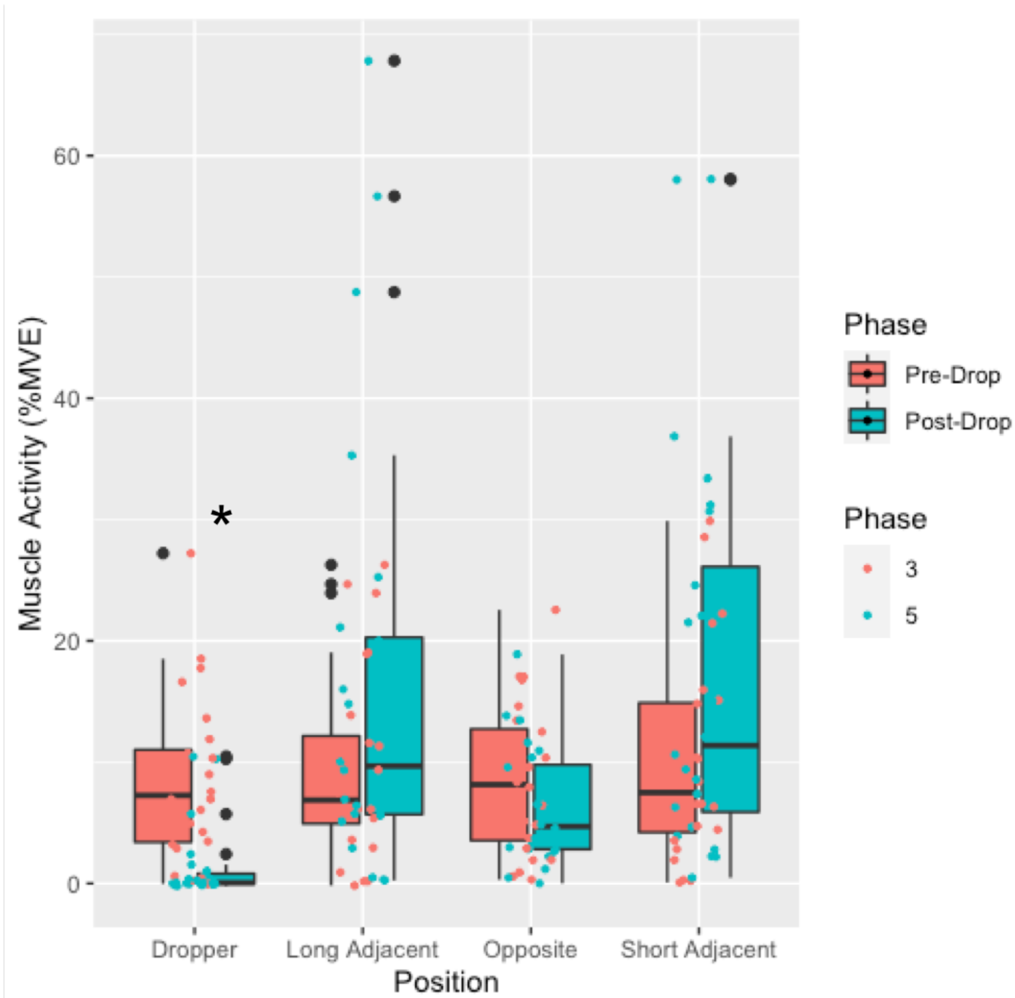

Figure 12. A box and whisker plot of amplitude of the Biceps Brachii muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the rectangular configuration (2 x 4 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant differences in BB activity due to lifter position. While the adjacent lifters saw an increase in muscle activity from the pre-drop phase to phase 4, it was not statistically significant. However, we saw an increase in the variability of the muscle activation for both the adjacent lifters.

5.3.2 Anterior Deltoid

During release trials, a significant interaction between lifting phase and lifter position ($F(3, 9) = 12.04$, $p<0.05$, $n_G^2 = 0.51$), a significant main effect of lifting phase ($F(1, 3) = 22.80$, $p<0.05$, $n_G^2 = 0.27$), and a significant main effect of lifter position ($F(3, 9) = 12.27$, $p<0.05$, $n_G^2 = 0.50$) was observed for anterior deltoid activation for the square configuration. Prior to the drop, AD activation was similar amongst all lifters, while following the drop we see a significant change in activation levels, specifically for the lifter to the left of the drop position (Figure 13). While these changes are considered significant, it should be noted that the values are very low (0.41-3.17 %MVE pre- to post-drop).

During release trials for the rectangular configuration, a significant main effect of lifting phase ($F(1, 3) = 30.87$, $p<0.05$, $n_G^2 = 0.09$) was observed for anterior deltoid amplitude. Much like the BB activation, we do not see an interaction for AD activation. Due to the coding of lifter position switching from left and right to short and long adjacent, the right side only EMG does not have as great of an impact on the values. Additionally, with the lifters to the left of the dropper being a part of either the short or long adjacent data, we see an increase in the variability of both positions AD activation (Figure 14).

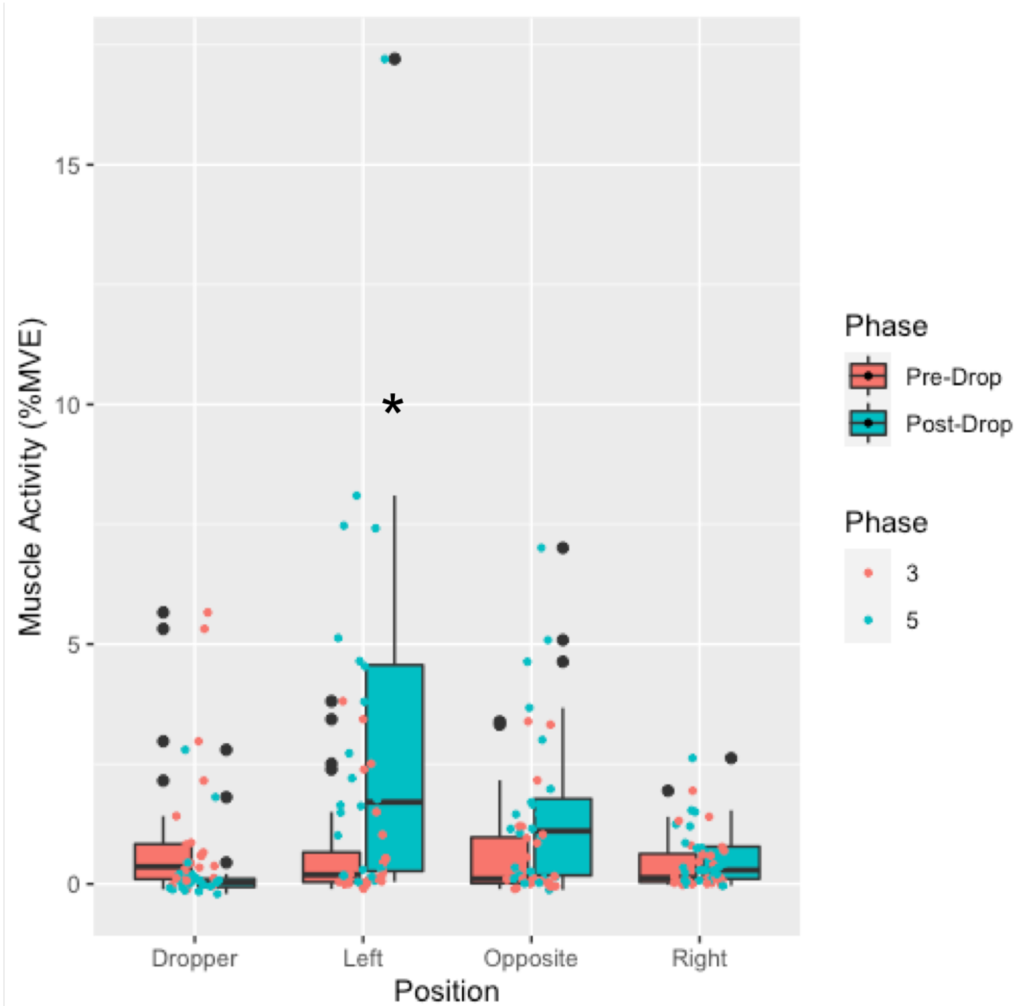

Figure 13. A box and whisker plot of amplitude of the Anterior Deltoid muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the square configuration (2 x 2 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in AD activity due to lifter position. The left position lifter saw a significant increase in AD muscle activation and an increase in variability following the load release.

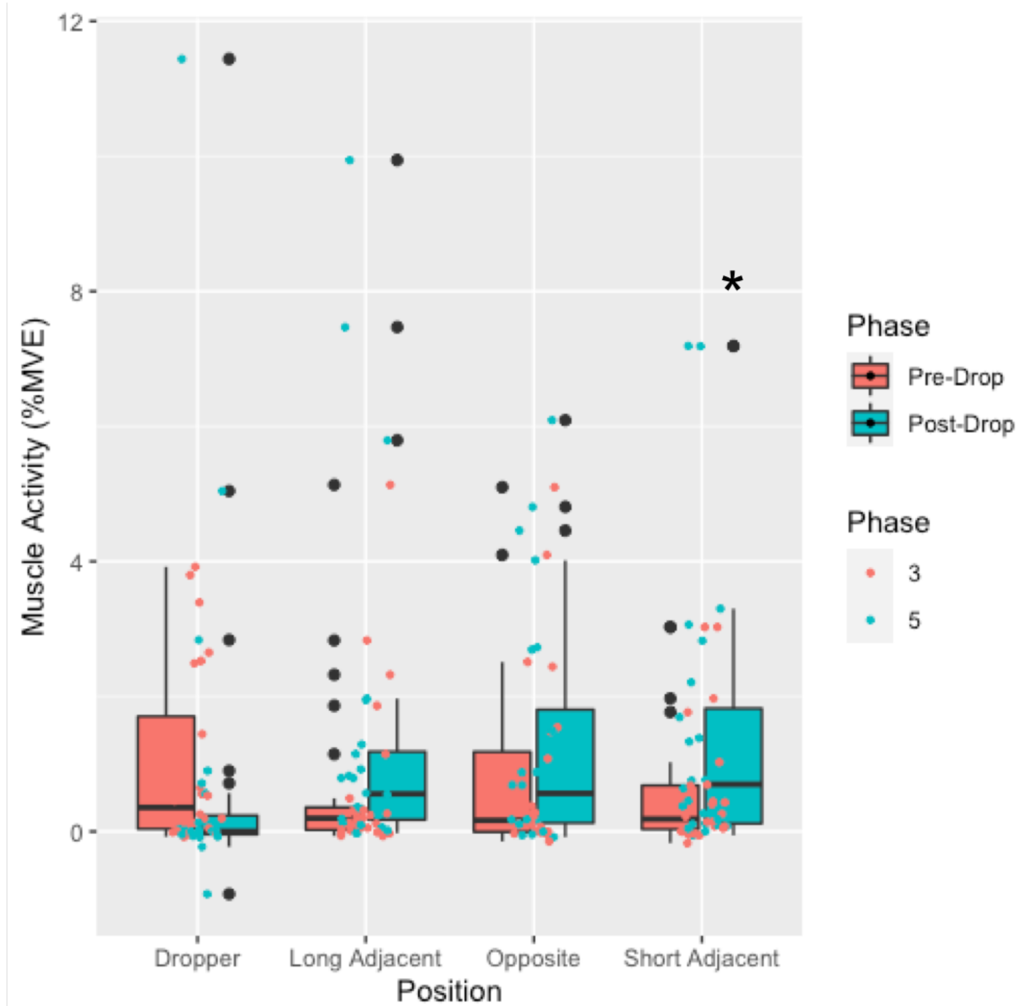

Figure 14. A box and whisker plot of amplitude of the Anterior Deltoid muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the rectangular configuration (2 x 4 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant differences in AD activity to lifter position between the dropper and the short adjacent lifter post-drop. Following the load release, we saw no significant changes in AD muscle activity, however we saw an increase in variability for all remaining lifters (opposite, long and short adjacent).

5.3.3 Upper Trapezius

During release trials, a significant interaction between lifting phase and lifter position (F (3, 9) = 15.98, p<0.05, $n_G^2 = 0.34$) and a significant main effect of lifter position (F (3, 9) = 7.15, p<0.05, $n_G^2 = 0.34$) was observed for upper trapezius amplitude for the square configuration. We see the interaction between lifting phase and lifter position via the lifter to left of the dropper, with an increase in UT activation from 4.9 to 16.2 %MVE from the pre-drop phase to the post-drop (Figure 15).

During release trials using the rectangular configuration, there was a significant interaction between lifting phase and lifter position (F (3, 9) = 4.95, p<0.05, $n_G^2 = 0.22$), a significant main effect of lifting phase (F (1, 3) = 17.17, p<0.05, $n_G^2 = 0.05$), and a significant main effect of lifter position (F (3, 9) = 4.45, p<0.05, $n_G^2 = 0.23$) was observed for UT amplitude. We see a similar result for the rectangular configuration, with the short adjacent lifter experiencing a significant increase in UT activation from the pre-drop phase to the post-drop. Additionally, for both the square and rectangular configuration, we see a large amount of variability for the left and short adjacent lifters in comparison to the other lifter positions (Figure 16).

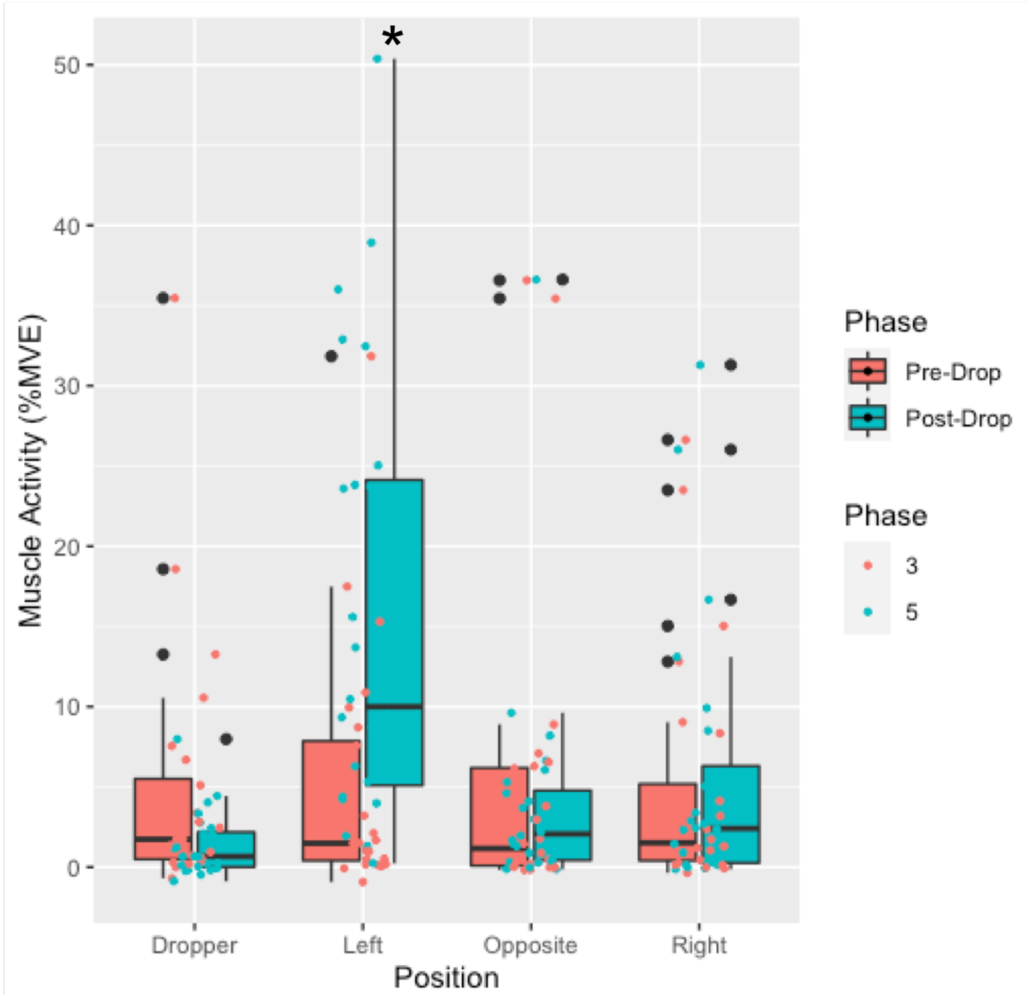

Figure 15. A box and whisker plot of amplitude of the Upper Trapezius muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the square configuration (2 x 2 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in UT activity due to lifter position. From the pre-drop phase to the 3-lifter phase we saw a significant increase in UT activation, as well as an increase in variability for the lifter to the left of the dropper.

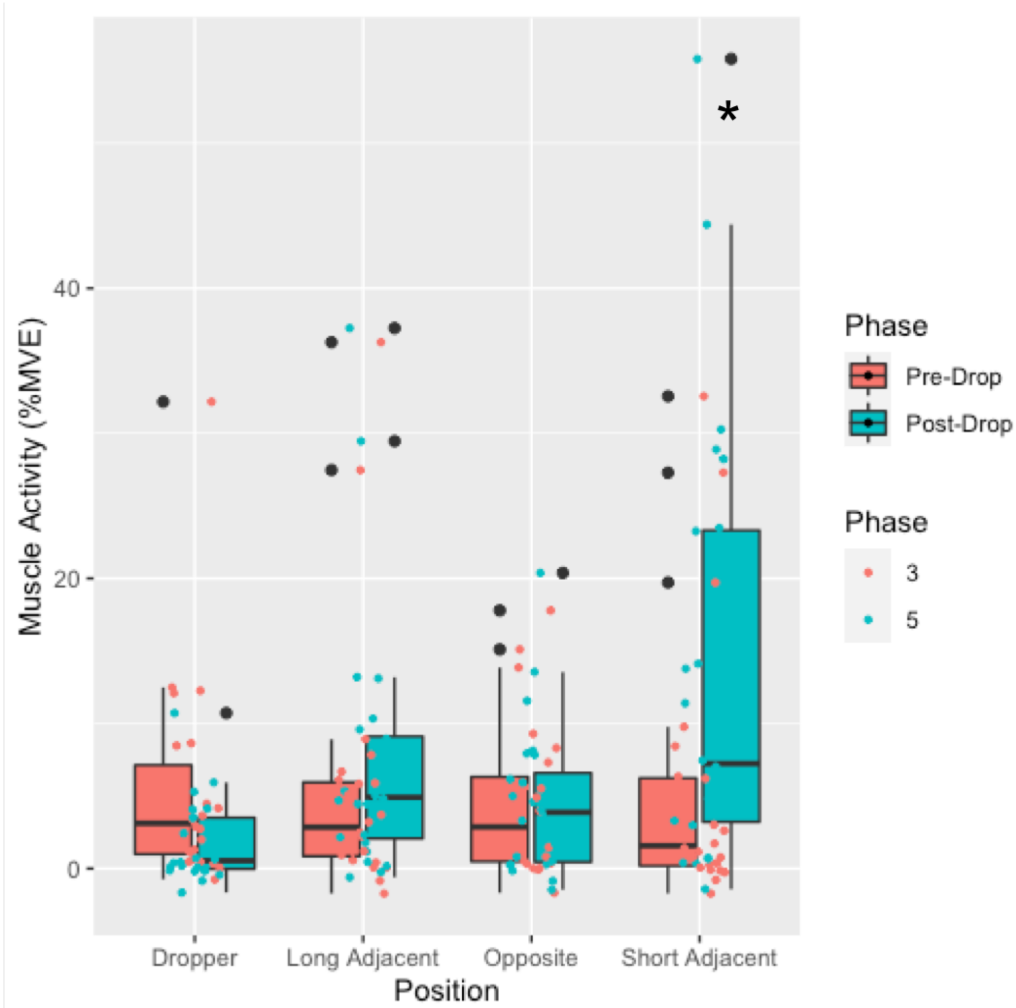

Figure 16. A box and whisker plot of amplitude of the Upper Trapezius muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the rectangular configuration (2 x 4 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in UT activity due to lifter position. From the pre-drop phase to the 3-lifter phase, we saw a significant increase in UT activation, as well as an increase in variability for the short adjacent lifter.

5.3.4 Lumbar Erector Spinae

During the release trials, a significant interaction between lifting phase and lifter position ($F (3, 9) = 87.87$, $p<0.05$, $n_G^2 = 0.84$) and a significant main effect of lifter position ($F (3, 9) = 59.58$, $p<0.05$, $n_G^2 = 0.85$) were observed for lumbar erector spinae amplitude for the square configuration. Unlike the other muscles, we see a significant interaction between phase and position due to LES activation of the lifter to the right of the drop position, with an increase from 10.60 to 17.40 %MVE from pre- to post-drop (Figure 17).

During the release trials for the rectangular configuration, a significant interaction between lifting phase and lifter position ($F (3, 9) = 9.97$, $p<0.05$, $n_G^2 = 0.49$) and a significant main effect of lifter position ($F (3, 9) = 13.62$, $p<0.05$, $n_G^2 = 0.65$) were observed for LES amplitude. However, for the rectangular configuration, we see a similar result. While both the short and long adjacent lifters see an increase in LES activation from pre- to post-drop, we see a greater increase for the short adjacent lifter (3.50 vs. 5.00 %MVE) (Figure 18).

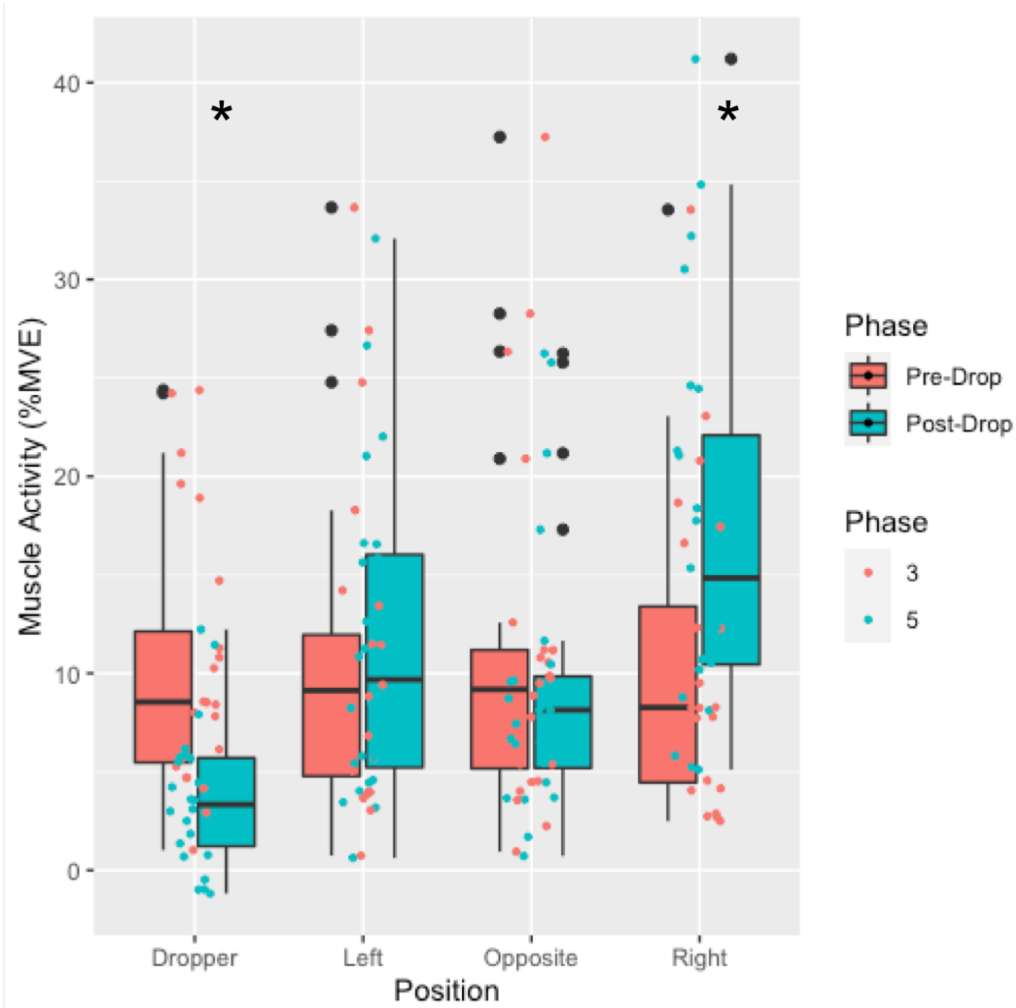

Figure 17. A box and whisker plot of amplitude of the Lumbar Erector Spinae muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the square configuration (2 x 2 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in LES activity due to lifter position. From the pre-drop phase to phase 4, we saw a significant increase in LES activation for the lifter to the right of the dropper. Additionally, both the left and right lifters saw an increase in variability from phase 3a to 4.

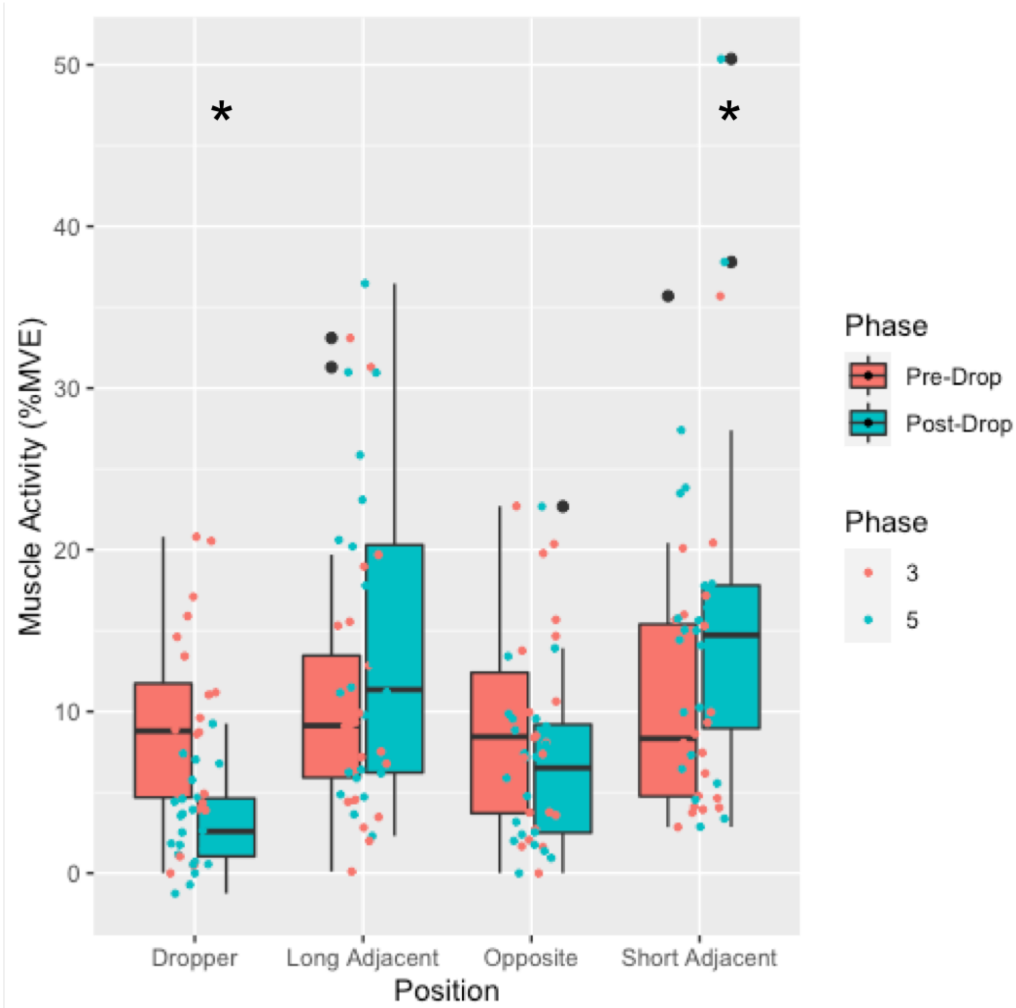

Figure 18. A box and whisker plot of amplitude of the Lumbar Erector Spinae muscle activity (%MVE) from phase 3a (pre-drop phase) to phase 4 (post-drop phase/3 lifter steady state) by lifter position for the rectangular configuration (2 x 4 ft.). Where the tip of the whiskers represents the highest and lowest score for each position, and from the tip of the whisker to the edge of the box represents the upper and lower 25% of the scores. The black line in each square represents the median and the entire box represents the middle 50% of scores. The light grey points represent the values with jitter applied to avoid overlapping. The black points represent values deemed to be outliers. Asterisks denote significant interaction between lifting phase and position, as well as significant differences in LES activity due to lifter position. From the pre-drop phase to phase 4, we saw a significant increase in LES activation for the short adjacent lifter, as well as a decrease in variability. While the long adjacent lifter saw no significant increase in LES activation, we saw an increase in variability from phase 3a to 4.

5.4 Timing for Force and Muscle Activity

5.4.1 Time to Peak Force

Time to peak force was calculated in order to see the time it took lifters adjacent to the dropper to reach their peak force from the initiation of the drop. A time period we were interested in was the 25 to 150 ms (0.025 to 0.15 s) window following a perturbation in order to determine whether muscle activity was reflexive or anticipatory. With 2 trials reaching peak force within the reflex window, the remainder of the trials taking anywhere from 0.15 s to 1 minute to reach peak force (Figure 19).

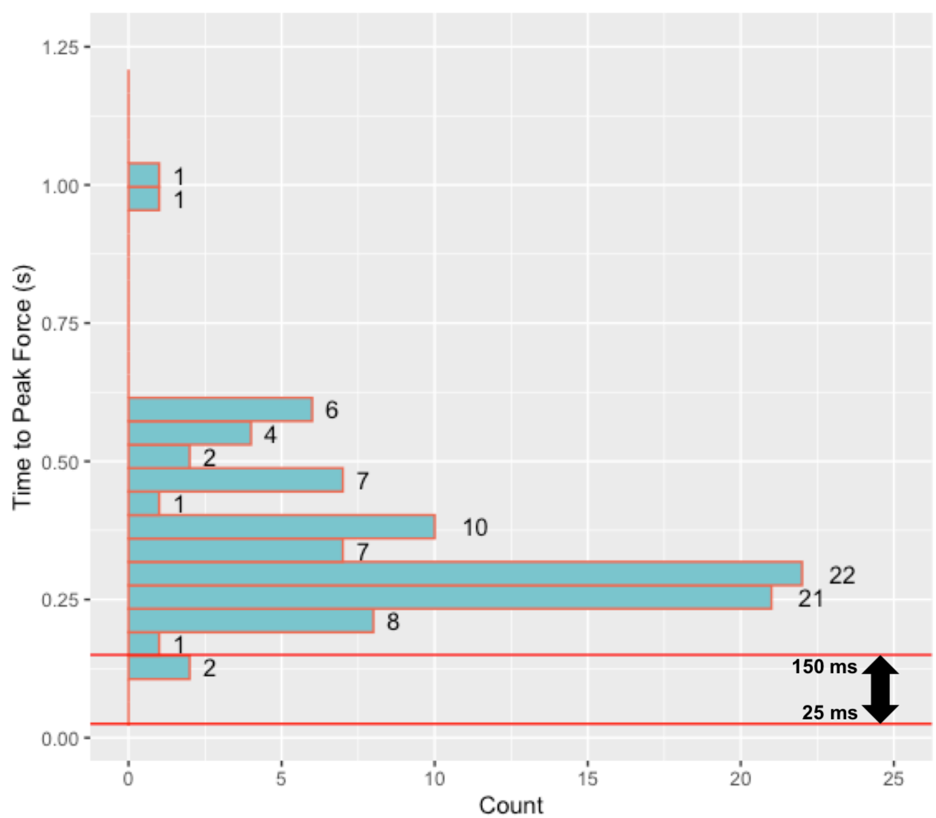

Figure 19. A bar plot of time to peak force occurrence (s) calculated from the initiation of the drop. The two horizontal red lines indicate the reflex zone (25 to 150 ms). All but 2 trials reached peak force after the reflex window. The numbers represent the count.

5.4.2 Time to Peak Muscle Activity

Time to peak muscle activity was calculated in order to see the time it took adjacent lifters to reach their peak muscle activity (BB and LES) from the initiation of the drop. As with the time to peak force, we were interested in where these values fell in relation to the reflex time period. It was added to this graph to provide insight into how many trials may present as anticipatory (Figure 20). While the majority of trials did fall outside of this time period, one from each muscle (BB and LES) were inside the window and others were very close to it, telling us that there may be some anticipatory muscle activity.

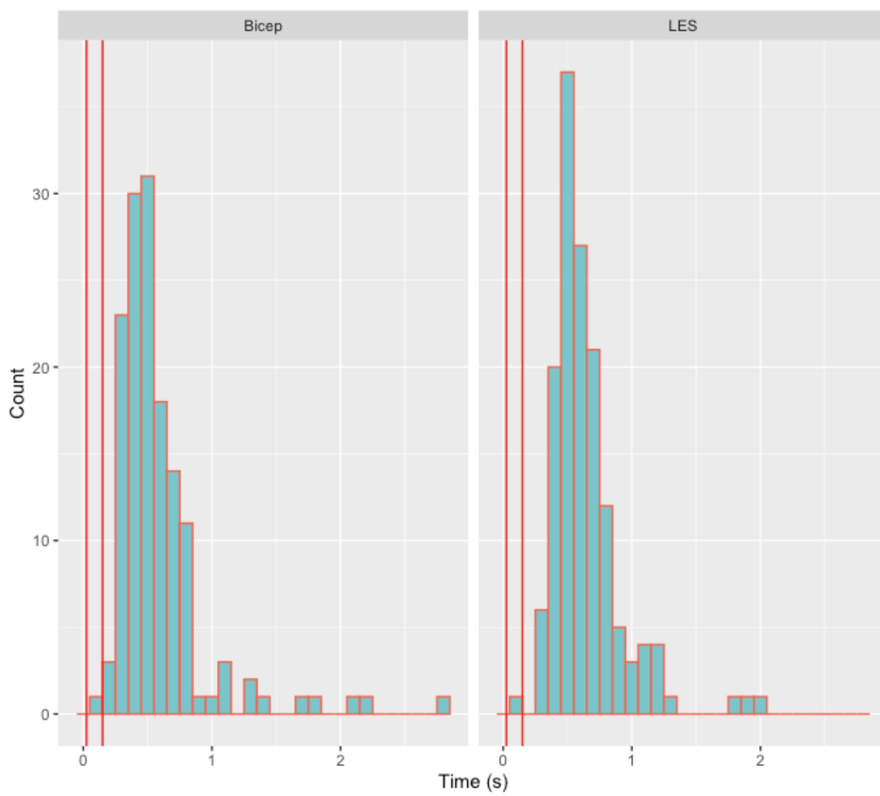

Figure 20. A bar plot of the time to peak muscle activity for both BB (left) and LES (right) calculated from the initiation of the drop. The two vertical lines on each graph represent the reflex period (25 to 150 ms). One trial from each muscle reached peak muscle activity inside the reflex period.

5.4.3 Time to Peak Force vs. Time to Peak Muscle Activity

We were most interested in the comparison between time to peak force and time to peak muscle activity. In order to determine whether lifters muscle activity was reflexive or anticipatory, we needed to determine how soon after peak force was reached was peak muscle activity reached. Time to peak muscle activity was subtracted from the time to peak force to calculate how long after peak force was reached was peak muscle activity reached. Once again, the 25-150 ms window was displayed on the graph in order to show the number of trials that fell within or outside the time points (Figure 21). The majority of times fall either within the reflex window or after, however we do see some peak muscle activity inside the anticipatory time period. We found 6 values for BB and 2 for LES that are considered anticipatory.

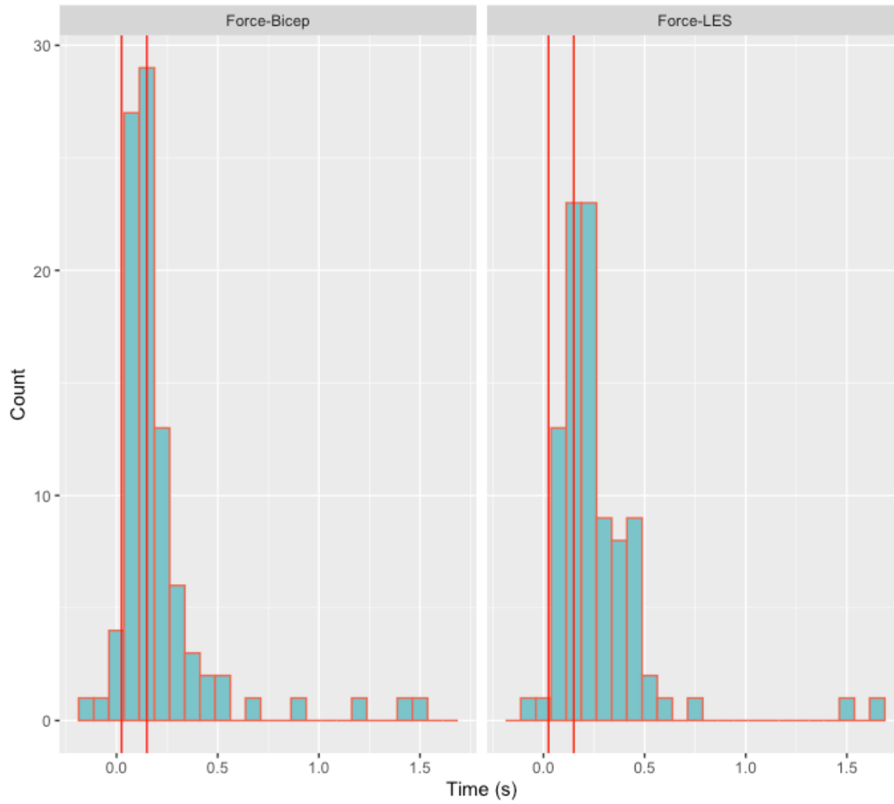

Figure 21. A bar plot of the comparison of the time to peak force (s) and the time to peak EMG (s) for both BB (left) and LES (right). The two vertical red lines represent the reflex period (25 to 150 ms). 6 BB and 2 LES time to peak activity values were anticipatory, while the remaining times were within or after the reflex period.

6.0 Discussion

While team lifting is highly prevalent in the workplace, it remains relatively unstudied. The investigation of teamwork may not seem to be a novel venture, however only recently have advancements been made in understanding the perception and actions of people working in teams. Joint action is defined as, the coordination of multiple people to accomplish a common goal (Sebanz et al., 2006; van der Wel, 2011; Vesper et al., 2011, 2017). Understanding how joint lifting is accomplished is imperative, and while some joint lifting research does exist, the majority of studies involve virtual lifting tasks rather than actual lifting (Bosga & Meulenbroek, 2007; Isenhower et al., 2010; Newman-Norlund et al., 2010; Masumoto & Inui, 2013). In this thesis, we made a novel attempt to determine whether a lifter's biomechanical signals may contribute to successful joint action despite the intended outcome to be an unsuspected load release.

The current study was primarily motivated by previous work that quantified biomechanical demands during a 4-member team lifting task and how these demands may be altered with a single-member load release (Craig et al., 2021, abstract in Appendix A). We found that the configuration of the slab resulted in different individual lifter demands before and after a sudden drop. Additionally, following a load release, lifters located to the left and right of the dropper (short and long adjacent for 2 x 4 ft. configuration) experienced a significant increase in force at the hands, while the lifter located opposite of the dropper experienced a decrease in force. Ultimately, we attributed these increases to load shape. Due to the shape of the load (square and rectangular), a load release from a single member resulted in the two closest lifters (left and right or short and long adjacent) bearing the brunt of the load and acting as a fulcrum, causing the load to tilt up from the opposite lifter and decreasing the vertical force experienced at the hand and wrist of the opposite lifter. Additionally, the configuration of the load has increased implications on the lifters adjacent to the dropper. While both lifters saw significant increases in vertical force at the hands following a release of the rectangular slab, the lifter on the short edge in relation to the dropper experienced a 44 N greater increase than the long adjacent lifter.

Previous literature on team lifting capacity suggests that 60 kg for a 4-lifter team is extremely conservative. Sharp and colleagues (1995) had participants select the load of a box that they could lift and carry for one hour and still be able to perform their remaining duties of an eight-hour day. In teams of two and as individuals, males maximal acceptable load for lifting and carrying was deemed to be above 60 kg (Table 1). Additionally, Sharp and colleagues (1993a) investigated the maximum team lifting capacity as a function of team size, and found that 4-person male teams had a lifting capacity of 493.2 ± 65.3 kg. While this is a 1-RM value, the standards used by the military to determine the load of infrequent lifting represents only 28-32% of this determined lifting capacity. While the weight of the constructed slab for this study was conservative in relation to real-world stone slabs carried by masons (ranging from 100-150 kg) and previously determined team lifting capacities, we still saw significant increases in the mean vertical force that could be representative of possible workplace injuries. Particularly in the short adjacent lifter, we see an increase from 161 ± 30.7 N to 253 ± 62 N, which is a change from just over 25% of the load (approximately 15 kg) to 43 % of load (approximately 26 kg). Despite the load, we saw a 92 N increase in force at the hands, however with a greater, more representative load we could see an increase of 2-3 times this. If a 4-member team is carrying a load of 100-150 kg, they are already all lifting more than the recommended limit for single workers outlined by NIOSH, assuming equal distribution. Therefore, if an unexpected release were to occur, the lifters located closest to the dropper are likely to be injured.

From the same study (Craig et al., 2021 abstract in Appendix A), right-side EMG was collected for the biceps brachii, anterior deltoid, upper trapezius, and the lumbar erector spinae. Again, the shape of the load altered lifter demands, with a significant increase in BB amplitude following a release for the lifter left of the dropper. However, this may be explained due to the collection of right-side only EMG, thus placing the right arm of the lifter to the left of the dropper and in closer proximity to the release. This is supported by the fact that when lifter position was coded for short and long adjacent, we saw a significant increase in BB amplitude for both of the lifter positions, as short and long adjacent lifters were to left of the dropper (Figure 7). Contrary to the BB data, we saw an opposite result for LES activation. For the square configuration, we see a higher mean activation for lifters to the right of dropper rather than the left. This makes sense, as a perturbation to the left of the lifter would cause a shortening response to the left erector and stretch response to the right, resulting in the increased activation. Similarly, to the BB data for the rectangular configuration, the LES became less one sided and evened out between the short and long adjacent lifters. However, only the short adjacent lifter's muscle activity was significant from the pre-drop phase to the 3-lifter steady state phase (15.7 ± 11.0 %MVE).

Due to the implications of a sudden release seen via right-side EMG, we believe it would be extremely beneficial to collect EMG bilaterally. We opted for right-side only, as it allowed us to collect four muscles for four separate lifters simultaneously. Despite this, we expect that had left side EMG been collected, the results of the study would be amplified. First, the right position lifters would experience similar muscle activity levels to that of the lifter to the left of the dropper for square configuration lifts. Additionally, we believe that during rectangular configuration lifts, both short and long adjacent muscle activity would increase, meaning that short adjacent lifters would be experiencing even higher increases in muscle activation following a drop, than already presented. A confirmation of this is necessary, as it is important to determine whether the sudden perturbation effects both sides equally. In a study by McGill and colleagues (2013) examining the effects on the low back of carrying a load in one hand versus two, they found that carrying loads in one hand resulted in greater spinal compression than splitting the load up into two hands. Additionally, these results were exacerbated with an increase in load and when carrying 30 kg in one hand, the low back compression exceeded 2800 N. However, when 30 kg was carried in both hands (30 kg per hand) it actually decreased the spinal compression when compared to carrying 30 kg in one hand, providing merit to balancing loads evenly during task design (McGill et al., 2013). Thus, it is imperative that we determine whether or not the biomechanical implications of a sudden perturbation effect both hands equally.

We hypothesized that, during a release where the goal was to elicit an unexpected response from the group, that the dropper would alert the other lifters of the imminent release via their muscle activity, resulting in a tactile indication through a change in vertical force. More specifically, we expected that the dropper would alert the other lifters through an increase in muscle activation and thus vertical force at the hands that a drop was about to occur.

Additionally, we suspected that the lifter opposite the dropper would show evidence of coordination with the dropper. This was a novel approach to determine whether joint action could be detected via biomechanical measures, as no prior literature exists. A cross-correlation analysis was conducted on the vertical force during the pre-drop phase and the catch phase between the dropper and the three remaining lifters for all drop trials. While there was no clear theme for correlation values, lifters located opposite the dropper were positively correlated and the adjacent lifters were negatively correlated. This makes sense, as we can see in the force data that as the dropper decreases their force (or drops the load), so does the opposite lifter, while the adjacent lifters see an increase in force. The pre-drop phase was analyzed for both the drop and non-drop trials in order to detect any differences in force leading into a drop vs. a non-drop. However, the data did not indicate that pre-drop phases were different for drop vs. non-drop trials. Effectively, they were the same, therefore the original study design and protocol were effective. This made it difficult to find joint action in these data, however it does seem to be a good process.

We had additionally hypothesized that the remaining lifters might show evidence that they were aware of the drop by way of the timing of their peak muscle activity in relation to the timing of their peak force. We expected that their muscle activity would be considered anticipatory rather than reflexive. However, there were only 8 instances in which lifter muscle activity reached its peak before the lower threshold of the reflex window (25 ms). While this is not a significant outcome, it does indicate that despite the dropper's intention to elicit an unexpected response from the remaining lifters to a dropped load, some lifters reacted prior reaching their peak force. Once again, the original study design was effective in evoking unexpected responses from the remaining lifters making it difficult to detect joint action. However, determining the timing of lifter's muscle activity in relation to the force they experience via the drop, could help in observing mechanisms of joint action under different circumstances.

6.1 Limitations

There are a few limitations in this investigation. As COVID-19 prevented collecting human data, existing data was re-analyzed. While the approach to investigating team lifting and joint action was novel, the original study was not designed in order to look for joint action coordination strategies. As the original study involved the dropper attempting to evoke an unexpected response from the other lifters, rather than to perform a successful joint lift, it posed an interesting opportunity to explore the concept of joint action. Especially considering, a common strategy used by co-actors during teamwork, is to make themselves more predictable in order to better coordinate their actions, therefore we decided that an exploratory study may be fruitful. Additionally, the pool of joint lifting research was minimal, and with much of being focused on virtual lifting we attempted to add to it in a new way.

As this thesis was conducted on previously collected data that was originally used as an independent study, the sample size was relatively small. Although we had 24 participants, they were only arranged into 6 groups. However, much of the team lifting data comes from studies with between 12 and 30 participants (Karwowski, 1988; Rice et al., 1995; Sharp et al., 1993a, b, 1995).

Finally, as we opted for right-side only EMG, we were limited to 4 channels on the right side. We believe that some results would have benefited from bilateral data and left-side EMG would have strengthened the results indicating the implications associated with being an adjacent lifter during an unexpected release.

6.2 Future Investigation

In terms of future research, there certainly is a need for a study on joint action involving actual joint lifting, rather than virtual. A study design similar to this thesis could be used to determine whether the underlying mechanisms of joint action interfere with a lifters intent to be inconspicuous during an intended load release. With the inclusion of left side EMG, eye tracking (to see where lifters are looking prior to a release), and an extension of the pre-drop phase could be beneficial in determining joint action coordination mechanisms. We believe that with left side EMG we would see more anticipatory muscle activity for lifters to the right of the dropper than we found in the current study. Additionally, tracking eye movements and gaze of lifters may alert experimenters to whether or not lifters pick up on clues as to who may be dropping. As a common technique to accommodate the coordination of team efforts is for co-actors to make themselves more predictable (Vesper et al., 2011), we expect that other lifters may pick up on a change in the dropper's behaviour during drop trials. Finally, we believe that an extension of the pre-drop phase may allow for less variable force data during non-drop trials, allowing a clearer indication in deviation during release trials. This potential approach with the intention of looking for mechanisms of joint action during team lifting would add much needed information to the current limited body of knowledge.

6.4 Conclusion

While the concept of teamwork to accomplish a common goal is not a novel idea, there is still much to learn about perception and the actions of humans in teams. Co-actors may make themselves more predictable by decreasing the variability of their actions during teamwork, however this may not be the case when the intention is to be elicit an unexpected response from the team. This thesis proposed a novel investigation of mechanisms supporting joint action during team lifting by analyzing biomechanical signals produced by the lifter responsible for a load release and the response of the remaining lifters. Although these methods were exploratory, we found that there was no difference in the dropper's force production during lift or drop trials during the pre-drop phase. While some evidence exists in anticipatory muscle responses from adjacent lifters, further investigation is needed to determine the cause. As the field of joint action is relatively new, combining multiple strategies that facilitate joint action in order to investigate how lifter's in teams better coordinate their actions is a challenging endeavour. Future investigations including specific joint action measures as well as a complete docket of biomechanical outcomes could eradicate some issues and shed some light on joint lifting.

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Appendices

Appendix A: Independent Study Abstract - Accepted to 2020 Ontario Biomechanics Conference

Load Dimension Alters Lifter Demands Before and After Sudden Release in Team Lifting

Heavy and awkward lifts are common in the masonry industry, making team lifts necessary. During team lifting, concerns with load distribution and drops are a large concern.

The purpose of this study was to quantify biomechanical demands during 4-member team lifts, and assess load distribution when one member unexpectedly released their grip.

Twenty-four males aged 18-35 participated. Each 4-person team performed 30 lifts of a 60 kg “slab” in rectangular (2’x4’) and square (2’x2’) configurations. Participants lifted and held by participants for 20 seconds, before returning it to the start position. In 8 of the lifts, one participant released their grip to simulate a sudden, unexpected drop. Motion capture of the apparatus, tri-axial hand forces, and surface electromyography (EMG) were collected.

A significant *lift position* by *lift phase* (4-person vs 3-person hold) interaction was observed for both shape configurations. For the square configuration, participants adjacent to the drop experienced a significant increase in mean force (η^2= 0.82), while participants opposite the drop experienced lower force (Figure 1). The rectangular configuration elicited similar force increases (η^2= 0.82), however, participants located on the shorter adjacent side experienced a greater increase.

Prior to load release, load sharing between participants was uniform for the square configuration (23.3-25.7% of the total load each), while the rectangular configuration showed more variance across lifters (20.3-28.7%). Following release of one corner, adjacent lifters experienced increased loading (41-41.8%), while the opposite corner decreased to 17.2% in the square configuration. A heightened response was found for the rectangular configuration, where the short edge lifter experienced greater vertical force (47.2% of load). EMG echoed force findings but was limited to the right side. These findings suggest that the risk of injury varies with position during team lifting.

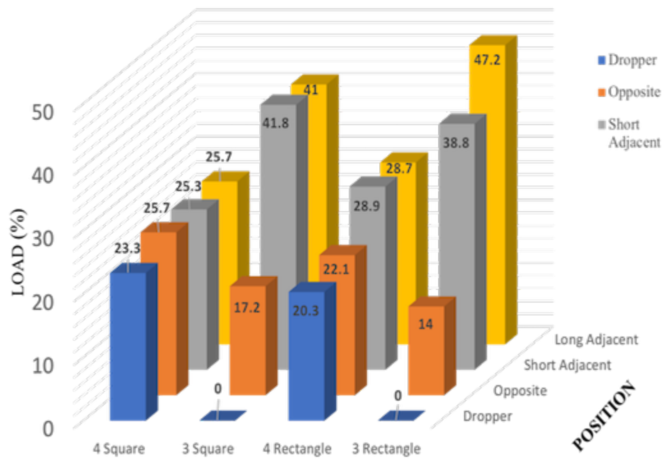

Figure 1. Interaction between 3 vs. 4-participant equilibrium, position and load sharing (% of load). For square configuration the short adjacent represents left of dropper and long adjacent represents right.

Appendix B: Letter of Informed Consent

McMaster University

Inspiring Innovation and Discovery

Principal Investigator:

Co-Investigator

Student Investigator

Purpose of the Study

Peter Keir, PhD
Professor
Department of Kinesiology McMaster University

(905) 525-9140 ext. 23543

Colin McKinnon, PhD Postdoctoral Fellow Department of Kinesiology McMaster University

(519) 505-1696

Daanish Mulla, MSc Department of Kinesiology McMaster University
(905) 525-9140 ext. 20175

Letter of Information and Consent

Biomechanical responses to sudden load release during team lifting

Team lifting is common in many workplace settings in which the weight of the load exceeds the lifting strength and safety limits of a single worker. Physical demands associated with lifting are known risk factors for shoulder and low back disorders, and it is essential to understand musculoskeletal loads encountered during team lifting tasks to develop safe workplace practices. Team lifting requires coordination of all members, and loss of this coordination could cause a single team member to release the load, resulting in a sudden, asymmetrical increase in load distribution among remaining worker members. The goal of this study is to quantify the biomechanical demands during 4-member lifts and how they may be altered with a single-member load release would be beneficial in developing workplace team lifting guidelines.

Procedures involved in the Research

This study will involve a single laboratory session taking approximately 3 hours to complete. Note that data will be collected with groups of 4 participants. The following procedures will be performed simultaneously for each of the 4 participants:

1. After completing this informed consent form, your height and weight will be measured and recorded on a data collection spreadsheet. Height will be measured with a tape measure and weight will be measured using a scale.
2. You will lay on a padded assessment table, and muscles to be measured with EMG will be palpated by one of the researchers. You will be asked to flex certain joints to ensure the location of the specific muscles being tested. Electrodes will be affixed to the skin over your right shoulder, arm, and back to record muscle activity for the anterior deltoid (front of shoulder), upper trapezius (top of shoulder/neck), biceps brachii (upper arm), and erector spinae (middle of back). The electrodes will be taped down using tape. These areas will be shaved with a new, disposable razor and cleaned off with alcohol prior to the application of the electrodes. These procedures are required to obtain a high quality signal.

3. You will be asked to perform a series of maximum voluntary exertions where you maximally perform a specific contraction that will be used to normalize EMG signals. You will perform 2 repetitions for each maximal contraction (5 seconds in duration each). Two minutes rest will be given between maximal contractions.
4. Each 4-participant lifting team will perform group lifts of a 60 kg rectangular slab (2 x 4 ft.) and a 60 kg square slab (2 x 2 ft.). Participants will be positioned at the four corners of the slab, and perform a vertical group lift from 15 cm above ground level. Each team will perform 10 lifts with each slab (20 total lifts) with 4 trials designated as “release” trials.

   Release trials: the experimenters will instruct each participant to release the load on a single, designated trial (4 total release trials). Lifters will not know which trial other lifters have been assigned to as their release trial. Verbal cues will be given by an experimenter to coordinate timing of the lift, participants will lift and balance the load for 5 seconds, and then a visual cue will instruct the designated participant to release their corner of the slab. The remaining 3 participants will be required to hold and balance the load for an additional 15 seconds. Upon completion of the trial, experimenters will assist in returning the load to the ground level position.

   Non-release trials: all remaining (16) trials will not involve a release in an effort to simulate a sudden, unexpected response during release trials. Participants will lift and balance the load for 20 seconds, and return the load to the ground level position.

5. You will be given 5 minutes rest between lifting trials to mitigate fatigue effects.
6. EMG electrodes will be removed. Alcohol can be used to remove any tape residue, if desired.

Potential Harms, Risks or Discomforts

Minimal risks are anticipated from this study.

Skin sensitivity

Participants may experience mild skin irritation/redness from the adhesive of the electrodes. This is similar to the irritation that may be caused by a bandage and typically fades within 2 to 3 days.

Maximum Voluntary Exertions

Muscle soreness following the maximum voluntary exertion trials is possible since you will be asked to maximally contract certain muscles. This discomfort and soreness is not harmful or long lasting (dissipates within 2-3 days). It is similar to the discomfort experienced after a mild-moderate workout.

Muscle Fatigue

You may feel fatigued following the session due to the weight of the slab lift being performed. You will be given 5 minutes rest between lifts to mitigate these effects, but may still experience fatigue similar to that following a mild-moderate workout.

Potential Benefits

The outcome of the study will allow us to inform occupational guidelines for safe team lifting. The research will not benefit you directly.

Confidentiality:

Your name and email address will be collected for this study, but will not be linked to any collected data. All data will be kept anonymous and used for research purposes only. This signed consent form will be scanned, encrypted and uploaded to MacDrive, and the original paper copy will be shredded.

Participation:

Your participation in this study is voluntary. If you decide to participate, you can decide to stop at any time, even after signing the consent form or part-way through the study. If you decide to stop participating, there will be no consequences to you. If you do not want to answer some of the questions you do not have to, but you can still be in the study. Note: because this study uses groups of 4 participants, should one participant decide to stop participation, the experimental session will end. All remaining participants will be invited to return on another scheduled day.

Remuneration

You will receive $10 per hour for participating in this study as remuneration for your time. The amount received is taxable. It is your responsibility to report this amount for income tax purposes.

Information about the Study Results:

You may obtain information about the study results by contacting Dr. Peter Keir at (905) 525-9140 (x 23543).

Questions about the Study:

If you have questions or need more information about the study itself, please contact me at:

Colin McKinnon colin.d.mckinnon@gmail.com

This study has been reviewed by the McMaster Research Ethics Board (MREB). is responsible for ensuring that participants are informed of the risks associated with the research, and that participants are free to decide if participation is right for them. If you have any questions about your rights as a research participant, please contact MREB at ethicsoffice@mcmaster.ca or (519) 525-9140 ext. 26117 or 23142.

CONSENT

- I have read the information presented in the information letter about a study being conducted by Dr. Colin McKinnon and Dr. Peter Keir of McMaster University
- I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested
- I understand that if I agree to participate in this study, I may withdraw from the study at any time
- I understand that any data recorded prior to withdrawal may still be used for data analysis
- I understand I will receive a signed copy of this form
- I agree to participate in the study

Signature: ____ Date: _________________________ Name of Participant (Printed) _____________________________________

1. ___Yes, I would like to receive a summary of the study's results
Please send them to me at this email address ___________________________________
Or to this mailing address: ____

____
____

___ No, I do not want to receive a summary of the study's results

Person Obtaining Consent

Signature: ____ Date: _________________________ Name of Researcher (Printed) _____________________________________

Appendix C: Individual Participant Data

Group	Participant	Height (cm)	Weight (kg)	Age (years)
1	S001	183.5	89.3	24
	S002	194.0	85.5	22
	S003	185.5	100.0	24
	S004	181.5	107.5	23
2	S005	184.5	89.9	23
	S006	182.5	83.4	19
	S007	184.5	76.6	29
	S008	180.5	74.0	22
3	S009	182.5	78.8	30
	S010	186.0	93.0	24
	S011	193.0	117.2	22
	S012	184.5	76.0	24
4	S013	172.5	68.6	23
	S014	179.5	67.2	20
	S015	183.5	80.2	20
	S016	180.5	67.9	21
5	S017	182.0	85.1	22
	S018	180.0	69.2	19
	S019	175.5	73.6	21
	S020	168.5	67.1	19
6	S021	188.5	75.0	22
	S022	184.0	81.7	24
	S023	190.0	80.2	21
	S024	182.5	82.3	19

Appendix D: Ethics Approval

McMaster Research Ethics Board

1.1 This first screening question determines whether you should proceed with an application to the McMaster Research Ethics
Board (MREB) or if you should instead apply to the Hamilton Integrated Research Ethics Board (HiREB).
In general, if the Principal Investigator (PI) is appointed by any Faculty other than the Faculty of Health Sciences (FHS), then
the study is reviewed by MREB. If the PI is from FHS, Hamilton Health Sciences or St. Joseph's Healthcare Hamilton, then the
project should be reviewed by HiREB. For student research, if the Faculty Supervisor (FS) and Student Investigator (SI) are
both in a Faculty other than FHS, then the study is reviewed by MREB. If both are from FHS, then the study is reviewed by
HiREB. For situations where the PI holds appointments in both FHS and another Faculty, or where the FS is from FHS and the
SI from another Faculty (or vice versa), please click on the information button to the right for more direction.
There are also some exceptions to the general rule. If you would normally apply to MREB, but your study involves FHS participants, hospital patients, invasive procedures, medical interventions or other similar aspects, or if you are otherwise
unsure where to apply, then please click on the information button to the right for a detailed explanation of to which REB you
should submit an ethics application.
I should apply to HiREB or am still unsure where I should apply.
I should apply to MREB and continue with this application.
1.2 What kind of research ethics application do you wish to create? Click on the info button for an explanation of each application
type.
Standard MREB Application
1.3 Is this a post-doc, graduate or undergraduate student project? If so, the Faculty Supervisor's contact information will be
requested and the Faculty Supervisor must sign the application prior to submission.
Yes
No
1.4 If you are submitting this application for the first time, or are submitting after the Research Ethics Officer requested changes to
complete the application, then select "Initial Submission". If you have already received ethics review feedback from an MREB
Chair and are responding to the comments, then select "Response to REB comments".
Initial Submission
Response to REB Comments

Choosing the Application Type

Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 1 of 26
1.5 Upload the document summarizing your revisions below (see #3 above). Only upload the summary document here, as revised
supporting documents (e.g. letter of information) should be uploaded in the appropriate section of the form.
Type Document Name File Name
Version
Date Version Size
Response
Documents
McKinnon_1754_Response to Reviewer
Comments_Mar6 2019
McKinnon_1754_Response to Reviewer
Comments_Mar6 2019.docx

Mar/06/2019 v1
37.9
KB
<-- Previous Next --> Navigation Pages
To go to the previous page click <-- Previous under the Actions menu in the upper left of the application. To go to the next page
click Next -->. To return to the Index of the Sections of this application click Navigate.

Parameters of Risk

2.1 Faculty Supervisor (for PhD, MA, Undergrad Student PI lead projects)
Title First Name Surname
Dr. Peter Keir
Organization McMaster University
City Hamilton
Telephone 905 525 9140 ext. 23543
Email pjkeir@mcmaster.ca
Supervisors must be registered with MacREM (have logged in with MacID at least once) before they can sign. Ask your supervisor to login to MacREM before you can request their signature. Also make sure all fields are complete on this contact form.
2.2 What is the faculty/department of the Supervisor?
Science - Kinesiology

Principal Investigator

Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 2 of 26
2.3 Student Principal Investigator
Title First Name Surname
Mr. Daanish Mulla
Organization McMaster University
City Hamilton
Telephone 905 525 9140 ext. 20175
Email mulladm@mcmaster.ca
2.4 What is the faculty/department of the Student Principal Investigator?
Science - Kinesiology
2.7 Are there any Co-Investigators?
Yes
No
2.8 Are there any Collaborators?
Yes
No
2.9 Are there any Research Assistants or Coordinators?
Yes
No
2.10 Are there any Student Investigators?
Yes
No

Co-Investigator(s)

Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 3 of 26
2.11 Co-Investigator
Title First Name Surname
Dr. Colin McKinnon
Organization McMaster University
Department Kinesiology
Faculty Science
City Hamilton
Telephone 519 505 1696
Email colin.d.mckinnon@gmail.com
3.1 Provide a short title for your research.

Providing a short title will really save "screen real estate" and is highly recommended.
Team lifting load release
3.2 Provide the full title for your research project:
Biomechanical responses to sudden load release during team lifting
3.3 Is your grant title different from above? (If your research is not funded or you don't have a grant just select NO)
Yes
No
The Grant Title is required for funded research.
Project Title
Lay Summary of the Proposed Research
Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 4 of 26
3.5 How would you describe the research activity conducted in this protocol to a lay person unfamiliar with your discipline's
methodologies and jargon? (max 250 words)?
Team lifting is a common workplace strategy for heavy loads. Limited evidence is available regarding load distribution among workers during 4-member team lifting, particularly in response to load release by a single member. The purpose of this project is to quantify biomechanical factors (hand forces, shoulder and low back muscle activity) during 4-member team lifting of a heavy slab when a single member suddenly releases the load. Each 4-participant lifting team will perform group lifts of a 60 kg rectangular slab (2 x 4 ft.) and a 60 kg square slab (2 x 2 ft.). Each team will perform 10 lifts with each slab (20 total lifts) with 4 trials designated as "release" trials where a visual cue will instruct the designated participant to release their corner of the slab. The biomechanical responses during these release trials will likely emphasize the importance of lifter coordination and highlight the fact that assuming load is evenly distributed across all lifters may not be appropriate. This research will serve as basis for load distribution guidelines between 4-member lifting teams, and will suggest some potential approaches for adapting single-lifter guidelines to multiple team members.
3.6 What is the date you plan to begin recruiting participants? (For secondary use of data, what is the date you plan to receive the
dataset, or, if applicable, the date you plan to start obtaining consent from individuals to use their data for research?)
Feb/01/2019
3.7 What is the estimated last date for data collection with human participants?
Jul/31/2019
Start and End Dates
4.1 For which Level of Project(s) will the data be used? (Check all that may apply)
Faculty Research
Post-Doctoral Research
Ph.D. Thesis
Master's (Major Research Paper - MRP)
Master's (Thesis)
Graduate Course Project
Staff/Administration Research
Undergraduate Honour's Thesis
Undergraduate (Independent Research)
Other
Level of Project
4.2 Is this project currently being funded?
Yes
No
Funding and Granting Agencies
Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 5 of 26
4.6 Is funding or additional funding being sought?
Yes
No
4.7 What granting agency are you applying to? Check all that may apply
NSERC
SSHRC
CIHR
ARB

CFI
USRA
Health Canada
NCE
School of Graduate Studies
Internal Funding
Other
4.7.1 If applying to Other granting agency, specify:
Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) Seed Grant Program
4.8 Are you requesting ethics clearance for a research project that was not originally designed to collect data from human
participants or their records (i.e., your research project originally did not involve collecting data from humans or their records
but you now intend to do so)?
Yes
No
5.1 Select the location(s) where research will be conducted.
McMaster University
Community
Hospital
Outside Canada
School Boards
Other

Location of the Research

Review by Other Research Ethics Boards

5.2 Has any other Research Ethics Board(s) or equivalent already cleared this project?
Yes
No
5.4 Will any other Research Ethics Board(s) or equivalent be asked for clearance?
Yes
No
5.5 Has a version of this study been disapproved or rejected by any Research Ethics Board/Committee?
Yes
No
6.1 Will your research involve collecting data from a Canadian Indigenous community(ies) and/or will the data pertain to Indigenous
identity or knowledge?
Yes
No
If you answer No, but are not sure, please answer Yes to see the criteria statements, or contact the Research Ethics Office for more information.

Research Involving Canadian First Nations, Inuit and Metis Peoples

7.1 Do any researchers conducting this study have multiple roles with potential participants that may create real, potential, or
perceived conflicts of interest? Or could multiple roles create situations of undue influence, power imbalances, or coercion,
which could affect participant decision-making processes such as consent to participate? Examples of dual roles include acting
as both researcher and therapist, health care provider, family member, caregiver, teacher, advisor, consultant, supervisor,
student peer, work colleague, and/or employer.
Yes
No

7.4 Will the researcher(s), members of the research team, and/or their partners or immediate family members receive any personal
benefits (for example a financial benefit such as remuneration, intellectual property rights, rights of employment, consultancies,
board membership, share ownership, stock options etc.) as a result of or being connected to this study?
Yes
No

Conflicts of Interest

7.6 Are there any restrictions regarding access to or disclosure of information (during or at the end of the study) that have been
placed on the investigator(s)? These restrictions could come from a study sponsor, community partners, an organization being
researched, or another group involved in the study.
Yes
No

8.1 Describe concisely and in plain language the study background of the proposed research project (e.g., context of the research,
previous research, importance of this area of study, etc.).

We were approached by the Infrastructure Health and Safety Association (IHSA) for the Masonry Trade Management with concerns regarding team lifting of large slabs of 200 lb. (usual maximum) to 300 lb. (occasional maximum) and concerns of injury to the masonry workers. Team lifting is common in many workplace settings in which the weight of the load exceeds the lifting strength and safety limits of a single worker. Challenges with using assistive mechanical devices, such as environmental barriers during masonry work, prohibit their use, hence a team of workers are commonly required to cooperatively lift heavy loads. Team lifting comprises 57% of all lifting tasks performed by military personnel and 50-88% of loads lifted greater than 25 kg by ironworkers. As manual lifting accounts for a large portion of many professions and physical demands associated with lifting are known risk factors for shoulder and low back MSDs, it is essential to understand musculoskeletal loads encountered during team lifting tasks to develop safe workplace practices. There are relatively few studies examining the biomechanics of team lifting, with most research limited to 2-member lifting conditions. It is expected that there is greater potential for impaired coordination between workers during 4-member lifts, especially in the presence of worksite obstacles, as compared to 2-member lifts. In an extreme loss of coordination, a single team member may release the load being lifted, resulting in a sudden, asymmetrical increase in load distribution among remaining worker members that would disproportionally increase risk for injury. Accordingly, quantifying biomechanical demands during 4-member lifts and how they may be altered with a single-member load release would be beneficial in developing workplace team lifting guidelines.

8.2 Describe concisely and in plain language the specific purpose / research question for the proposed study.

How are biomechanical demands (hand forces, shoulder/back muscle activities) distributed among workers during a 4-member team lifting task of a heavy slab in response to a sudden load release by a single member?

Description of the Project

If researching several sub-populations, use a heading for each population and provide details for each. Answer the next
questions for each type of study population that you may have.

9.1 What is the approximate number of participants required for this study? Where applicable, also provide a rationale for your
choice in sample size and/or the sample size calculation (e.g., to explain how a low sample size will still provide meaningful
results, or to justify the number of participants needed in research that includes significant risks).

Twenty-four male participants (12 participants will be construction apprenticeship students and 12 will be university undergraduate students).

Participants

9.2 What are the salient participant characteristics (e.g., age, gender, location, affiliation, etc.)? Describe any specific inclusion/exclusion criteria (e.g., BMI > 30, immigrated to Canada in the past year, etc.)

All participants will be male, aged 18-35 with no history serious injury that may impair lifting. Male participants will be used because our construction apprenticeship program partner has very few female students. All males will be used for consistency between construction and university student groups. We will recruit university students with less than 4 months experience working in the construction sector to distinguish between group experience under the lifting conditions tested in this study. These participants will also, have at least 2 year's experience with recreational weight-lifting.

9.3 Categories of Participants: (Check all that may apply)

Children - not school aged
Adolescents
School children/pupils
Adults
Pregnant women
Elderly
Canadian Indigenous people
McMaster students
Hamilton community
Mental Health Patients (Non-HHS or SJHH)
Prisoners
International Participants
Other
9.3.2 Specify Other category of participant:
Construction Apprenticeship Program students recruited through our partners at the Infrastructure Health and Safety Association (IHSA)
9.4 Will your study include participants who are not fluent in the English language?
Yes
No

Categories of Participants

If researching several sub-populations, use a heading for each study population and provide details for the type of participant or group and who does the recruiting. Refer to the Menu above Help – Templates to find the "How to Unpack
the Recruitment Details" worksheet and other sample documents you may modify.

Recruitment

Date Printed: Mar/06/2019
MREB Application Form| MREB Application Form| Team lifting load release, 2 Page 9 of 26
10.1 How will each type of participant be recruited?
McMaster students will be recruited from undergraduate Kinesiology classes and posters in the Ivor Wynne Centre (IWC) building. To avoid any conflict of interest, students will not be recruited from classes taught by Dr. Keir (co-investigator) or TA'ed by Mr. Mulla (student investigator).
Construction Apprenticeship students will be recruited from the program affiliated with our IHSA partner.
10.2 Who will recruit each type of participant?
Project researchers Dr. McKinnon and Mr. Mulla will recruit participants.
10.3 What are the relationships (if any) between the investigator(s) and participant(s)? Select all that might apply:
Instructor (Teaching Assistant)-Student
Manager-Employee
Family Member
Friend(s)
Student Peers
Fellow Club Members
No Relationship
Business/Work Colleagues or Clients
Other
10.4 Will you require permission to conduct any of the above recruitment strategies? (e.g., permission from an employer to recruit
employees on site).
Yes
No
10.7 Identify the documents that will be used during recruitment (select all that apply):
Recruitment poster
Study information or brochure
Video/audio recording
Social media / Online advertisements
SONA ad
Verbal / Telephone script
Email script (sent direct to participant)

Email script (sent from holder of participant contact)
Recruitment for follow up interview
Snowball recruitment script
Reminder email/script
Appreciation letter/certificate/thank you card
Not Applicable (e.g. study only involves secondary use of data)
Other

Participant Recruiting Methods

10.7.2 Upload your recruitment poster(s). Please upload PDFs only.

Type Document Name File Name Version Date Version Size
Recruiting Materials McKinnon_1754_Recruitment poster_v1 McKinnon_1754_Recruitment poster_v1.pdf Feb/05/2019 v1 70.8 KB

10.7.6 Upload your verbal / telephone script(s). Please upload PDFs only.

Type Document Name File Name
Version
Date Version Size
Recruiting
Materials
McKinnon_1754_Recruitment
Script_MAC_v2
McKinnon_1754_Recruitment
Script_MAC_v2.docx
Feb/28/2019 v2
21.5
KB
Recruiting
Materials
McKinnon_1754_Recruitment
Script_CON_v1
McKinnon_1754_Recruitment
Script_CON_v1.docx
Feb/28/2019 v1
21.3
KB

10.8 Will potential participants answer screening questions to determine eligibility to participate in the study?
Yes
No

Research Methods

11.1 Describe sequentially, and in detail all data collection procedures in which the research participants will be involved (e.g.,
paper and pencil tasks, interviews, focus groups, lab experiments, participant observation, surveys, physical assessments etc.
—this is not an exhaustive list). Include information about who will conduct the research (include tasks done by assistants,
translators, transcriptionists etc.), how long it will take, where data collection will take place, and the ways in which data will be
collected (e.g., computer responses, handwritten notes, audio/video/photo recordings etc.).

This study will involve a single laboratory session taking approximately 3 hours to complete. All procedures will be completed by the researchers in the study (Dr. McKinnon and Mr. Mulla). Note that data will be collected with groups of 4 participants. The following procedures will be performed simultaneously for each of the 4 participants.

1. Informed consent form will be completed upon entry into the laboratory. Participant height and weight will be measured and recorded on a data collection spreadsheet. Height will be measured with a tape measure and weight will be measured using a scale.
2. Participants will lay on a padded assessment table, and muscles to be measured with EMG will be palpated by one of the researchers. Participants will be asked to flex certain joints to ensure the location of the specific muscles being tested. Electrodes will be affixed to the skin over the right shoulder, arm, and back to record muscle activity for the anterior deltoid, upper trapezius, biceps brachii, and erector spinae. The electrodes will be taped down using tape. These areas will be shaved with a new, disposable razor and cleaned off with alcohol prior to the application of the electrodes. These procedures are required to obtain a high quality signal.
3. Participants will be asked to perform a series of maximum voluntary exertions where they will be asked to maximally perform a

specific contraction that will be used to normalize EMG signals. Participants will be asked to perform 2 repetitions for each maximal contraction (5 seconds in duration each). Two minutes rest will be given between maximal contractions. During maximal efforts participants will be instructed to not hold their breath, therefore avoiding the increase in blood pressure associated with such a maneuver.

4. Each 4-participant lifting team will perform group lifts of a 60 kg rectangular slab (2 x 4 ft.) and a 60 kg square slab (2 x 2 ft.). Participants will be positioned at the four corners of the slab, and perform a vertical group lift from 15 cm above ground level. Each team will perform 10 lifts with each slab (20 total lifts) with 4 trials designated as "release" trials.

Release trials: the experimenters will instruct each participant to release the load on a single, designated trial (4 total release trials). Lifters will not know which trial other lifters have been assigned to as their release trial. Verbal cues will be given by an experimenter to coordinate timing of the lift, participants will lift and balance the load for 5 seconds, and then a visual cue will instruct the designated participant to release their corner of the slab. The remaining 3 participants will be required to hold and balance the load for an additional 15 seconds. Upon completion of the trial, experimenters will assist in returning the load to the ground level position.

Non-release trials: all remaining (16) trials will not involve a release in an effort to simulate a sudden, unexpected response during release trials. Participants will lift and balance the load for 20 seconds, and return the load to the ground level position.

5. Participants will rest for 5 minutes between lifting trials to mitigate fatigue effects.

6. EMG electrodes will be removed. Alcohol can be used to remove any tape residue, if desired.

11.2 Describe your data analysis methods, (e.g. statistical analysis, textual analysis, NVIVO, etc.)?

Mean and peak surface EMG values will be calculated for each lift (release trials) during 3 separate time frames: (1) 3-second window prior to load release during which all 4 team members are holding the load steadily at baseline, (2) 3-second window immediately following the load release, and (3) 3-second window once the load lifted is stabilized by the remaining 3 team members (i.e. forces from the hand-loads reach a steady-state).

Summary data (means and standard deviation) will be calculated for all outcome measures grouped by lifting experience (2 populations: construction trainees, non-trainee university students), slab dimension (2 dimensions: 2 x 4 ft., 2 x 2 ft.), participant location (3 non-release locations), and time of lift (3 time frames of analysis as described above: before release, immediate postrelease, delayed post-release). Mixed-effects models will be used throughout statistical analysis to account for both fixed- and random-effects in order to address the unbalanced repeated measures study design. Assumptions of normality and sphericity will be verified. An alpha value of 0.05 will be set for each statistical procedure. Post-hoc testing will be conducted using a t-test with Sidak's correction for multiple tests. All statistical analysis will be performed using STATA 14.2 (StataCorp LLC, TX, USA).

Types of Research Methodology

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11.3 In addition to describing your methods above, also check the following boxes that apply to study design and the methods used
in this research. The checklist allows for accurate reporting of the types of methods reviewed by MREB. (Check all that apply)

Ethnography/participant observation
Autoethnography
Surveys/questionnaires (paper and pen)
Online Survey
Interviews (face-to-face)
Interviews (telephone / Skype)
Focus groups
Community Engagement
Delphi
Internet research
Participatory action research (CBPR)
Secondary use of data (non-public records and datasets)
Secondary use of data for another research purpose
Chart review (medical records not at HHS or SJHH)
Photovoice
GIS/GPS
Deception
Experiments
Physical assessments/exercise
Auditory tests
EEG/EMG/ECG
Eye tracking
Cortisol
Standardized test instruments (e.g. PANAS)
High Risk test instruments (e.g. Beck Depression Inventory)

Quantitative
Qualitative
Mixed Methods
Survey Research
Pilot study/proof of concept
Cross-sectional
Longitudinal
Randomized
Observational
Pedagogical
Other
11.4 Are you using an online survey tool?
Yes
No
11.6 Are you doing community based research? Click on the info icon to the right for a definition of community based research.
Yes
No

Community Based Research

11.14 Select and upload copies of all questionnaires, interview guides (i.e., lists of questions), tests, or data collection instruments,
etc.
Demographic Form
Instructions for Participants
Interview Guide (for face to face, telephone)
Focus Group Guide (questions for focus group)
Questionnaire or Survey
Rating scales/inventories/assessment instruments
Role-play simulation scripts
Stimuli used to elicit responses
Pictures (or diagrams) of what the participant will experience in the study, such as wearing equipment (e.g. EEG) or doing
physical tasks
Not Applicable (e.g. study only involves secondary use of data)
Other
11.14.11 Upload your Images (photos, diagrams etc.) depicting instruments, equipment, exercises, etc. Please upload PDFs only.
Type Document Name File Name Version Date Version Size
Test Instruments McKinnon_Surface EMG SOP_Feb 2019 McKinnon_Surface EMG SOP_Feb 2019.pdf Feb/05/2019 v1 195.3 KB

Test Instruments and Interview Guides

12.1 In this current research project are you planning to use secondary data that was originally collected for another purpose?
Yes
No

Secondary Use of Data

12.32 Does your research involve the creation and/or modification of a research database (databank) containing human participant
information? A research database is a collection of data maintained for use in future research. The human participant information stored in the research database can be identifiable or anonymous.
Yes
No
A research database is a formal collection of data maintained and administered by you for use in future research by you

and other researchers. This is different from simple data storage of your research data for your own future use. Big Data
or databank projects most likely would need to select Yes but most researchers collecting data can select No. Contact the
ethics office if not sure.

Research Database

This section asks different questions for incentives, reimbursement and compensation as each are considered different
forms of payment.

13.1 Will participants receive an incentive for participation?
Yes
No

13.2 What type of incentive will be provided? (Check all boxes that apply)
Financial
In Kind
Other

13.3 Provide all incentive details for each category of participants.
Participants will receive $10 per hour remuneration for participation in this study (estimated $30 total).

13.4 If participants choose to withdraw, please describe how you will deal with their incentive.
Participants may withdraw from the study at any time without penalty. To do so, they should indicate this to the investigators by saying, "I no longer wish to participate in this study". The data collected before withdrawal may still be used for analysis with the participant's consent. Participants will still be compensated for their time at a rate of $10 per hour.

Incentives

13.5 Will participants be reimbursed for expenses related to participating in the research (e.g., transportation, parking, childcare,
taking unpaid leave from work)?
Yes
No

Reimbursements

The application section of Article 3.2 in the TCPS notes participants should be informed about any compensation they may be
entitled to for research-related injuries. This is only applicable if your study has a genuine likelihood of causing physical injury or
financial harm (e.g. job loss) to participants. This will not apply for most studies reviewed by MREB.

Compensation

13.8 Will participants be entitled to any compensation for research-related injuries?
Yes
No

13.10 Will you keep a payment log?
Yes
No

Payment log

Indicate if the participants might experience any of the following risks:

Risks and Benefits Inherent in the Research

14.1 Physical risks (including any bodily contact or administration of any substance)?
Yes
No

14.2 Describe the physical risks and how the physical risks will be managed or minimized. Include an explanation regarding why
alternative approaches with less physical risk cannot be used.
Minimal risks to participants are anticipated.
Skin sensitivity

Participants may experience mild skin irritation/redness from the adhesive of the electrodes. This is similar to the irritation that may be caused by a bandage and typically fades within 2 to 3 days.
Maximum Voluntary Contraction
Muscle soreness following the MVC trials is possible since participants will be asked to maximally contract certain muscles. This discomfort and soreness is not harmful or long lasting (dissipates within 2-3 days). It is similar to the discomfort experienced after a mild-moderate workout.
Muscle Fatigue
Participants may feel fatigued following the session due to the weight of the slab lift being performed. Participants will be given 5 minutes rest between lifts to mitigate these effects, but may still experience fatigue similar to that following a mild-moderate workout.

Physical Risks

Psychological Risks

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14.3 Psychological risks (including feeling demeaned, embarrassed, worried or upset)?
Yes
No
No psychological risks?
Most research has inherent risks, even if only minimal risks. Consider again whether there are no conceivable psychological risks
(e.g. sensitive questions).
14.5 Social risks (including possible loss of status, privacy and / or reputation as well as economic risks)?
Yes
No
No social risks?
Most research has inherent risks, even if only minimal risks. Consider again whether there are no conceivable social risks (e.g.
where a data breach could affect a participant's status in their community, place of work, etc.).

Social Risks

14.7 Are any possible risks to participants greater than those the participants might encounter in their everyday life?
Yes
No

Risks greater than everyday life

14.9 Do you have a list of community counselling or other support services to give participants if they were to become distressed
during participation in your research?
Yes
No

Community Counselling or Support Services

Deception and Partial Disclosure

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14.11 Is there any deception or partial disclosure involved in this research?
Yes
No
14.20 Discuss any potential benefits to the participants, scientific community and/or society that justify involvement of participants in
this study.
There are no benefits to participants other than the opportunity to be involved in scientific research.

Benefits

14.21 What is your experience with this kind of research? Include information on the experience of all individual(s) who will have
contact with the research participants or their data. If this is student research, include the experience of your supervisor.
Mention your familiarity with: (a) the proposed methods (b) the study population(s) and/or (c) the research topic.
All researchers involved have extensive experience with the procedures and data collection methods in this study. Dr. McKinnon's research background has focused on occupational biomechanics and injury prevention specific to the spine and upper extremity. He has extensive experience in laboratory-based research within the area of occupational biomechanics. Dr. Keir's research program

focuses on occupational biomechanics and ergonomics as it pertains to the prevention of work-related musculoskeletal disorders. Mr. Mulla is Dr. Keir's graduate student and is familiar with all techniques and procedures used in the lab.

Experience with the Research

15.1 Describe the process the investigator(s) will use to obtain informed consent from participants with the capacity to provide
consent. Include details on who will be obtaining consent and plans (if any) for on-going consent. For participants lacking
capacity to consent see the question below.

Participants will complete an on-paper informed consent form upon entering the laboratory. Dr. McKinnon or Mr. Mulla will obtain informed consent from all participants.

Informed Consent

15.2 Do any individuals lack the capacity, in the context of your study, to make an informed choice to participate in the research
(e.g. children, people with cognitive impairments)?

Yes

No

Alternative Consent Processes

15.4 Are you seeking an exception to the requirement that researchers seek consent from participants prior to the collection of
data?

Yes

No

15.6 Describe how consent will be documented. If a written consent form will not be used to document consent then explain why and
describe the alternative documentation (e.g. verbal script and consent log). Even if there is no written consent, participants
should still be provided with a Letter of Information unless it is inappropriate in the context of the study.

Participants will sign an informed consent form.

15.7 Select the documents that will be used in the consent process.

Oral consent log
Oral / telephone consent script
Letter of Information / consent - Participants
Letter of Information / consent - Parent(s)
Letter of Information / consent - Guardian or Substitute Decision Maker
Letter of Information / Assent form - Minors
Online survey consent preamble and implied consent buttons
Letter of Support for Study
Research Agreement
Not Applicable (e.g. study only involves secondary use of data)
Other

15.7.3 Upload your Letter of Information / consent - Participants. Please upload PDFs only.

Type	Document Name	File Name	Version Date	Version	Size
Consent Forms	McKinnon_1754_ Informed Consent Form_v2	McKinnon_1754_ Informed Consent Form_v2.doc	Feb/28/2019	v2	55.0 KB

Documenting Consent

15.8 Will participants be able to learn about the study results (e.g., mailed/emailed brief summary of results in plain language;

posting on website or other appropriate means for this population)?
Yes
No

Providing Participants with Study Results

15.10 Explain how participants will learn about study results:

Participants will be given to option to provide their email on the informed consent form. This email will be used to provide a study results summary following completion of the study.

15.11 Will participants have the right to withdraw from the study during data collection (e.g. during an interview, during a lab session)?
Yes
No

15.11.1 Describe a) how the participants will be informed of their right to withdraw during data collection, and b) the procedures which will be followed to allow participants to exercise this right.

Participants may withdraw from the study at any time without penalty. To do so, they should indicate this to the investigators by saying, "I no longer wish to participate in this study".

15.11.2 Describe a) what will be done with any data collected up to the point of withdrawal, and b) consequences withdrawal might have on the participant, including any effect that withdrawal may have on the participant's incentive/reimbursement or continuation of services (if applicable).

The data collected before withdrawal may still be used for analysis with the participant's consent. Participants will still be compensated for their time at a rate of $10 per hour. This process is detailed on the informed consent form.

15.12 Will participants have the right to withdraw their data from the study after data collection has finished (e.g. after survey submitted, lab session complete)?
Yes
No

15.13 Explain why participants cannot withdraw their data after data collection is complete (e.g. data collection was anonymous).

Upon the completion of the experimental session, participants have already agreed to provide data for the study.

Participant Withdrawal

15.14 Is there a potential of material incidental findings resulting from your research? See the info button for further details (most studies reviewed by MREB will not have incidental findings).
Yes
No

Incidental Findings and Third Party Disclosure

15.16 Is there a reasonable possibility the researcher will obtain information from participants that will require the researcher to break confidentiality and report details to a third party? This could be a legal or ethical requirement (e.g. suspected child abuse, imminent self-harm or harm to others). See the info button for further details.
Yes
No

Confidentiality concerns the responsibility for the protection, privacy and security of information entrusted to researchers.
Anonymity concerns whether participant identities are known or not.
Please check the new MREB Data Storage and Security Tools documents in the Help - Templates menu above, for best practices to secure electronic and hard copy versions of data and study documents.

Management of Study Records

16.1 Are you collecting personal information for administrative purposes during the recruitment, screening or consent phases of the
study and/or to provide participants with incentives, reimbursements or study results? (e.g., name on consent form, email
address, etc.)?
Names and/or contact information might also be collected to link data over multiple data collection sessions, or to contact
participants for follow-up interviews.
Yes
No
16.2 Describe the identifiable personal/contact information that will be collected and the administrative purpose(s) for which this
information is required.
Participant names and email addresses will be collected to schedule experimental sessions. This information will not be linked to any recorded experimental data.
16.3 Describe who will have access to this information. Include people outside of the research team who will have access, or
knowledge of who participated (e.g., focus group participants may know the names of other participants).
Only the identified researchers for this study (McKinnon, Keir, Mulla) will have access to this data.
16.4 If applicable, upload oath of confidentiality document(s). Please upload PDFs only.

Collection of Personal/Contact Information for Administrative Purposes

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16.5 Describe the data security procedures that will be used to keep the information private and secure (including where the
information will be kept). Refer to the McMaster Research Data Management documents for recommendations and requirements for data security (go to Help - Templates in the above menu).
Each participant will be identified by an alphanumeric code instead of his or her name. Consent forms will be scanned, encrypted and uploaded to MacDrive. Original paper copies will be shredded. All other paper and electronic data will be kept for 7 years in a locked cabinet or secured hard drive (password protected), respectively, in a locked room (IWC 212) at McMaster University.
16.6 Are you collecting any research data that directly identifies participants (e.g., audio or video recording) or that could indirectly
identify participants (e.g., a combination of demographic variables - date of birth, postal code, occupation, ethnicity, etc.)?
In this section "research data" refers to information collected from participants for analysis or to describe the sample.
Yes
No
16.7 Do you plan on linking the research dataset with other available datasets that could result in the identification of some
participants?
Yes
No
16.9 Will there be a unique code linking the participant name/contact information to the data? (e.g., for a multi-session study where
data needs to be linked between sessions).
Yes
No
16.11.14 Describe the data security procedures that will be used to keep the research data private and secure during data
collection and analysis (including where the data will be kept). Refer to the MREB Data Storage and Security Tools documents for recommendations and requirements for data security (go to Help - Templates in the above menu).
All paper and electronic data will be kept for 7 years in a locked cabinet or secured hard drive, respectively, in a locked room (IWC 212) at McMaster University.

Confidentiality and Security of Research Data

16.12 Will you be physically transporting or electronically transmitting any research data and/or study related documents outside
McMaster and/or its affiliate institutions? (e.g., audio recordings, questionnaires, interview transcripts, signed consent forms,
etc.)
Yes
No

Transfer/Transport of Study Records

16.20 How will the data from study participants be reported in the dissemination of research results (e.g., aggregated data,
identifiable descriptors, de-identified descriptors, etc.)
Only aggregate summary data will be used, no individual data is expected to be presented in dissemination of research results.
16.21 Does your study include documents, other than research data, that can identify participants (e.g., consent forms, participant
contact information)?
Yes
No
16.22 State how long you plan to retain study-related documents that identify participants (e.g., consent forms, contact information).
7 years
16.23 Provide the rationale for the retention length of identifiable study-related documents.
Standard time frame for data retention
16.24 State how long you plan to retain your research data (e.g., interview transcripts, survey answers, EEG readings, etc.).
7 years
16.25 Provide the rationale for the retention length of research data.
Standard time frame for data retention
16.26 Will you be retaining identifiable and/or coded research data long-term (i.e. beyond the initial data analysis phase)? Coded
data refers to a de-identified data set that can be re-identified with a document linking participant ID numbers to names.
Yes
No
16.27 State at what point the data will be anonymized, or specify if the data was anonymous at the point of collection (e.g. an
anonymous online survey).
The data will be anonymous at the point of collection by using only an alphanumeric participant ID.

Dissemination of Findings and Final Disposition of Study Records

16.29 Will longer term storage procedures used for keeping research data or study related documents secure differ from the
storage procedures used during data collection and initial analysis described in the above sections?
Yes
No
16.31 Do you have plans to have identifiable data professionally archived?
Yes
No
16.33 Will someone other than the Principal Investigator be retaining the study data? In the case of student research, will someone
other than the Student Investigator and/or Faculty Supervisor be retaining the data?
Yes
No
16.36 Do you plan to post raw data to a database accessible by other researchers and/or the general public?

Yes
No
18.1 Do you have any additional information or documents relevant to this project that you wish to provide to the Research Ethics
Board?
Yes
No

Additional Information

18.4 Public posting your research title
It is the policy of MREB to post a list of cleared protocols on the Research Ethics website. Posted information usually includes: title,
name of principal investigators, principal investigator department, type of project (i.e. Faculty; PhD; Masters, Undergraduate etc.)
Do you request that the title be deleted from the posted information?
Yes
No

Posting of Approved Protocols on the Research Ethics Website

Principal Investigator Assurance(s)

A MacID is required to sign the form. A temporary MacID can be obtained for an external Principal Investigator. Contact the
ethics office at x23142 or ethicsoffice@mcmaster.ca.
20.3 Student Investigator Assurances
I understand that the following all constitute violations of the McMaster University's Research Integrity Policy:
failure to obtain research ethics clearance;
carrying out research in a manner that was not cleared by one of the university's REBs (see TCPS, Art. 6.11);
failure to submit an Amendment to obtain ethics clearance prior to implementing substantive changes to a cleared study (see
TCPS, Art. 6.16);
failure to submit an Annual Report in advance of the yearly anniversary of the original ethics clearance date; (see TCPS, Art.
6.14).
Additionally, researchers are required to report Adverse Events (i.e., an unintended negative consequence or result affecting
participants) to the MREB secretariat and the MREB Chair as soon as possible, and no more than 3 days after the event occurs (see
TCPS, Art. 6.15). A privacy breach affecting participant information should also be reported to the MREB secretariat and the MREB
Chair as soon as possible. The Reportable Events form is used to document adverse events, privacy breaches, protocol deviations
and participant complaints.
I confirm that I have read the McMaster University Research Integrity Policy, and I agree to comply with this and other university
policies, guidelines and the Tri-Council Policy Statement (TCPS) and the guidelines of my profession or discipline regarding the
ethical conduct of research involving humans.
20.4 Signature of Student Investigator (Student Principal Investigator) for Supervised Projects
S igned : Th is fo rm was s igned by Daan ish Mu l la (mu l ladm@mcmas te r .ca) on Ma r /06 /2019 1 :30 PM
This form is enabled to auto-submit after all signatures have been obtained. Before signing, please make sure that all
uploaded documents are in PDF format. If you have a unique document type that will not properly convert to PDF, please
contact the ethics office for assistance.
20.5 I am the supervisor for this proposed student research and have read this ethics application and supporting documents and

deem the project to be valid and worthwhile. I will provide the necessary supervision of the student researcher(s) throughout
the project, will ensure that the project will be conducted as cleared, and will make myself available should problems arise
during the course of the research.
This form is enabled to auto-submit after all signatures have been obtained. Before signing, please make sure that all uploaded documents are in PDF format. If you have a unique document type that will not properly convert to PDF, please
contact the ethics office for assistance.

Supervisor Assurance for Graduate or Undergraduate Student Research:

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20.6 Signature of Faculty Supervisor of Student Research
S igned : Th is fo rm was s igned by Pe te r Ke i r (p jke i r@mcmas te r .ca) on Ma r /06 /2019 12 :47 PM
Supervisors must be registered with MacREM (have logged in with MacID at least once) before they can sign. Make sure
the supervisor has logged into MacREM before you Request their signature. Also click the Share tile to give supervisors permissions to access the form.

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Appendix E: Post-hoc Results

Table 5. Post-hoc results using the Bonferroni correction comparing vertical force means from the pre-drop phase (3a) to the 3-lifter steady state phase (4) by lifting position for both configurations (2 x 2 ft. and 2 x 4 ft.). Values are organized by phase number and lifter position.

Config.	Position	3a-Left	3a-Opposite	3a-Right	4-Left	4-Opposite
2 x 2 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Right	1.00	1.00	-	-	-
	4-Left	2e-5	4e-5	4e-5	-	-
	4-Opposite	0.06	0.03	0.03	2e-10	-
	4-Right	4e-5	1e-4	1e-4	1.00	4e-10
		3a-Long Adj.	3a-Opposite	3a-Short Adj.	4-Long Adj.	4-Opposite
2 x 4 ft.	3a-Opposite	0.48	-	-	-	-
	3a-Short Adj.	1.00	0.391	-	-	-
	4-Long Adj.	0.08	4e-5	0.10	-	-
	4-Opposite	4e-5	0.07	3e-5	2e-10	-
	4-Short Adj.	6e-6	8e-10	8e-6	0.09	2.9e-15

Table 6. Post-hoc results using the Bonferroni correction comparing bicep muscle activity means from the pre-drop phase (3a) to the 3-lifter steady state phase (4) by lifting position for both configurations (2 x 2 ft. and 2 x 4 ft.). Values are organized by phase number and lifter position.

Config.	Position	3a-Left	3a-Opposite	3a-Right	4-Left	4-Opposite
2 x 2 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Right	1.00	1.00	-	-	-
	4-Left	9e-5	1e-4	8e-5	-	-
	4-Opposite	1.00	1.00	1.00	4e-5	-
	4-Right	1.00	1.00	1.00	4e-4	1.00
		3a-Long Adj.	3a-Opposite	3a-Short Adj.	4-Long Adj.	4-Opposite
2 x 4 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Short Adj.	1.00	1.00	-	-	-
	4-Long Adj.	0.47	0.22	0.71	-	-
	4-Opposite	1.00	1.00	1.00	0.03	-
	4-Short Adj.	0.21	0.09	0.34	1.00	0.01

Table 7. Post-hoc results using the Bonferroni correction comparing anterior deltoid muscle activity means from the pre-drop phase (3a) to the 3-lifter steady state phase (4) by lifting position for both configurations (2 x 2 ft. and 2 x 4 ft.). Values are organized by phase number and lifter position.

Config.	Position	3a-Left	3a-Opposite	3a-Right	4-Left	4-Opposite
2 x 2 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Right	1.00	1.00	-	-	-
	4-Left	3e-4	1e-4	2e-5	-	-
	4-Opposite	1.00	1.00	0.61	0.06	-
	4-Right	1.00	1.00	1.00	8e-5	1.00
		3a-Long Adj.	3a-Opposite	3a-Short Adj.	4-Long Adj.	4-Opposite
2 x 4 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Short Adj.	1.00	1.00	-	-	-
	4-Long Adj.	1.00	1.00	1.00	-	-
	4-Opposite	1.00	1.00	1.00	1.00	-
	4-Short Adj.	1.00	1.00	1.00	1.00	1.00

Table 8. Post-hoc results using the Bonferroni correction comparing upper trapezius muscle activity means from the pre-drop phase (3a) to the 3-lifter steady state phase (4) by lifting position for both configurations (2 x 2 ft. and 2 x 4 ft.). Values are organized by phase number and lifter position.

Config.	Position	3a-Left	3a-Opposite	3a-Right	4-Left	4-Opposite
2 x 2 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Right	1.00	1.00	-	-	-
	4-Left	1e-3	1e-3	9e-4	-	-
	4-Opposite	1.00	1.00	1.00	4e-4	-
	4-Right	1.00	1.00	1.00	3e-3	1.00
		3a-Long Adj.	3a-Opposite	3a-Short Adj.	4-Long Adj.	4-Opposite
2 x 4 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Short Adj.	1.00	1.00	-	-	-
	4-Long Adj.	1.00	1.00	1.00	-	-
	4-Opposite	1.00	1.00	1.00	1.00	-
	4-Short Adj.	0.02	8e-3	0.02	0.24	9e-3

Table 9. Post-hoc results using the Bonferroni correction comparing lumbar erector spinae muscle activity means from the pre-drop phase (3a) to the 3-lifter steady state phase (4) by lifting position for both configurations (2 x 2 ft. and 2 x 4 ft.). Values are organized by phase number and lifter position.

Config.	Position	3a-Left	3a-Opposite	3a-Right	4-Left	4-Opposite
2 x 2 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Right	1.00	1.00	-	-	-
	4-Left	1.00	1.00	1.00	-	-
	4-Opposite	1.00	1.00	1.00	1.00	-
	4-Right	0.09	0.12	0.08	0.20	0.02
		3a-Long Adj.	3a-Opposite	3a-Short Adj.	4-Long Adj.	4-Opposite
2 x 4 ft.	3a-Opposite	1.00	-	-	-	-
	3a-Short Adj.	1.00	1.00	-	-	-
	4-Long Adj.	1.00	0.40	1.00	-	-
	4-Opposite	1.00	1.00	1.00	0.02	-
	4-Short Adj.	0.68	0.10	0.56	1.00	4e-3