THE EFFECT OF UNILATERAL LOAD CARRIAGE ON THE MUSCLE ACTIVITIES OF THE TRUNK AND LOWER LIMBS OF YOUNG HEALTHY MALES DURING GAIT

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ABSTRACT

The aim of the study was to examine the effect of unilateral hockey bag load carrying of different weight and sizes on the trunk and lower limb muscle activities. Three differently massed loads (10%, 20%, and 30% bodyweight) and two sizes of hockey bags (small and large) were investigated through trunk and lower limb electromyography (EMG). Walking without a hockey bag was the control condition. Fifteen male participants (aged 23.44 ±2.63 years) underwent a quantitative EMG measurement of the trunk and lower limbs and temporospatial kinematics using surface EMG and 3D motion analysis systems during their 8 m walk while carrying a hockey bag over their right shoulder. The results showed that double support time and stride width increased, while stride length decreased as the load of the hockey bag increased. Increased peak and integrated EMG occurred with an increased load weight in the semitendinosus, gastrocnemius, rectus abdominis, and vastus medialis. The left rectus femoris and left semitendinosus were both significantly greater than the right corresponding muscle. Carrying the large hockey bag produced greater peak EMG in the right rectus abdominis and the right rectus femoris, whereas the right vastus medialis showed a larger peak EMG in the small hockey bag during the 30% body weight load condition. It was concluded that, like backpack load carriage; hockey bag load carriage produced an increased peak EMG in the rectus abdominis. While significant increases in the left side, when compared to the right, reflects results from many side pack load carriage studies. The style of load carriage of hockey bags is different than just simply 'unilateral' or 'bilateral', but as the results indicate, a combination of the two styles.

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CHAPTER 1: INTRODUCTION

Background to the study

Load carriage is seen in the form of backpacks, side packs, and front packs. There is proof that these types of load carriage alter the gait, posture biomechanics, and muscle activities of the human body (Cook & Neumann, 1987; Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006; Knapik, Harman, & Reynolds, 1996; Motmans, Tomlow, & Vissers, 2006). Many studies indicate that the more drastic and perhaps the more injury prone method of load carriage is unilateral (side pack) carrying (DeVita, Hong, & Hamill, 1991; Fowler, Rodacki, & Rodacki, 2006; Motmans, Tomlow, & Vissers, 2006).

Unilateral Load Carriage

Carrying loads unilaterally, that is, carrying loads over one shoulder or in one hand, is a method of carrying that has become quite popular. This technique in carrying is commonly seen in students, postal workers, business workers, shoppers, and sports enthusiasts with their equipment. Sports such as tennis, golf, boxing, football, soccer, baseball, and ice hockey all require participants to carry their equipment to the field of play for the amateur and recreational athlete. More often than not, the equipment bags to these sports are carried unilaterally. Of particular interest is the sport of ice hockey and the hockey bag that players carry to and from the arena. Ice Hockey includes full body protective equipment for the player and the hockey bags in which the equipment is carried can be heavy and even heavier for the goaltenders that play the game. The hockey bag, when full of equipment, is large in volume and weight. Its weight is considerably more than the bags of tennis, football, and other sports.

Hockey in Canada

Hockey in Canada is an iconic symbol for the nation. Canada's identity to people from elsewhere in the world is often related to the sport of hockey. Being our national sport and with 577,077 registered players, more than any other country, it can be argued that Canada plays the game more often when compared to the rest of the world (Hockey Canada, 2010). Much research in hockey is devoted to improving the safety of the on-ice play of the game. This research includes improving equipment, on-ice materials, and rules, but little investigation has been devoted to safety off-ice, such as the heavy, unilateral load carriage it takes to bring the equipment to the arena (Rousseau, Post, & Hoshizaki, 2009; Weekes, 2005; St. Michael's Hospital, 2011).

The Hockey Bag

In a recent survey of 33 participants held at the University of Ottawa, Sports Complex arena, it has been found that male and female, university-aged students between 19-23 yrs. (avg. = 20.63 ± 1.53) when compared to their male and female older counterparts aged 26-57 (avg. = 40 ± 8.92) carry heavier hockey bags (18.77% BW ± 5.13% compared to 17.94% BW ± 4.76%) over one shoulder and walk further distances (641.67 m ± 687.67 m compared to 211.11 m ± 92.8 m) (Corrigan, Law, & Law, 2010). In the same survey, the maximum weight of a hockey bag that had been recorded was by a 21-year old, male, goaltender with a weight that equaled to 33.29% of his total body weight. In the survey, males were, on average, playing hockey more often during the week and for more months of the year than their female counterparts. This makes the males under heavier loads more frequently and perhaps more exposed to the affects of hockey bag unilateral load carriage. According to HockeyCanada.com, 85.16% of the 577 077 registered players are male (Hockey Canada, 2010). The load-weight carried by the college-aged and male population may make them more susceptible to the chronic back problems as mentioned by Perez (Perez, 2000).

The survey also examined the hockey bag dimensions and discovered the bags ranged in volume from 0.085 m^3 to 0.36 m^3. However, the volume of the hockey bag was not correlated with bag weight. This result indicates that hockey players were carrying heavy loads in both small and large bags.

The importance of this survey is that it reveals characteristics of the hockey bag and about the people who carry them. These characteristics include: unilateral carriage, large weight, varying sizes of bags independent of load weight and that the people carrying the hockey bags the furthest distances are those who are aged 19-23 years. The last point may be significant as they are exposed to a unilateral load for a longer period of time, perhaps increasing the chance of injury. In a study done in 2003 (Mackie, Legg, & Hedderley, 2003), school students have an initial preference for a school bag based on it's 'style and image' and that this thought changes with time to selecting a bag with more 'function and fit'. This theory may describe why there are more, young hockey players carrying hockey bags unilaterally and more older hockey players rolling bags with wheels. It should also be noted that during hockey bag load carriage there is a tendency to have the bag lay posterior-laterally and just above the hip, something that is seen in all participants of the study. For this reason, unilateral and bilateral studies were researched to aid in the formulating of hypotheses.

Hockey Bag: Load-Weight Effects

When carrying the equipment for hockey, the gait and posture are often altered to counter for the added weight. This unnatural gait allows for large forces to act asymmetrically on the spinal column and lower limbs. These types of forces may be hazardous to the musculoskeletal system, in that it creates tension on the muscles and tissues of one side of the body while compressing the tissues on the opposite side. It is also found that during play in hockey, participants perform repetitive or continuous forward trunk flexion. This particular movement in addition to the chronic and repetitive forward flexion with load carriage may be a product of back problems (Mountain, 2002; Baranto, Hellstrom, Cederlund, Nyman, & Sward, 2009). Load carriers in hockey will carry their equipment twice for any given practice or game. The times they are carrying differ in the amount of fatigue they; before play with little fatigue and after play with more fatigue. According to McGill, lower back injuries can result from accumulated trauma produced by either a repeated application to a relatively low load or the application of a sustained load for long duration (McGill, 1997).

Carrying a hockey bag to the local arena and then to participate in play which is largely in a bent-over position leaning over the hockey stick, may leave tissues of the back to be, in what McGill calls, sub-failure level. The sub-failure level may lead to a slow degradation to the tolerance the tissue can withhold before rupture (McGill, 1997). Tissue damage along the spinal column due to repetitive or over-forceful use of the muscles of the back can lead to a back injury.

It has been estimated that between 70% and 85% of the population will have a back problem in their lifetime, a number of which being chronic back problems (Andersson, 1999). In the study done by Claudio Perez, of Statistics Canada, more than 1 million Canadians developed chronic back problems between the years of 1994/1995 and 1996/1997 (Perez, 2000). In the same study, it was also found that one of the factors for chronic back problems can be a previous acute back injury or heavy exertion (Perez, 2000). With the large interest of hockey in Canada and the high incidence of back injuries and back problems among Canadians, it is important to investigate the changes in posture from carrying hockey bags. However much research will be needed to further explore load carriage and it's effect on back injuries and is not the primary goal of this study.

Hockey Bag: Size Effects

The effects of load size are not as clear as the effects of the load-weight of unilateral load carriage. Little evidence exists on the volume of the container (or bag) and its influence on the biomechanics of gait and posture in unilateral carrying. One study by Gillette examined different bucket sizes during unilateral and bilateral carrying in farm children and adult farmers (Gillette, Stevermer, Miller, Meardon, & Schwab, 2010). The unilateral carrying task involved carrying the small and large bucket, and the bilateral carrying task involved just carrying the small buckets. Gillette's focus was to study the effects of age of the load carrier, symmetry of load (unilateral or bilateral), size of the bucket (small and large), and load weight [0% body weight (BW), 10% BW, & 20% BW]. The bucket sizes yielded no significant results in joint range of motion (ROM) and maximum joint angles. Therefore, no conclusion from the study done by Gillette on container size can be reached. To author's knowledge, the effects of volume size during unilateral load carriage has yet to be determined.

Summary

To author's knowledge published biomechanics studies in unilateral load carriage have not looked at the biomechanical responses to carrying a relative weight of greater than 20% body weight. Yet, carried hockey bags can be up to 33.29% of body weight of hockey players (Corrigan, Law, & Law, 2010). For most people, when carrying a hockey bag, they will carry it in a posterior-lateral position over one shoulder. While side, front, low back, and high back have all been researched; the posterior-lateral technique has yet to be studied. Furthermore, another gap in load carriage study that has been missing from research is the impact of size of the bag on biomechanical responses, and how these two independent variables may affect the gait of the carrier. And finally, little is known about the muscle activity during unilateral load carrying, let alone posterior-lateral carrying, during walking. Therefore a comprehensive study on the temporospatial kinematics and muscle activities of walking while carrying a hockey bag will enhance our understanding of the impact of carrying a heavy and large dimension hockey bag, and a new form of unilateral load carriage on gait and posture.

Key Terms

Load Carriage - Refers to the gait or standing posture, while carrying a load in a pack either unilaterally or bilaterally.

Unilateral Load Carriage - The carrying of a pack, either during gait or static standing posture on one sagittal side of the body. The load can be carried by hand, on shoulder, or across body.

Bilateral Load Carriage - The carrying of a pack symmetrically. Either using both shoulders or hands to carry the load in static standing or during gait. This method is different than the anterior pack (which is a load placed in front of the participant). It is to be assumed that bilateral load carriage refers to the posterior form of load carriage.

PURPOSE

The purpose of the study was to examine the impact of unilateral carrying of a hockey bag during level walking on the muscle activities of the trunk and lower limbs. The secondary purpose was to form an understanding on the relationship of load-weight and volume size of a hockey bag on the biomechanical responses of the trunk and lower limbs.

VARIABLES

Independent Variables

The independent variables were load weight and bag size. Three different load weights of 10%, 20%, and 30% of the body mass of each subject were used for testing. The hockey bag sizes of small (0.11 m^3) and large (0.36 m^3) were tested. The small hockey bag resembled more of a recreational player's hockey bag, whereas the large bag resembled that of the goaltender's hockey bag. The loads were compared to the control of walking with out a bag.

Dependent Variables

a) Temporospatial variables

The temporospatial gait parameters were stride length (m), stride width (m), and double and single support time (%). Temporospatial parameters provide knowledge about balance during the gait. It has been suggested that the stride length is a measure related to patterns in gait and stride width and double support time are related to a balance control mechanism during locomotion (Gabell & Nayak, 1984).

b) Peak EMG

Peak electromyography (EMG) was calculated as the highest value of a particular muscle against one gait cycle. The peak EMG were normalized to the control condition and represented as a percent of the control.

c) Integrated EMG

The integrated EMG was the total area under the curve of a particular muscle against one gait cycle.

INDEPENDENT VARIABLES	
Category	Description
Load Weights	0% BW 10% BW 20% BW 30% BW
Hockey Bag Size	Small (0.11 m^3) Large (0.36 m^3)

DEPENDENT VARIABLES	
Category	Description
Temporospatial	Stride Length (m) Stride Width (m) Double Support Time (%) Single Support Time (%)
Peak EMG	Highest Value divided by the highest value of the control
Integrated EMG	Area under the curve of one gait cycle normalized to peak of the control (mV•s)

Table 1: Independent and dependent variables of interests

HYPOTHESIS

Load Effect

As seen with the kinematics in bilateral packs during gait, unilateral load carriage has shown: swing phase decreased (Kinoshita, 1985; Martin & Nelson, 1986; Choi, Hwang, Choi, Kim, & Yi, 2007; Ozgul, Akalan, Kuchimov, Uyger, Temelli, & Polat, 2011), stride length decreased (Crosbie, Flynn, & Rutter, 1994; Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Martin & Nelson, 1986), velocity decreased (Crosbie, Flynn, & Rutter, 1994), and increases in cadence and double support time (Choi, Hwang, Choi, Kim, & Yi, 2007; Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Crosbie, Flynn, & Rutter, 1994; Ozgul, Akalan, Kuchimov, Uyger, Temelli, & Polat, 2011). These changes in kinematics tend to differentiate more in their respected experimental settings as load weight increase.

Research done by Motmans on the muscle activity of the rectus abdominis and erector spinae during the different types of load carriage have shown that unilateral load carriage produces significant differences between the left and right rectus abdominis. Greater muscle activation has been shown in the rectus abdominis of the unloaded side when compared to the loaded rectus abdominis. The erector spinae also showed significant differences between the left and right, again with the stronger activation on the non-carrying side (Motmans, Tomlow, & Vissers, 2006). In backpack carriage, the peak activation of the erector spinae show a greater decrease when compared to an unloaded reference, while the rectus abdominis peaks are much greater (Al-Khabbaz, Shimada, & Hasgawa, 2008; Cook & Neumann, 1987; Bobet & Norman, 1984).

The gastrocnemius muscles have shown to increase in peak activity in backpack loading (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Norman, 1979), as well as in the integrated EMG (iEMG) (Simpson, Munro, & Steele, 2011). Also in backpack loading, the quadriceps shows mixed results with no increases and significantly increases in activity (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Norman, 1979) with an increase in load. Harman et al. (1992) discovered the hamstrings were not significantly different than when compared to no load. However in the recent study by Simpson (2010), hamstrings did show an increase in burst activity and burst duration in female hikers carrying a backpack of up to 40% BW.

In comparison with the control condition of no load, when weight of the load is increased:

a) Stride length will decrease

b) Stride width and double support will increase

c) Peak EMG of the rectus abdominis, and peak and iEMG of the gastrocnemius will increase

d) Peak erector spinae will show no significance or decrease with added weight, but show increases in peak EMG in the non-carrying side in unilateral load carriage.

e) Quadriceps and hamstrings muscles have showed mixed results, but it is hypothesized in this study that increases in peak and iEMG may occur because of the high load weight.

Size Effect

As previously mentioned, little is known on the effects of volume and more importantly load-body displacement during unilateral load carriage. It is assumed that a larger bag will increase the difficulty of the carriage task and affect the balance and posture of the participants. Results similar to those found in a study by Lee and Li on the combined effect of load carriage and high-heeled walking can be anticipated (Lee & Li, 2011). The high-heeled shoes increase difficulty of requiring balance during unilateral load carriage and this is especially prevalent in the temporospatial parameters. It is assumed the larger bag will decrease stride length and increase double support time.

RATIONALE

The rationale behind this study is to add to the understanding of the biomechanical responses in the unilateral carrying. As well, this research can be a basis in formulating new knowledge on the combined effects of container size and load, as well as posterior-lateral load carriage.

Hockey is a popular past time for many Canadians young and old, education and proper technique on carrying their hockey bag should be determined and reviewed to help in eliminating any negative effects resulting from carrying a load improperly. Increasing the knowledge towards the effects unilateral load carriage has on the biomechanics of the human body can help provide a better means into the development of more ergonomic hockey bags.

LIMITATIONS

In order to achieve the temporospatial kinematic data, anatomical landmarks must be located. Due to human error, it may be difficult to place markers on the exact same spot in any two separate trials (Pohl, Lloyd, & Ferber, 2010). Placement of markers on the skin (ankle malleoli) or shoes may show inaccurate readings as well, as the over lying tissue of skin or material will move over bones and joints. The computer will pick this up as segment or joint movement, when in actuality it is just the surface layer gliding (Leardini, Chiari, Della Croce, & Cappozzo, 2005). It has been suggested that the largest amount of kinematic noise results from underlying muscle firing and the inertia effects of the marker on the soft tissue upon foot strike (Taylor, Ehrig, Duda, Schell, Seebeck, & Heller, 2005).

Surface electromyography sensors share similar limitations as the anatomical markers, in that placement may vary between participants in locating the most accurate spots for reading. The distance between the active fibers and the electrode detections surface will vary among subjects (i.e. adipose tissue, thicker dermis layer) and therefore alter the amplitude and frequency of the signal (De Luca, 1997). Other limitations with EMG include fiber type composition, blood flow in the muscle, and fiber diameter (De Luca, 1997). All of which may affect the amplitude and conduction velocity. Noise and interference from other under/overlying muscles can also affect readings. Determining gait cycle was done visually to the judgment of the researcher with the help of 3-dimensional capture of the heel, toe, medial and lateral malleoli. Force platforms were used to help in distinguishing foot strike and toe off.

Other limitations include laboratory settings such as a smooth floor surface, which may not be empirical to the hockey player who commonly carries their equipment over sidewalks, bumps, snow, and gravel. The composition of the bag used during testing was not filled with equipment, but rather styrofoam and metal weights so that the correct mass and volume of the bag can be achieved. Finally, fitness level, weight, height, and experience carrying hockey bags may have altered the results among participants, but was accounted for in a pre-examination questionnaire.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction

Hockey bags have evolved over the years so that they can be carried bilaterally over both shoulders or wheeled like that of an airplane luggage bag. Problems with the wheeled and bilateral bags however, are that there exists a social stigma towards carrying these types of hockey bags. According to a recent survey, many hockey players believe hockey is a physical game involving tough players and their reactions to wheeled bags and backpack-styled bags are that they do not give that intimidating hockey player appearance (Corrigan, Law, & Law, 2010; HF boards, 2009). In the present study, a questionnaire took place just prior to the experiment. Among some of the questions was the question, “Why don’t you use a wheeled hockey bag?” Some of the responses included the inflicted image that it would cast off, the malfunctioning of the wheeled bag, and the cost comparison between the wheeled bag and the unilateral bag. A diagram of the results from the questionnaire can be seen in “Appendix B”. Functional problems that associate with the backpack-styled hockey bag are that it does not allow for easy packing and there is a challenge when trying to fit all of a player’s gear in the bag, especially for the goaltenders. Lifting a bilateral hockey bag involves throwing the body off balance, trying to swing it to the other shoulder to get the strap on. A mechanical problem associated with the wheeled hockey bag occurs when there is snow or dirt stuck in the wheels causing them to stop rolling. Also, the imbalance of the wheeled hockey bag creates the bag to topple over anytime stairs or uneven terrain is met. The wheels for these bags add extra weight requiring more work when it is needed to carry them.

Aside from hockey, carrying bags unilaterally has become popular for students in school and it can also allow easier access to grab objects out of the bag with the free arm. For this reason, the postal service will equip their postal workers with unilateral bags so that they can easily access the mail out of their bag. Unilateral load carriage can be seen everywhere around us, in grocery stores carrying groceries in a basket, shopping malls and stores designing a bag to be carried by only one hand, business workers carrying their laptop bags over their shoulder, carrying purses, carrying gym bags, and of course carrying sports equipment.

The biomechanical studies involving unilateral load carriage vary in how the load is carried. Some by hand, over shoulder, or across body but one common attribute of unilateral experiments is the tendency of using loads that tend to weigh less than the loads we typically see studied in bilateral studies. Perhaps in most cases during our every-day-activity the loads that are carried on one side of the body are not as heavy as many of the bilateral loads we carry, but the hockey bag proves to contrast this idea, especially for the goalies who have shown to carry loads of up to 33% body weight (Corrigan, Law, & Law, 2010).

Currently, there has been no research on the biomechanics of carrying hockey bags or unilateral bags of comparable weight and bag size, or carriage in the posterior-lateral position; however the biomechanical behavior may be similar to some of the previous bilateral and unilateral load carriage studies that are discussed in this paper.

2.2 Bilateral packs

Previous Load carriage studies have been done on loads with bilateral straps and primarily focused on soldiers, hikers, and students. Aims of improving carrying techniques (Birrell & Hooper, 2007) and establishing recommendations on load weight (Simpson, Munro, & Steele, 2011; Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006) are the main purposes of these studies as well as answering why carrying loads this way can create back pain or other injuries. Bilateral back pack studies are known to experiment with a variety of differently massed loads ranging from 10% of the subject's body weight (Al-Khabbaz, Shimada, & Hasgawa, 2008) in school bag studies to as high as 70% BW (Birrell & Hooper, 2007) as seen in the loads of soldiers. The studies on bilateral load carriage branch off into physiological and biomechanical streams (Knapik, Harman, & Reynolds, 1996). In this paper, the focus will be chiefly on biomechanical studies.

2.3 Bilateral packs – Temporospatial Kinematics

Many of the biomechanical experiments on bilateral load carriage study the movement during a subject's gait (Tilbury-Davis & Hooper, 1999; Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006)or in static standing (Al-Khabbaz, Shimada, & Hasgawa, 2008) to examine the kinetics and kinematics of the musculoskeletal system. The changes in the kinematics of the head, cervical vertebrae, shoulder (Chansirinukor, Wilson, Grimmer, & Dansie, 2001), trunk (Knapik, Harman, & Reynolds, 1996; Al-Khabbaz, Shimada, & Hasgawa, 2008; Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Simpson, Munro, & Steele, 2011), hip (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006), and lower limb during walking with a load have been reported (Tilbury-Davis & Hooper, 1999). It has been found that during gait with bilateral load carriage and load weight increase, the double support time increases (the phase when both feet are in contact with the ground) (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992), swing phase decreases (Kinoshita, 1985; Martin & Nelson, 1986), stride length decreases, (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Kinoshita, 1985; Martin & Nelson, 1986) and step frequency increases (Knapik, Harman, & Reynolds, 1996). Smith also noticed an increase in double stance time as load increased when he compared 7 obese subjects and 16 healthy weight subjects in evenly distributed load walking (Smith, Roan, & Lee, 2010). Injuries, such as disc hernias, disc avulsion, and vertebral fusion leading to a lack of spine mobility, MCL and ACL ruptures, and foot over-pronation, has been shown to be similarly linked with load carriers and obese individuals (Dalen, Nilsson, & Thorstensson, 1978; Knapik, Reynolds, Staab, Vogel, & Jones, 1992; Must & Strauss, 1999). In Smith's study, the comparison was between obese load carriers (body mass index [BMI]> 25 kg/m^2) and normal weight carriers (BMI< 24.99 kg/m^2). Between both groups, there is an increase in total hip flexion and knee flexion post heel contact. This is suggested to be a stability mechanism, bringing the body lower to the ground in an effort to control the balance offset from the load (Kinoshita, 1985; Tilbury-Davis & Hooper, 1999; Martin & Nelson, 1986). As well from this study, there was an increase in trunk flexion to translate the center of gravity forward so that it is properly aligned for better balance (Knapik, Harman, & Reynolds, 1996; Al-Khabbaz, Shimada, & Hasgawa, 2008; Simpson, Munro, & Steele, 2011). When obese load carriers and normal weight load carriers were compared, only hip range of motion (ROM) increased significantly in the obese, leading to a greater vertical range of motion in the obese.

From this information, when experimenting on load carriers it is important to keep measure of all subjects BMI and to assess results in accordance.

Al-Khabbaz observed trunk movement through all three planes (sagittal, transverse, and frontal) during static trials of unloaded, 10 % BW, 15% BW, and 20% BW in 19 university aged males (21 ± 3 years) (Al-Khabbaz, Shimada, & Hasgawa, 2008). The results showed no significance in side flexion or trunk rotation, but yielded significance ($P<0.05$) as load increases with forward trunk flexion (Al-Khabbaz, Shimada, & Hasgawa, 2008) indicating that a bilateral pack will only influence the trunk and the spinal column in the sagittal plane.

Like Al-Khabbaz' study, many other researchers examined only male subjects (Tilbury-Davis & Hooper, 1999; Choi, Hwang, Choi, Kim, & Yi, 2007). This inspired the works of Barbara Smith, who examined pelvic movement in female students carrying a backpack (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006). Unlike Al-Khabbaz, Smith found significant differences in angular pelvic tilt, pelvic obliquity, and rotation range of motion (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006). Simpson was another to study only female bilateral load carriers (Simpson, Munro, & Steele, 2011). Simpson and colleagues studied the posture of the trunk of 15 females (22.3 ± 3.9 years) with three-dimensional kinematic analysis using an OPTOTRAK 3020 motion analysis system. They found that the trunk flexion angle became smaller (more forward bending) once load was applied (20%, 30%, and 40%BW) and there was also a significant difference between the 40% BW load and the 20% BW load in that respect. The women in the study had to hike an 8 km circuit with a pack, and significant differences arrived in peak trunk flexion when the 6 km and 8 km analysis points were compared with the initial and 2 km analysis points (Simpson, Munro, & Steele, 2011). This indicates a fatigue factor in load carriage studies and should be taken into consideration for hockey load carriage or in daily life when the player carries the bag after participating in the hockey practice.

Chansirinukor and colleagues (2001) examined adolescents, males and females between the ages of 13 and 16, on the biomechanical responses to backpack carrying, with the following purposes (Chansirinukor, Wilson, Grimmer, & Dansie, 2001):

a) To determine if cervical and shoulder posture changed when carrying a backpack.
b) To determine if carrying a backpack of 15% body weight produced changes in the cervical and shoulder posture.
c) To determine if carrying the pack unilaterally alters cervical and shoulder posture.
d) To determine if the time the load was carried altered cervical and shoulder posture.

Chansirinukor also wanted to establish a healthy load weight for children and adolescents. The researchers figured 15% BW to be this healthy amount of load weight from the previous research (Pascoe, Pascoe, Wang, Shim, & Kim, 1997) with 17% body weight loads. The methods used to analyze the standing posture were slide photographs and Easy Digit Analytical Computer Graphics Digitizer Software, a rather outdated approach for today but considered most reliable during the time of the publication. The results of the study showed no significant changes in effect of weight of a backpack on cervical and shoulder posture but there was a significant difference when carrying a pack of 15% of body weight in anterior head alignment and craniovertebral angle. The study had no significant differences when carrying a load unilaterally except for the craniohorizontal angle (the angle of the mid-ear to the eye in the sagittal plane). The researchers found much variability among participants for this aspect of the study and determined that there was no conclusive evidence that carrying a backpack unilaterally on the right shoulder alters cervical posture and that further investigation is necessary (Chansirinukor, Wilson, Grimmer, & Dansie, 2001).

To summarize the key temporospatial and sagittal parameters associated with bilateral load carriage, cadence and double support time tend to increase as load weight increases or becomes more difficult (i.e. wearing high heels), whereas stride length and single support time tend to decrease. The trunk angle decreases as load is increased or applied, so that there is a forward leaning posture.

2.4 Bilateral packs – Electromyography Analysis

A backpack causes the center of mass to become more rearward creating a torque around the lower back that the erector spinae muscles must overcome and thus creating tension on the abdominals (Knapik, Harman, & Reynolds, 1996; Bobet & Norman, 1984; Flloyd & Silver, 1951). This tension is overcome by the activation of the rectus abdominals and anterior core muscles to bring forward the body, so as to be in an equal state of balance. It was found, however, that as load increases the erector spinae muscles also increase in activity, although not as large as the rectus abdominis (Knapik, Harman, & Reynolds, 1996; Cook & Neumann, 1987). This is because there is a constant effort between the muscles of the core (anterior and posterior) to stabilize the body with the added rearward load (Al-Khabbaz, Shimada, & Hasgawa, 2008). Muscles of the gastrocnemius show increases in activity as load increases and there have been mixed findings on the quadriceps, either significant activity or no significant activity (Harman, Han, Frykman, Johnson, Russell, &

Rosenstein, 1992; Norman, 1979). The possible reasoning behind the mixed findings could relate to the instruments used at the time of the experiments. Electromyography (EMG) technique has been changed significantly over the past decades, improving in signal reading and preparation techniques. Another possible explanation to the mixed findings could be due to the inconsistency between studies in locating and recording the desired muscle in an appropriate way.

The tibialis anterior and the hamstrings show no change when carried load increases (Knapik, Harman, & Reynolds, 1996; Al-Khabbaz, Shimada, & Hasgawa, 2008). Another study done by Hong, Li, and Fong, looking at the effects of 20-minute walking and load carriage on muscle activity and muscle fatigue in 15 male children all aged at 6 years old. The children carried backpacks of 0%, 10%, 15%, and 20% body weight and resulted in increased lower trapezius muscle activity (% of voluntary muscle activity). The researchers used power spectral frequency analysis to determine muscle fatigue by the shift in median power frequency. Increased muscle fatigue (Mean muscle power frequency) occurred when time increased to 20 minutes and during the 20% BW load carriage (Hong, Li, & Tik-Pui Fong, 2008). The upper trapezius showed a significant increase in fatigue but not activity under the same condition, while the rectus abdominis showed no significant increases in fatigue or muscle activity (Hong, Li, & Tik-Pui Fong, 2008). Muscle activity in the lower trapezius initiated within the 5-minute mark and the 15-minute mark of the 15% body weight load and the 20% bodyweight load respectively. The researchers concluded that children's backpack loads be no greater than 15% of their bodyweights for 20 minutes of walking.

Studies of backpack carrying in children and adolescents are common (Hong, Li, & Tik-Pui Fong, 2008; Chansirinukor, Wilson, Grimmer, & Dansie, 2001). Children are most affected by the loads they carry to and from school, sometimes over long distances and five times a week. The idea here is that spinal loading at a young age may result in chronic back pain as adolescents' age into adulthood. LeVeau and Bernhardt (1984) suggest this type of loading may also influence growth development (LeVeau & Bernhardt, 1984).

Considering the results from Hong, Li, and Fong (2008) on the children carrying backpack loads, hockey in Canada has more than 500 000 children in Canada, aged 6-18, who are registered for minor hockey (McNabb). A hockey bag typically weighs much more than a school bag and has a greater volume, making walking with a hockey bag a difficult task. Although, most children are not carrying their hockey bags for 20 minutes daily, as they would for carrying a school bag, there are competitive hockey programs requiring children to be at the arena for practice every day on top of going to school. Therefore, studying not only bilateral load carriage in children, but unilateral load carriage as well, is an important aspect in increasing our understanding of the biomechanical responses to load carriage.

2.5 Bilateral packs – Kinetics

The vertical ground force kinetics has also been shown to significantly increase with load increase when carrying a bilateral pack ($p \leq 0.005$) (Al-Khabbaz, Shimada, & Hasgawa, 2008; Norman, 1979; Tilbury-Davis & Hooper, 1999; Hale, Colemon, & Karpovich, 1953). This increase in ground reaction force begins compressing soft tissue of the human body from the area that the load is applied creating a downward force. Repetitive loading or acute loading involving a large mass may cause injuries along the spinal column such as intervertebral disc hernia, avulsion, or a compression fracture (Knapik, Harman, & Reynolds, 1996). A study done by Tilbury-Davis and Hooper (1999) on 10 trained military soldiers carrying a standard military pack bilaterally showed that the increases in ground reaction forces with increasing load masses of 0 kg, 20 kg, and 40 kg were proportionate to the subject's body mass (Tilbury-Davis & Hooper, 1999). The researchers found forces necessary to balance these loads increase significantly and can lead to lower limb stress fractures (Tilbury-Davis & Hooper, 1999).

2.6 Studies Involving Combined Unilateral and Bilateral Loads

One of the more interesting questions when dealing with load carriage is which method of carrying is best (i.e. most healthy in terms of posture). In experiments from both Smith et al. (2006) and Chansirinukor (2001), exploration of this question is further investigated. In Smith's experiment, she examined the impact of biomechanical responses in backpack carriage in college-aged female students (mean 22.4 years). Smith (2006) recorded motions using a more suitable and modern array of instruments compared to Chansirinukor (2001), who also studied backpacks on students. Smith used a 3-dimensional model with VICON Clinical Manager and collected ground reaction forces with AMTI force plates. The walking distance in this study was short as it took place in a lab setting, 10 trials of each condition were analyzed. The conditions were: 1) no bag, 2) bilateral bag of 15%, and 3) unilateral bag of 15%. Results of the study showed a greater sagittal pelvic tilt when carrying a 15% load unilaterally compared to bilaterally resulting from the increase in lateral flexion along the spinal column. Smith states that continuously carrying a load on one side of the body may be more prone to muscle fatigue due to increased muscle use on side opposite to the load (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006). These results agree with the conclusions of previous studies (Norkin & Leangie, 1992; Cook & Neumann, 1987; Pascoe, Pascoe, Wang, Shim, & Kim, 1997).

2.7 Unilateral packs – Kinematics

Studying unilateral packs has stemmed out from previous research on bilateral packs. As previously mentioned, studies involving students carrying backpacks also looked at the different methods of carrying backpacks for students, such as unilaterally. The unilateral method of carrying is quite popular, used by postal workers, travelers, and used as a gym bag. This type of carriage provides a quick access to the materials inside, but may be more harmful to the musculoskeletal system, if the weight is heavy.

Early unilateral load carriage research came from DeVita (1991) after reviewing the negative effects that side weight-lifting has on the musculoskeletal system when compared to anterior weight-lifting (DeVita, Hong, & Hamill, 1991). DeVita examined lower limb kinematics of the hip, knee and lumbo-sacral joint of L5/S1 of 5 males (mean age = 25 years), when carrying a unilateral load on the left shoulder. The loads were 0%, 10%, and 20% bodyweight and showed little in terms of the changes during unilateral carrying. The technology of capturing human motion were quite premature and still emerging, and many of the measurements were made manually, not through a computer, but by measuring the displacement of markers through recorded video of gait. This practice may increase the likely hood of human error through measurement.

Crosbie (1994) used a similar method as the one mentioned by DeVita, to examine the kinematics of gait, also using 10% and 20% bodyweights but, in this case, by including a population of ten males and 10 females (mean age of 22.5 years

(Crosbie, Flynn, & Rutter, 1994). Crosbie found that cadence increased and walking velocity decreased with a unilateral load and that significant changes resulted in step length and step width only in males and not in females (Crosbie, Flynn, & Rutter, 1994).

Expanding on the knowledge of load carriage, O'Shea and colleagues studied the impacts of backpack carriage on the back kinematics of 21 young adults carrying unilateral loads (15% bodyweight) over one shoulder and across the body (O'Shea, Bettany-Satikov, & Warren, 2006). O'Shea had the participants perform standing, static trials for four minutes while 15 anatomical landmarks on the back provided data for the Microscribe 3DX-digitizer (O'Shea, Bettany-Satikov, & Warren, 2006). The results showed elevation of the loaded shoulder and depression of the unloaded shoulder, at the trunk there was a lateral shift away from the load and an overall lean forward. In the cross-body loading the results were similar but had a less overall impact on posture than same-sided.

Another study that examined back kinematics was by Fowler et Al. (2006) on the changes of stature and spine kinematics during an asymmetrical loaded walking task (Fowler, Rodacki, & Rodacki, 2006). The study was designed to investigate the effects of postal workers using a unilateral pouch. To make this study empirical, the researchers designed a methodology that included an 8 500 m walk where, initially, the bag was filled with 17.5% of the participant's body weight but had it gradually reduce just as it would during a normal mail route.

Kinematic data was collected several times during the walk on the treadmill by two calibrated optoelectric cameras (ELITE, BTS, Milan, Italy) that were placed behind the participants to allow for 3D reconstruction. The results of this study included an increase in forward flexion, spinal shrinkage that initially showed when load was first applied, and a loss in stature that was three-times greater than when no load was applied (Fowler, Rodacki, & Rodacki, 2006). Mailbags that are symmetrical, with two lateral bags have been shown to present better working conditions than asymmetric, with greater comfort (Fowler, Rodacki, & Rodacki, 2006).

In a study by Choi and colleagues (2007), the researchers looked at the movement of the center of mass as well as joint moments while carrying different load weights in a duffle bag. The duffle bag was held in the hand (the hand that did the carrying was designated randomly) and the load weights were 0, 5, 10, and 15 kg. This weight equated to a weight no greater than 20% of any participants body weight (Choi, Hwang, Choi, Kim, & Yi, 2007). With a small sample size of just 5 males, the researchers discovered that the value of abduction around the hip joint decreased as the load weight increased, a mechanism, the researchers suggest, used to minimize energy consumption when carrying a load on one side. It was found that there was large hip extension on the carrying side to support the weight during mid-stance. In turn, the other limb experiences a small hip extension and moves quickly through swing phase. The center of mass and the trunk leaned more to the non-carrying side during gait, and a large, carrying side, moment occurred to compensate for body center of mass as the side load increased in mass.

Zhang and colleagues studied posture and ground reaction force in unilateral loading of hand held weights during gait (Zhang, Ye, & Wang, 2010). They also wanted to explore how the trunk moved when carrying loads with the dominant hand and the non-dominant hand (all subjects were right handed). The loads the participants carried were 10% and 20% of their bodyweight. Complementing the previous literature, stride width and lateral trunk bending all increased as the load weight increased and there were also significant forces in medial/lateral and free vertical moment ground reaction forces when carrying the 20% bodyweight load (Zhang, Ye, & Wang, 2010). Participants tend to lean contralaterally (away from weight) for 89.5% of the time when carrying a 10% load in their dominant right hand but this changed to bending contralaterally 57.9% of the time with an increased weight of 20% bodyweight, ipsilateral bending took the remaining time. The data becomes more interesting when participants carry the weight with the left hand as ipsilateral bending takes a larger role being 63.2% and 100% for the 10% and 20% bodyweight loads respectively (Zhang, Ye, & Wang, 2010). Hip adduction of both legs also increased when there is an ipsilateral bend. This result should be noted when studying participants under unilateral load carriage as it could affect results if all participants are required to carry the load in the same hand/shoulder even if that side is not their dominant side. This might serve as a limitation in the study done by Smith (2006) who had a coin-toss decide which shoulder the load will be applied (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006)or DeVita who chose the left side to have the pack (DeVita, Hong, & Hamill, 1991)or Choi who had the participants carry with the right hand only (Choi, Hwang, Choi, Kim, & Yi, 2007).

In another experiment examining the biomechanics of the unloaded and loaded side of the body, Ozgul and colleagues set out to discover if the unloaded side is actually unloaded (Ozgul, Akalan, Kuchimov, Uyger, Temelli, & Polat, 2011). The results from their study showed that peak ankle dorsiflexion, range of hip motion in the sagittal plane, mean hip abduction during stance, range of pelvic tilt increased and mean pelvic obliquity decreased at the unloaded side when loaded as compared to not loaded. The temporal parameters showed that stance period (% gait cycle) and double support period (% gait cycle) increased and swing phase (% gait cycle) decreased significantly (Ozgul, Akalan, Kuchimov, Uyger, Temelli, & Polat, 2011). This indicates that differences take place on the 'un-loaded' side and measures of future studies should take that in account.

Gillette and associates studied the influence of age on the biomechanics of load carrying (2010) The experiment involved investigating unilateral load carriage through hand held loads determining how four different age groups may affect results (4 groups: [8-10yrs], [12-14yrs], [15-17yrs], and adults [18+]), three load weights (3 groups: 0%, 10%, and 20%), two load volumes (2 groups: small bucket, 3.8 L and large bucket, 18.9 L), and two carrying methods (2 groups: unilaterally and bilaterally) (Gillette, Stevermer, Miller, Meardon, & Schwab, 2010). The focus of the study was to explore the influence of carrying buckets for 'farm children and adult farmers' by examining the lower limb kinematics using an eight-camera Peak Motus motion analysis system (Centennial, CO). The researchers stated that in the sagittal plane the range of motion of the hip, knee, and ankle was significantly different in the children and adolescent groups when they were compared to the adult groups (Gillette, Stevermer, Miller, Meardon, & Schwab, 2010). However, the tables of the results show that the groups were not consistent. The sagittal hip range of motion showed only a significant increase for the 8-10 year old group compared to the adult group, the sagittal view of the knee range of motion showed significant decreases in only the groups 12-14 years old and 15-17 years old. Finally, in the sagittal view of the ankle range of motion the 8-10 year olds showed a significant decrease while the 15-17 year olds showed a significant increase when compared to adults. The researchers did discuss these differences proclaiming it could be due to the mixed ratios in each groups of male to female or the uneven number of participants filling each group. In the 8-10 year old group there were 7 participants with a 6:1 male to female ratio. In the adult group there were 16 participants, more than any other group, and the male to female ratio is 9:7, much closer than the 6:1 seen in the youngest age group. The range of motion of the ankle in the transverse plane showed to be significantly greater in the younger age groups when compared to the adult age group. However, these groups did not decrease with increasing age but, again, remained relatively inconsistent (Gillette, Stevermer, Miller, Meardon, & Schwab, 2010).

Adduction and abduction in hip were an interesting result to this study, as all age groups showed a decrease in hip adduction and an increase in hip abduction as age increased. Hip internal rotation and external rotation showed this same trend with a decrease in hip internal rotation and an increase in external hip rotation as age increases. It should be noted that the data from the bilateral and the unilateral carrying methods were combined for these results.

The hip showed significant decrease in the range of motion within the frontal plane but significant increase in the range of motion among the transverse plane during the 20% body weight load condition. The knee showed significantly greater extension while the hip showed significantly greater flexion, internal rotation, and adduction for the 20% body weight load. Again, for these results the unilateral and bilateral carrying methods were combined making it difficult to formulate any conclusion on unilateral load carriage (Gillette, Stevermer, Miller, Meardon, & Schwab, 2010).

As mentioned, the weakness in Gillette's experiment was in the age groups, being mixed with males and females, especially in the 12-14 year-old and 15-17 year-old groups. It is at these ages that the onset and progression of puberty differs between the genders, as well as individually among either gender. Gillette et al. failed to define and test for maturity in puberty in this experiment. The results of the study showed little difference in unilateral load and so the results of unilateral load and bilateral loading had been combined to form one group. Due to this fact, the evidence presented here may be questionable. The authors stated that further research is needed to examine the joint moments, joint contact forces, and electromyography.

A study done by Lee and Li (2011), examined the combined effects of asymmetrical load carriage and high-heeled shoes on the biomechanics of lower extremity. The lower limb kinematics and kinetics in young females during high-heeled walking was analyzed (Lee & Li, 2011). In this particular study the asymmetrical load was a purse filled with weights to match 5% and 10% of the participant's body weight. The researchers found that the moment of the knee extensor was significantly different from no load to 5% ($p<0.001$) (Lee & Li, 2011). Peak plantar flexion moments were also significant among groups, 0%-5% ($p=0.002$), 0%-10% ($p=0.008$), and 5%-10% ($p=0.001$). Another finding from this study contributing to the unilateral load carriage field is that ankle plantar flexion moment increased with load weight but decreased with high-heel height. Also, when comparing both limbs of a participant the only significant differences occurred when heels were introduced, indicating that the combined effect contributes to become the most hazardous to the human body. The results here, suggest that the additional challenge that requires the body to maintain balance, such as high heels, can increase the chance of injury. Perhaps another challenge affecting balance is the uneven surface that many hockey players face when carrying their bag through summer or winter, whether it be from snow and ice on the ground, stairs they have to climb, or doors they have to open while carrying the bag.

2.8 Unilateral packs– Electromyography Analysis and Kinetic Analysis

One study compared the various methods of carrying loads on level ground and used EMG to record the muscle activity of the rectus abdominis and the erector spinae of 19 participants (9 males, 10 females, 20.12 ±2.03 years) (Motmans, Tomlow, & Vissers, 2006). The carrying methods of the loads included: carrying a bag on the shoulder (across the body), on the back, on the front, and then a combination of front and back (Motmans, Tomlow, & Vissers, 2006). The participants in this study performed standing, static trials of carrying a load of 15% their bodyweight. The results of the study showed the highest amount of muscle activity recorded in the rectus abdominis for the backpack carrying and the highest muscle activity for the erector spinae recorded during the front pack carrying (Motmans, Tomlow, & Vissers, 2006). The type of carrying method that used the second most muscle activation for both muscles (erector spinae and rectus abdominis, left and right combined) was the unilateral, over the shoulder and across the body type of carriage. The unilateral load was carried only on the right side shoulder. The normalized EMG results showed that the left rectus abdominis and the left erector spinae were much more activated than the same muscle on the right side of the body (when compared to normalized muscle forces: 108% for left rectus abdominis and 90% for the right; while 177% for the left erector spinae and 75% for the right). Following the trend of the results, perhaps the external obliques of the abdomen muscle group would show greatest activation during unilateral load carrying and should be looked at further in the future. Also, the EMG results for the rectus abdominis and the erector spinae during the unilateral load carrying in this experiment may have been higher if it had been placed over the shoulder and not across the body. The comparisons of these two methods were studied further in an experiment done by O'Shea (O'Shea, Bettany-Satikov, & Warren, 2006). O'Shea did not study the muscle activity but rather the posture of the back. The erector spinae is a muscle that is antagonist to forward flexion and thus activation of this muscle will become greater when a front pack is loaded in an effort to maintain balance. The same can be said about the rectus abdominals being antagonist for back extension and requiring much more activation of this muscle when a load is applied posterior to the body. The researchers conclude that asymmetric bag carrying should be avoided because of the overuse and imbalance of muscle activity on one side (Motmans, Tomlow, & Vissers, 2006).

Going back to DeVita's study on unilateral load carriage (1991), results showed unbalanced lateral trunk muscle dominance between left and right limb stance phases, an increase in right hip and knee moments, while a decrease in the left hip and knee moments with increasing load weight, and shifts of L5/S1 moment to the right side during left and right single support phase (DeVita, Hong, & Hamill, 1991). DeVita concluded that asymmetric loading may have a greater injury potential compared to symmetric carrying. He recommended that when carrying loads of 20% bodyweight or more, a symmetric carrying technique should be applied, and finally, when having to carry unilateral loads they should be carried interchangeably to both shoulders to avoid muscle imbalance. The techniques of capturing joint kinematics used in the study of DeVita is now outdated, using 2 cine-cameras (DeVita, Hong, & Hamill, 1991). The problem with this method is that the film is studied manually by estimating the locations of joint centers. Sometimes it may be difficult to locate the joint center because of poor resolution and quality in the film. The modern method of 3-D kinematics still has it's problems in the biasness of the examiner' location of joint centers (when applying the reflective markers) but it can be somewhat standardized with previous literature.

2.9 Load Carriage and Injury

As we know, carrying loads can be harmful to the musculoskeletal system when it is done with large weight and large dimensions of the bag or over longer durations. In the beginnings of a carrying task the inter-vertebral discs are fully filled with fluid and leaning of the trunk in the sagittal and frontal plane are greatest. It has been proposed, by Dolans and Adams that during the initial carrying phase the risk of injury is at it's highest due to the increased intra-disc pressure and volume (Dolan & Adams, 2001). After prolonged carrying the inter-vertebral discs become more elastic and are less prone to injury after having a part of the fluid content expelled from within the disc (Dolan & Adams, 2001). Prolonged walking while carrying a load can be more associated with stature loss due to this fluid loss and lateral bulging of the inter-vertebral discs (Dolan & Adams, 2001). When carrying a hockey bag, the athlete only carries for a relatively short duration when compared with soldiers and hikers yet they carry more weight under two conditions: when they are un-fatigued (before practice/game) and when they are fatigued (post-practice/game).

Therefore, the research by Dolans and Adams may suggest that people participating in hockey and carrying their bags may be at a greater risk of back injury before the practice or game when carrying as opposed to carrying after (Dolan & Adams, 2001). Research done by Hong, Li, and Fong show muscle fatigue becomes apparent in children when walking with a load and should limit the duration to 20 minutes of load carriage, suggesting that muscle fatigue, in this case the trapezius, can lead to an overuse injury or muscle strain (Hong, Li, & Tik-Pui Fong, 2008). This data suggests that carrying the hockey bag after a game or practice might be more susceptible to muscle injuries related to fatigue.

Research Gaps & Research Differences

Carried Weight-Load

Of the studies done on load carriage, bilateral experiments seem to test the highest load weight relative to the body compared to unilateral studies. To author's knowledge there has been no unilateral load carriage study looking at biomechanical responses to carrying a relative weight of greater than 20% body weight (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006; DeVita, Hong, & Hamill, 1991; Crosbie, Flynn, & Rutter, 1994; Motmans, Tomlow, & Vissers, 2006; Fowler, Rodacki, & Rodacki, 2006; Zhang, Ye, & Wang, 2010; Gillette, Stevermer, Miller, Meardon, & Schwab, 2010; Lee & Li, 2011; Choi, Hwang, Choi, Kim, & Yi, 2007; O'Shea, Bettany-Satikov, & Warren, 2006). Recommendations have been made to limit loads from as high as 40-60% in soldiers carrying bilateral packs (Fergenbaum, 2007) to as low as students carrying 10% backpacks (Chansirinukor, Wilson, Grimmer, & Dansie, 2001; Lee & Li, 2011). Little has been done in an effort to establish limits for unilateral loads. Although the purpose of this study will not be to establish limitations on load weight, it can be used to add to the understanding in eventually determining those limitations.

Like the bilateral pack, the unilateral pack is used for different types of recreation and professions but for many players in hockey the unilateral load can be up to 33.29% of their body weight (Corrigan, Law, & Law, 2010). Although that amount of weight for hockey bag carriers is lower to the weight military soldiers carry in bilateral packs, having load on one side of the body has proven to be more damaging to the musculoskeletal system (DeVita, Hong, & Hamill, 1991). The interest in studying hockey bags comes from the large popularity of the sport in Canada during the winter and summer months, as well as to add to the understanding of unilateral load carrying.

Another factor in load carriage that has been missing from research is the size and volume of the bag and how those two independent variables may affect the gait of the carrier.

Load Material

Another problem that many of the experiments on load carrying encounter is the material that fills the bags, which has been shown in a plethora of ways throughout the field of load carriage. All studies have developed unique ways to make the bag realistic to what usually occupies these bags. However, the problem arrives when making the load to an exact percentage of one's bodyweight. In the study done by Smith et al. (2006) looking at school bags of females in college, concrete was used to fill the bags (Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006). This may have added more discomfort to carrying the bag and because it does not take the full shape of the bag it can be unreliable. The same can be said when experiments use metal weights. In Motmans' study (2006), textbooks were used with weights in an effort to make it more realistic and produce an accurate body percentage of the load (Motmans, Tomlow, & Vissers, 2006). Other materials used, that may be more efficient in filling the volume of the bag as well as being precise in the weight measurements, were lead pellets (Gillette et al., 2010) and sandbags (Simpson, Munro, & Steele, 2011).

Distance

When looking at the distance travelled during these experiments, different lengths are observed and sometimes just a static analysis is tested. The longer distances, like the distance used in Fowler's study of postal workers, has the participants walking on a treadmill for 8.5 km (Fowler, Rodacki, & Rodacki, 2006). This technique proves to be efficient for calculating kinematic data over long periods of time but calls on the participants to walk at a constant velocity. Other studies use the 6-25m lab space they have available and cameras mounted around the volume (DeVita, Hong, & Hamill, 1991; Crosbie, Flynn, & Rutter, 1994). The smooth laboratory floors and settings make walking much easier when compared to out-door walking and most studies acknowledge this as a limitation. This problem was partly answered in a study done by Simpson et al. (2010) on female hikers. The researchers designed a walking course to include in-lab data collection as well as an outdoor component on gravel and a slight uphill (Simpson, Munro, & Steele, 2011).

Much of the data available regarding unilateral loading is largely kinematic. Early research on the kinematics of unilateral load carriage by DeVita (1991) and Crosbie (1994) used cine-cameras and manual digitizing (Crosbie, Flynn, & Rutter, 1994; DeVita, Hong, & Hamill, 1991). Later, studies focused on how the unilateral load affects posture of the spine (O'Shea, Bettany-Satikov, & Warren, 2006; Fowler, Rodacki, & Rodacki, 2006; Zhang, Ye, & Wang, 2010) and lower-body kinematics

(Smith, Ashton, Bohl, Richard, Metheny, & Klassen, 2006; Gillette, Stevermer, Miller, Meardon, & Schwab, 2010). Little is known about the lower limb muscle activity during unilateral loading on a level surface. Research by Motmans examining the rectus abdominis and erector spinae (Motmans, Tomlow, & Vissers, 2006) is the only known study to examine muscle activities in unilateral load carriage.

CHAPTER 3: METHODOLOGY

Materials & Instrumentation

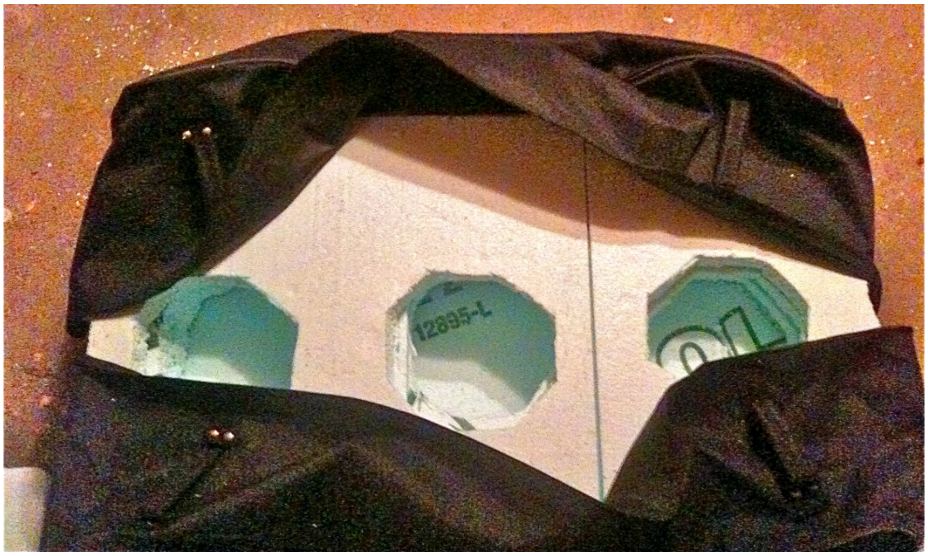
A) Hockey Bags

Two ice-hockey bags of different sizes were used in this experiment. One was a Reebok player's hockey bag that was 0.11 m^3 in volume and the other was a Reebok goaltender's hockey bag that was 0.36 m^3 in volume (See Figure 1).

Insulation was placed in the hockey bags to allow for a full volume and metal weights were positioned into the hockey bags to account for the load weight of 10%, 20%, and 30% of the subject's body weight (BW). The insulation and metal weights allowed for an equal distribution of weight and avoided any shifting or movement of the weights during gait (See Figure 2).

The hockey bags were weighed using a Heys, xScale digital luggage scale to make sure the weight was accurate for the trials. The scale can measure weights of up to 50 kg and is accurate to within 0.22 kg.

Figure 1: The two Reebok hockey bags that were used in the study. Small (0.11 m^3) and Large (0.36 m^3).



<u>Figure 2:</u> The large hockey bag is shown above with styro-foam and designated sections along the center for the placement of metal weights.

B) Walking Path

The walking path was 8 m in length and was surrounded by infrared motion analysis cameras that made up a volume to capture two gait cycles (right and left) in the middle of the 8 m path. The walking path was located in a laboratory and had smooth rubber flooring. In the middle of the 8 m pathway were four force plates, placed in a staggered position to capture foot contact (See Figure 3). The flooring in the laboratory was made flush with the force plates.

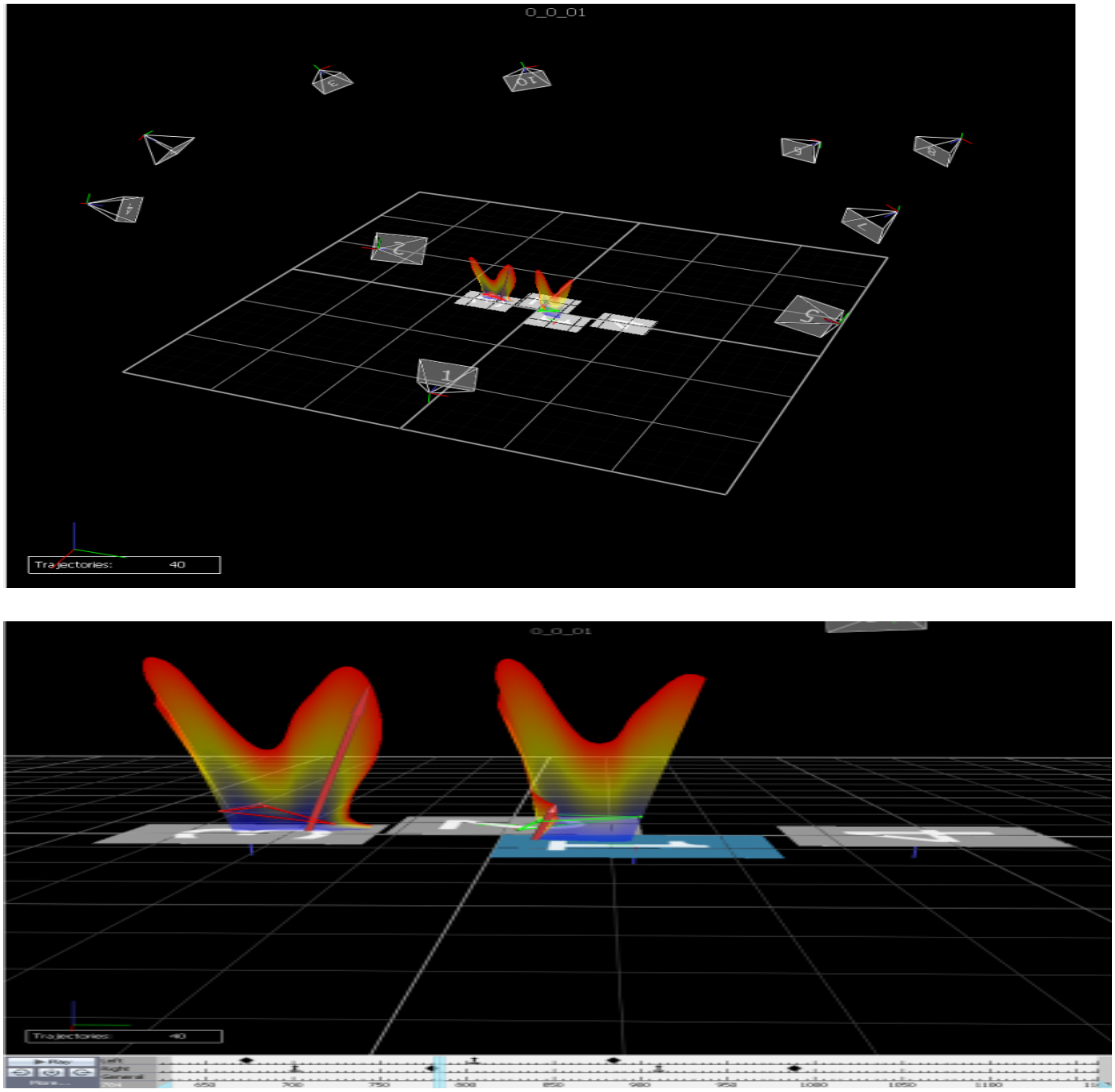


Figure 3: A view of the laboratory setting (10 Vicon infrared cameras for motion analysis & 4 staggered force plates for foot contact)

C) Motion Analysis System

The instruments used to capture temporospatial kinematic data included ten infra-red, high speed, optical cameras to translate collected retro-reflective markers into a three-dimensional image with the Vicon Motion Analysis System, recording at 100Hz (Vicon MX-13, Oxford Metrics, Oxford, UK). The Vicon cameras are set up around the walking path either from mounted tripods or hung from the ceiling.

Retro-reflective markers were attached via double sided tape to the anatomical landmarks of the toe, heel, lateral and medial malleoli of both feet (VICON, Oxford Metrics, Oxford, UK). These markers provided enough data to determine temporospatial parameters such as stride length, stride width, and double and single support time.

D) Force Plates

Four force plates were used to aid in the detection of foot contact (two models 9286AA, Kistler Instruments Corp, Winterhur, Swtz; two models FP 4060-08, Bertec Corporation, Columbus, OH, USA). The force plates were positioned in a way that mocks a regular walking pattern.

E) Electromyography (EMG)

A 16-channel EMG system (DS-B04, Bagnoli™-16 Desktop EMG system, DelsysInc., Boston, MA) was used to record muscle activity in 16 muscles at 1000 Hz. The sensors were applied with double sided tape and placed on the muscle belly of the muscle being recorded. The bars of the sensors were aligned perpendicular with the muscle fibers to achieve best results. The analog data coming from the EMG sensors were then synchronized with the temporospatial data through a VICON acquisition board (Vicon MX-13, Oxford Metrics, Oxford, UK).

F) Participant Attire

Participants wore their own gym shorts and gym shirt with regular running shoes. Spandex shorts were worn underneath the loose shorts so that EMG wires could travel in between the loose and the spandex shorts to avoid tangling and tripping during gait.

G) Participants

The participants were composed of 15 male hockey players (23.4 ±2.63 years) with an average of 16.56 ±4.92 years of ice hockey experience and therefore hockey bag carriage experience. The average body mass index (BMI) of the participants was 24.97 and no participant was in an obese weight range. All, but one of the participants carried the bag on their dominant right shoulder. For the one participant who carried his bag on his dominant left, the left gait cycle and left muscles were used for analysis and pooled in with the right of the others.

Using G*Power (3.1) an estimated sample size of 13 was proven to be effective for 0.8 power (1- β error probability) and with a significance level of α <0.05 in a previous study (Lee & Li, 2011; Erdfelder, Paul, & Buchner, 1996).

Figure 4: A display of the style (posterior-lateral) of how each participant carried the hockey bag. The small hockey bag is pictured on the left and the large hockey bag is pictured on the right.

PROCEDURES

The participants were asked to come to the biomechanics lab at the University of Ottawa campus (200 Lees Ave., Ottawa) once for data collection. The details of the research and the experiment procedures were explained to each participant before reading and signing a consent form approved by the University of Ottawa Health Sciences and Science Research Ethics Board. A questionnaire regarding the subject's experience with hockey bag load carriage (See Appendix A) was completed at this time. Participants were then asked to change into gym attire as mentioned in the earlier section entitled 'Participant Attire'. Participants were encouraged to warm up on a stationary bicycle and stretch before executing the trials in the experiment.

EMG sensor placement

Subjects were then prepared for EMG sensor placement. The skin overlying the following muscle bellies (left and right) were shaven and cleaned with alcohol wipes: erector spinae (ES) (located at the level of the L4-L5 inter-space and 2 cm away from the midline), rectus abdominis (RA) (located on the belly of the muscle just below the umbillicus), rectus femoris (RF), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), medial gastrocnemius (GAS), and gluteus maximus (GM) with the reference electrode placed on the skin overlying the left olecranon. The location of the ES muscles are referenced from Al-Khabbaz's study on the effect of backpack heaviness (Al-Khabbaz, Shimada, & Hasgawa, 2008) while the other muscle locations were referenced from Seniam (Hermens, Freriks, & Merletti, 1999).

Dynamic Motion Capture

Calibration of the VICON system took place before participant arrival. After set-up, the participant performed 3-5 practice trials of normal walking to maintain a normal gait unaffected by the increased attention. These practice trials were used again for each experimental condition. The participant was reminded to ignore the force plates, as they were only a supplemental aid in determining foot contact. The other aid was the retro-reflective markers. When ready, the participant would commence the trials. The participant carried the hockey bag over their self-chosen dominant shoulder in a manner they would carry their own hockey bag and walked the 8 m through the testing area, captured by 10 VICON MX-13 cameras. It should be noted that all subjects carried the bag as shown in figure 4. The subjects performed four trials of each condition of 0% BW (no load), 10% BW load in smaller hockey bag, 20% BW in smaller hockey bag, 30% BW in smaller hockey bag, and 10% BW in the larger hockey bag, 20% in larger hockey bag, and 30% in larger hockey bag. The total number of trials was 28. The presentation of each condition was decided in a random and balanced manner, to avoid any order effects among participants. The condition order for each participant was randomly selected from one of the scenarios in a Latin Square design. The walking speed of the participants was self-determined and at a natural pace. The participant, in some cases, may have been subject to more trials of any particular condition if a trial had become considered unsuccessful. Successful trials are defined by having all retro-reflective markers and EMG sensors still in place. The subject was allowed to take breaks at any time and at any time had the option to drop out of the experiment.

	0% (No load)	10% BW	20% BW	30% BW
Small Hockey Bag	4 trials	4 trials	4 trials	4 trials
Large Hockey Bag		4 trials	4 trials	4 trials

Table 2: Conditions and the number of trials performed. Note the 4 trials for the 0% condition did not include the carrying of either bag.

DATA PROCESSING

Movement was analyzed in three dimensions for one gait cycle, of right foot contact to right foot contact*.

Kinematic Data Processing

Data was expressed as percent of the right gait cycle. Foot contact was identified visually while inspecting the labeled markers of the heel, toe, and malleoli on VICON Nexus software (v1.3) and through force plate data signals. Measurements included stride length (right heel-to-right heel); stride width (max distance within the gait cycle between left medial malleolus to right medial malleolus), single leg support (left foot off-to-left foot on and right foot off-to-right foot on), and double support phase (right foot on-to-left foot off and left foot on-to-right foot off). These measurements were made through formulas on SMART Analyzer (BTS Software, Italy).

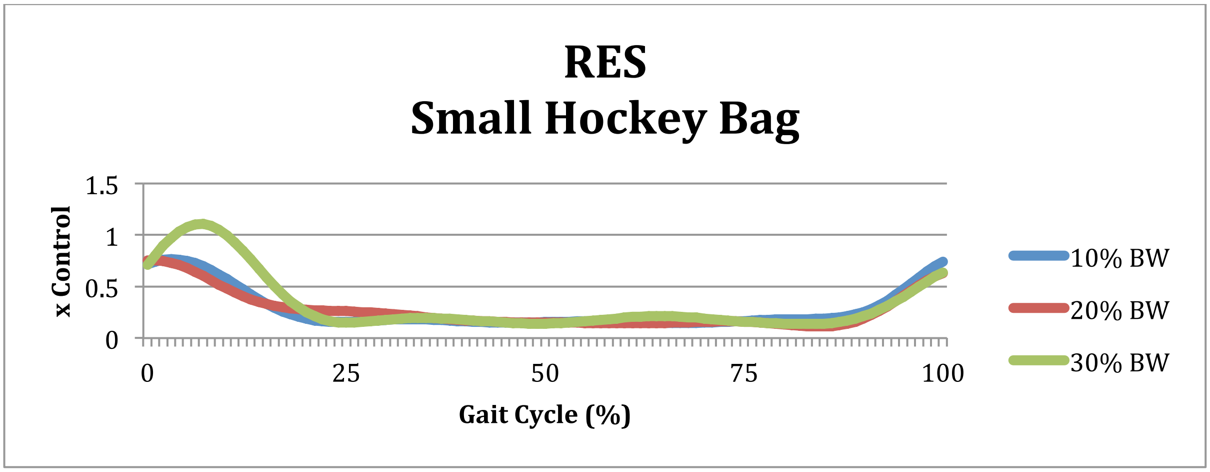
EMG Data Processing

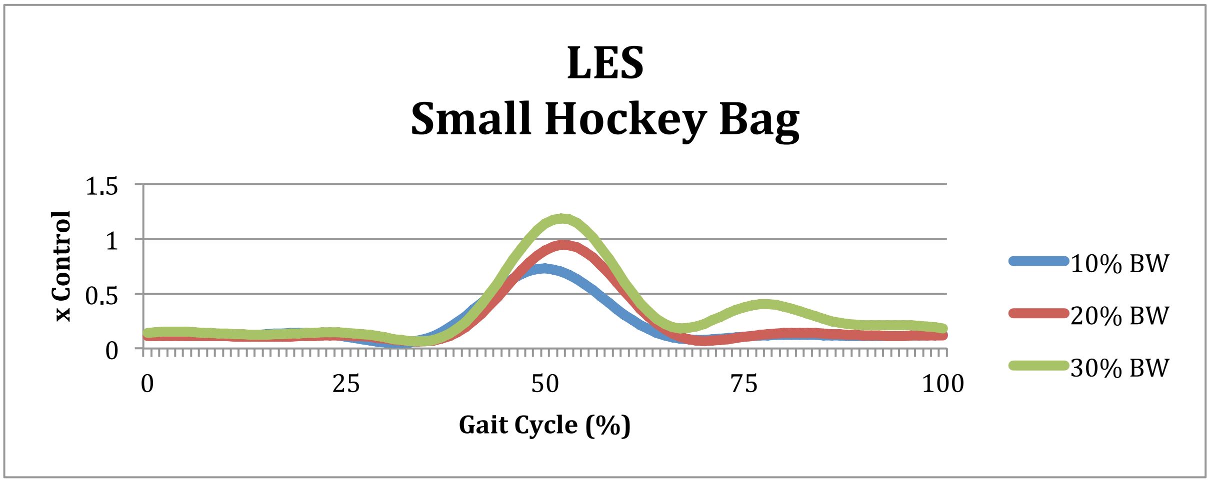
To analyze the raw EMG data, the files were transported to a .c3d file and imported into SMART Analyzer Software (BTS, Italy). The data were rectified using the temporal mean, filtered using a single, low-pass Butterworth filter to smoothen the data, and then processed with a cut of frequency of 4 Hz,. The filtered EMG data were then normalized to 100% of the gait cycle and plotted as a percentage of the peak amplitude in the average of the control condition. This was done to give representations of peak muscle activity in the 10%, 20%, and 30% BW condition in comparison to the control. Another option would have been to normalize the gait to EMG data obtained at the moment of the maximum force the participant could acquire for any given muscle. These are known as maximum voluntary contractions (MVC's). Performing MVC's manually, that is having the participant meet the resistance of a hand or a static object, can cause variation between participants as joint angles of the limb under testing may change. These changes in joint angles have proven to show various results in MVC data (Mirka, 1991). It has also been shown that for dynamic testing such as running, cycling and walking, using a control condition similar to the testing protocols would be more appropriate (Mirka, 1991; Benoit, Lamontagne, Cerulli, & Liti, 2003). As a result, data for the peak EMG is shown as a percentage. Integrated EMG (iEMG) was also examined. The iEMG was calculated using the normalized EMG with the following formula in Microsoft Excel (2011):

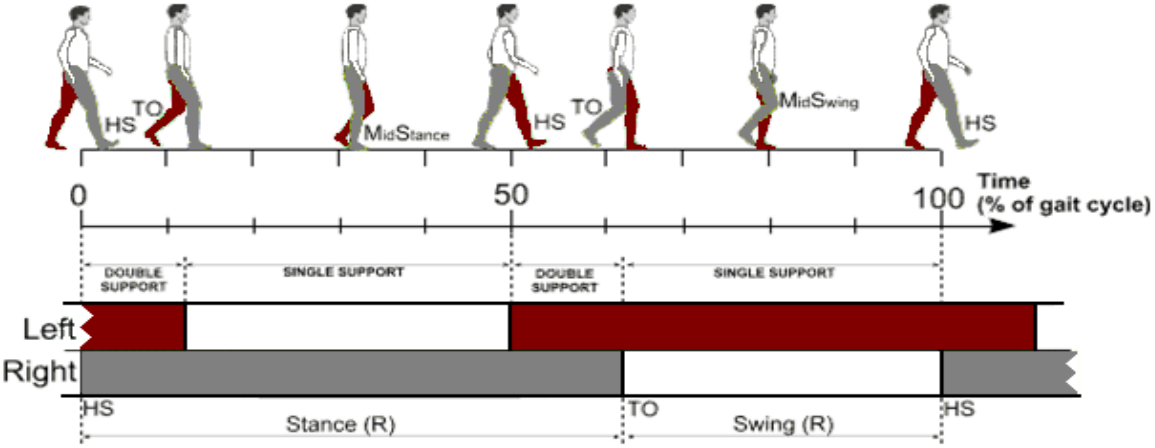
$$\text{area} = \sum_{\mathrm{x}=1}^{\mathrm{x}=\mathrm{i}} (\mathrm{x}_{\mathrm{i}+1} - x_i) * 1/2[f(x_{i+1}) + f(x_i)]$$

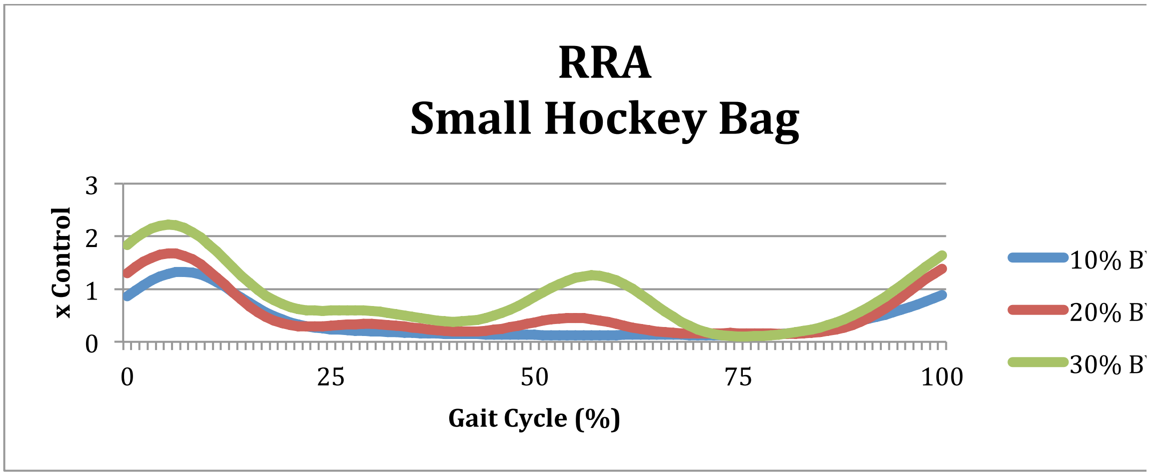
* One of the fifteen participants carried the bag on their dominant left side. To avoid confusion, the results of this subject's dominant carrying side will be treated as the "right side". This means, for example, that the muscle activity of the left erector spinae of the participant carrying the load on the left shoulder will be pooled in with the muscle activity of the right erector spinae of the right-sided carriers.

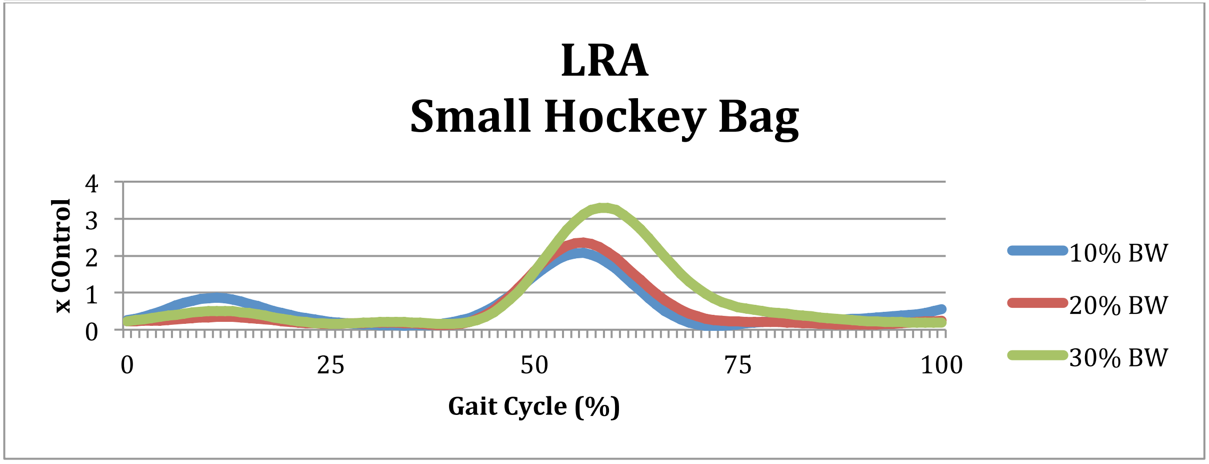
The EMG results were normalized to gait cycle on the x-axis and normalized to the peak control condition along the y-axis. The integrated EMG (iEMG) was calculated using the area under each curve. The load was carried over the right shoulder. This is demonstrated in the figures below taken from one of the participant's ES and RA:

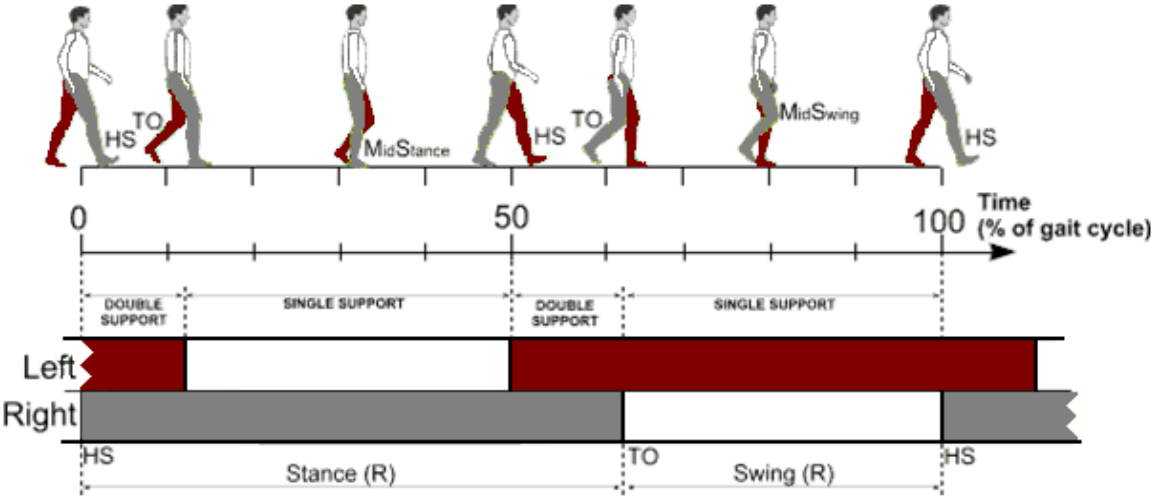












Figures 7-11: EMG graphs of one participant from the study. The maximum value of each condition represented the peak EMG. The area under the graph for a given condition represents the iEMG. The gait cycle is defined as right-heel-strike to right-heel-strike.

STATISTICAL ANALYSIS

All measurements and results from the experiment are expressed as a mean with standard error (±). A two-way repeated measures analysis of variance (2-way repeated measures ANOVA) was used to examine the differences between the repeated factor of hockey bag load weight (4 levels: no load, load of 10% BW, load of 20% BW, and load of 30% BW) and the repeated factor of hockey bag size. (2 levels: small hockey bag, and large hockey bag). When significance was found, a Bonferroni Post-Hoc test was performed using repeated measures t-tests. The Bonferroni Post-Hoc test was chosen because of it being most conservative and acceptable when experimenting with few groups for each independent variable. The probability of making a type-I error in all tests is presented with a P-value of <0.05. All significant data that is shown has proved to be spherical through Maulchy's Test or has been modified using the appropriate correction. All analyses were performed using the statistical software package SPSS 20.0 for Macintosh (SPSS Inc. Chicago, IL, USA).

Data was inspected for outliers and excluded if found. Outliers were defined as data falling outside of 1.5 x the interquartile range. Outliers appeared in one participant, at the 30% BW conditions for the rectus abdominis, the semitendinosus, the vastus femoris, and the biceps femoris. Outlier data was most likely caused from measurement error.

ARTICLE 1: LOAD EFFECTS ON TRUNK AND LOWER LIMB MUSCLE ACTIVITY DURING UNILATERAL LOAD CARRIAGE OF YOUNG HEALTHY MALES

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ABSTRACT

The aim of this study was to explore the effects of unilateral load carriage of up to 30% of one's body weight on trunk and lower limb muscle activity during gait. The loads were carried in a hockey bag with the straps going over the participant's right shoulder. Peak muscle activity of trunk and lower limb were measured using electromyography (EMG) during walking and carrying a load with weight at 10%, 20%, and 30% of the subject's body weight (BW). These results were compared to the control of carrying no bag. Results showed significant increase in peak EMG and integrated EMG (iEMG) in the right vastus medialis, right rectus abdominis, both semitendinosus, and both gastrocnemii ($P<0.05$) at the 30% BW load condition. The left side showed a greater EMG peak in the semitendinosus and in the rectus femoris at the 30% BW load condition ($P< 0.05$). A shorter stride length ($P<0.001$) while a greater stride width ($P<0.001$) and double support time ($P< 0.001$) occurred with the increase in load. It was concluded that unilateral load carriage of up to 30% of body weight of young males significantly increases in the activities of the muscles involved with trunk flexion (rectus abdominis) while no significant change occurs for the trunk and hip extensors (erector spinae and gluteus maximus). Studies on backpack load carriage yield similar results. Significant increases in the peak EMG and iEMG of the left side of the rectus femoris and left semitendinosus when compared to the right sides of the same muscles are relevant to many unilateral studies (DeVita, Hong, & Hamill, 1991; Motmans, Tomlow, & Vissers, 2006).

INTRODUCTION

Unilateral load carriage has been shown to be more hazardous to the human body than bilateral, or backpack, load carriage (Knapik, Harman, & Reynolds, 1996). When carrying unilateral loads, the gait and posture are often altered to counter for the added weight. This unnatural gait creates forces to act asymmetrically on the spinal column and lower limbs. The forces, as a result of this type of load carriage may be hazardous to the musculoskeletal system. The asymmetrical forces generate tension on the muscles and tissues of the non-carrying side of the body while compressing the tissues on the carrying side.

Unilateral load carriage is commonly found in ice-hockey players carrying their equipment. It is also found that during play in hockey, participants perform repetitive or continuous forward trunk flexion. This particular movement in addition to the chronic and repetitive forward flexion with load carriage may lead to injury involving the spinal column (Mountain, 2002; Baranto, Hellstrom, Cederlund, Nyman, & Sward, 2009).

On another note, many of the unilateral load carriage studies use loads up to 20% of one's body weight (Crosbie, Flynn, & Rutter, 1994; DeVita, Hong, & Hamill, 1991; Fowler, Rodacki, & Rodacki, 2006; Gillette, Stevermer, Miller, Meardon, & Schwab, 2010; Lee & Li, 2011; Motmans, Tomlow, & Vissers, 2006). A pre-study survey showed that from a sample of 33 hockey players, the hockey bag can weigh up to 33% of one's body weight (BW) (Corrigan, Law, & Law, 2010).

Therefore, it was in the interest of this paper to investigate the trunk and lower limb muscle activity during heavy unilateral load carriage, as is seen most commonly in ice-hockey players. The study's relevance is aided by the research in backpack and side pack (bilateral and unilateral) evidence but the missing links of heavy unilateral in hockey bags had yet to be established. It was hypothesized that the muscles of the trunk and lower limb would increase in peak EMG and iEMG as load increases and that the left (non-carrying) side muscles would experience greater activation than the right (carrying side).

METHODS

Hockey Bag

The hockey bag was an adult bag meant for player's ice-hockey equipment. It was 0.11m^3 in volume. The hockey bag straps were non-adjustable, as like most hockey bags, and so the strap length stayed the same for each participant. The hockey bag was filled with styro-foam insulation to allow the bag to reveal it's true volume. Designated spots were cut out of the insulation to insert metal weights.

Participants

The participants were composed of 15 male hockey players (23.4 ±2.63 years) with an average of 16.56 ±4.92 years of ice hockey experience and therefore hockey bag carriage experience. The average body mass index (BMI) of the participants was 24.97 and no participant was in an obese weight range (BMI levels according to WHO, 2012). No injuries and musculoskeletal disorders that would alter gait or biomechanics of trunk and lower limbs were reported in any of the participants. All, but one of the participants carried the bag on their dominant right shoulder. For the one participant who carried his bag on his dominant left, the left gait cycle was used for analysis and pooled in with the right of the others. Also, for this one participant the left muscles were grouped with the right muscles of the other participants so that the "carrying side" and "non-carrying side" can be defined as right and left respectfully.

Prior to data collection, all participants read and signed an informed consent form approved by the University of Ottawa Ethics Committee.

Participants had their height and weight measured so that the bag could be adjusted to 10%, 20% and 30% of the participant's body weight (BW). The skin over lying the following muscles, as identified by project SENIAM and previous unilateral and bilateral load carriage studies (Hermens, Freriks, & Merletti, 1999; Al-Khabbaz, Shimada, & Hasgawa, 2008; Motmans, Tomlow, & Vissers, 2006), were shaven and cleaned with an alcohol swab: erector spinae (ES), rectus abdominis (RA), gluteus maximus (GM), biceps femoris (BF), semitendinosus (ST), rectus femoris (RF), vastus medialis (VM), and gastrocnemius (GAS). A 16-channel electromyography (EMG) system (DS-B04, Bagnoli™-16 Desktop EMG system, DelsysInc., Boston, MA) was set at a recording frequency of 1000 Hz and used to collect EMG activity.

Experimental Protocol

Eight retro-reflective markers were placed on the left and right first toe, heel, lateral, and medial malleoli. Ten infrared, high speed, optical cameras, capturing at 100 Hz, were used to translate collected retro-reflective markers into a three-dimensional image using the VICON motion analysis system (VICON, Oxford Metrics, Oxford, UK). Four force plates (2 Bertec; 2 Kistler) set in a staggered walking position and capturing at 1000 Hz, were used along with motion analysis to aid in determining foot contact (Fig. 1).

Participants walked and carried a standard hockey bag (0.11 m^3) over their dominant shoulder along an 8 m path of smooth laboratory flooring. The participants were instructed to carry the bag in their normal fashion. All participants carried the bag over their dominant shoulder above the hip and resting on the backside (fig. 1).

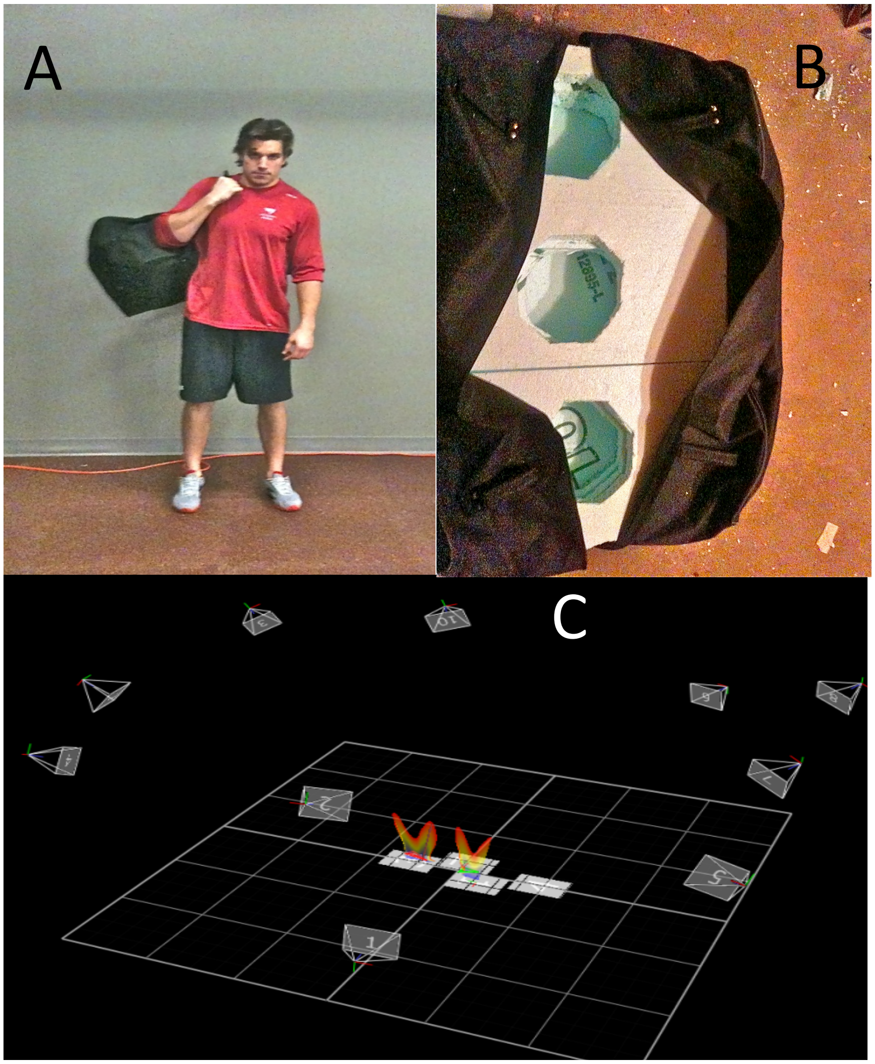


Figure 1: A: The method in which the hockey bags were carried over the dominant shoulder, and resting posterior-laterally. B: Inside look of the hockey bag and the Styrofoam. C: Walking path over four force platforms and surrounded by 10 VICON motion analysis cameras.

Participants were required to wear gym sneakers, shorts and a shirt. They were instructed to carry the bag as they would normally carry their own and walk at a comfortable speed. The participants were told to ignore the force plates. This encouraged natural stride lengths. Each participant practiced each task and when ready would complete four trials of each load condition (10% BW, 20% BW, and 30% BW) including the control condition of walking with no bag/no load. Each condition was presented through a Latin squares design

DATA PROCESSING

The right gait cycle was analyzed from heel-strike to heel-strike. This analysis took place at the gait cycle of the mid way point of the 8 m walk. The raw EMG data was transformed into a C3D file and imported into SMART Analyzer Software (BTS, Italy). The data was processed with a cut off frequency of 4 Hz, rectified using the temporal mean, and filtered using a single, low-pass Butterworth filter to smooth the data. The filtered EMG data was then normalized to 100% of the gait cycle and plotted as a percentage of the peak amplitude in the average of the control condition. This was done to compare peak muscle activity in the 10%, 20%, and 30% BW condition to the control. The integrated EMG (iEMG) was calculated using the following formula in Microsoft Excel (2011):

$$\text{area} = \sum_{\mathrm{x}=1}^{\mathrm{x}=\mathrm{i}} (\mathrm{x}_{\mathrm{i}+1} - x_i) * 1/2[f(x_{i+1}) + f(x_i)]$$

Temporospatial data was calculated using SMART Analyzer and built in functions to measure marker-to-marker distance and determine stride length, stride width, and support time. The foot contact was determined using motion analysis and force plate data.

STATISTICAL ANALYSIS

All of the results from the experiment are expressed as a mean with standard error (±). A two-way repeated measures analysis of variance (2-way repeated measures ANOVA) was used to examine the differences between the repeated factor of hockey bag load weight

(4 levels: no load, load of 10% BW, load of 20% BW, and load of 30% BW) and the muscle side (left and right; non-carrying and carrying side). When significance was found, a Bonferroni post-hoc test was performed using repeated measures t-tests. The probability of making a type-I error in all tests is presented with a P-value of <0.05. All significant data is spherical by not violating the Maulchy's Test of Sphericity. All analyses were performed using the statistical software package SPSS 20.0 for Macintosh (SPSS Inc. Chicago, IL, USA).

Data was inspected for outliers, if found they were excluded. Outliers were defined as data falling outside of 1.5 x the interquartile range. Outliers appeared in one participant, at the 30% BW conditions for the rectus abdominis, the semitendinosus, the vastus femoris, and the biceps femoris.

RESULTS

Load Effects

The results of the peak EMG and the iEMG are illustrated in figure 2. The carrying side is defined as the right side, while the non-carrying side is defined as the left.

The right RA increased in peak EMG (1, 1.083, 1.348, 1.863), with significance taking place for the 30% BW against all other load conditions (P≤ 0.026). Similar increases are found in the RA for the iEMG, with the right RA being significantly greater in the 30% BW load compared to all other conditions (P≤ 0.013).

The right VM was significantly higher in peak EMG for the 30% BW condition (2.084 ±0.27) when compared to all other conditions (P≤ 0.031). The iEMG for the same muscle showed similar significant results, with the 30% BW (81.801 ±11.246) condition larger than all the other conditions (P≤ 0.005). No significant increases in peak EMG and iEMG were discovered in the left VM.

Figure 2-4: Peak EMG and iEMG normalized to no load condition of the left and right muscles. Significance is shown at an alpha level of 0.05; "A" vs. right Control; "B" vs. right 10% BW; "C" vs. right 20% BW; "D" vs. right 30% BW ("a", "b" "c", and "d" are for left side). "*" denotes significance between left and right sides.

Figure 2

Peak EMG **iEMG**

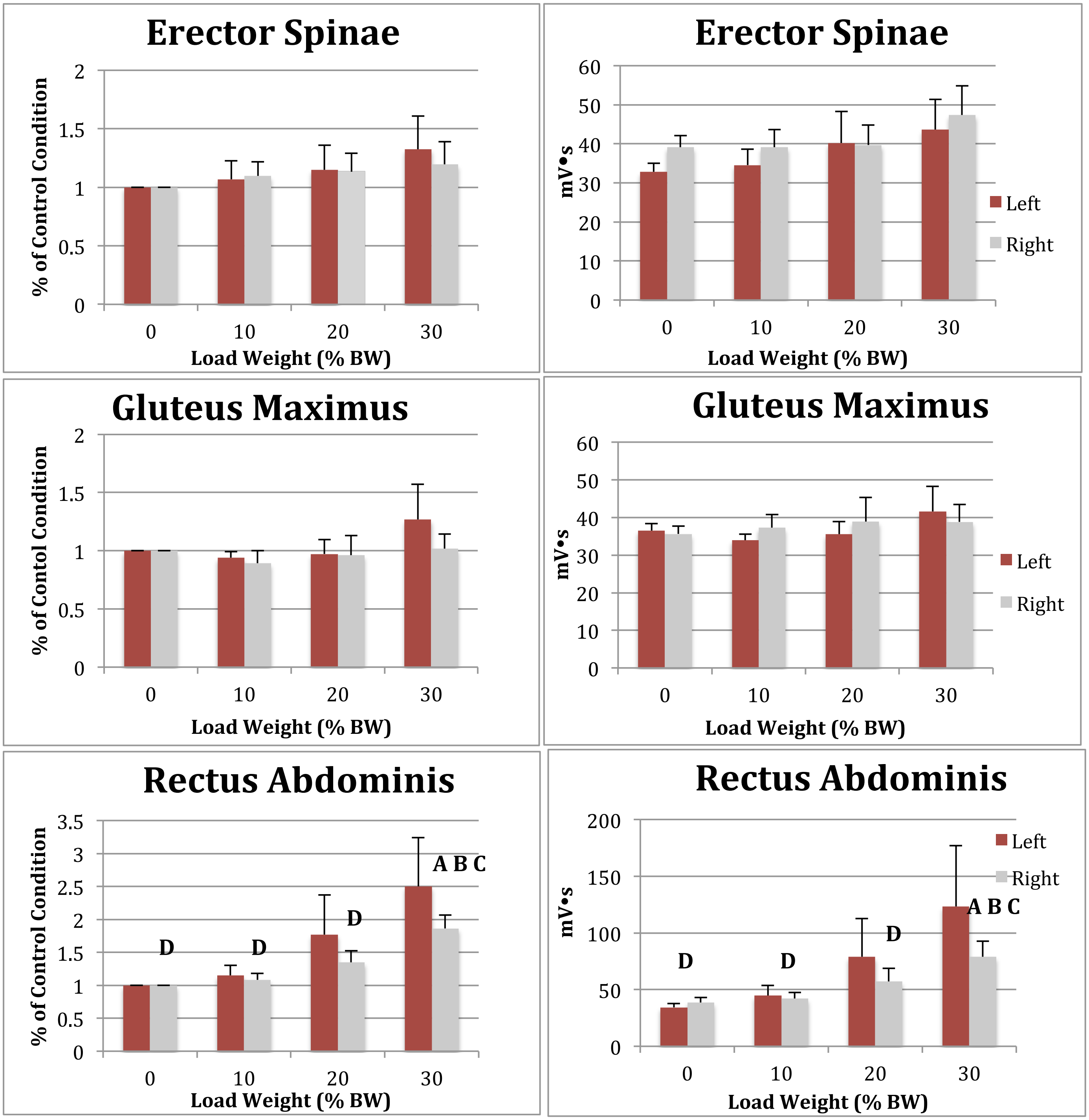


Figure 3

Peak EMG **iEMG**

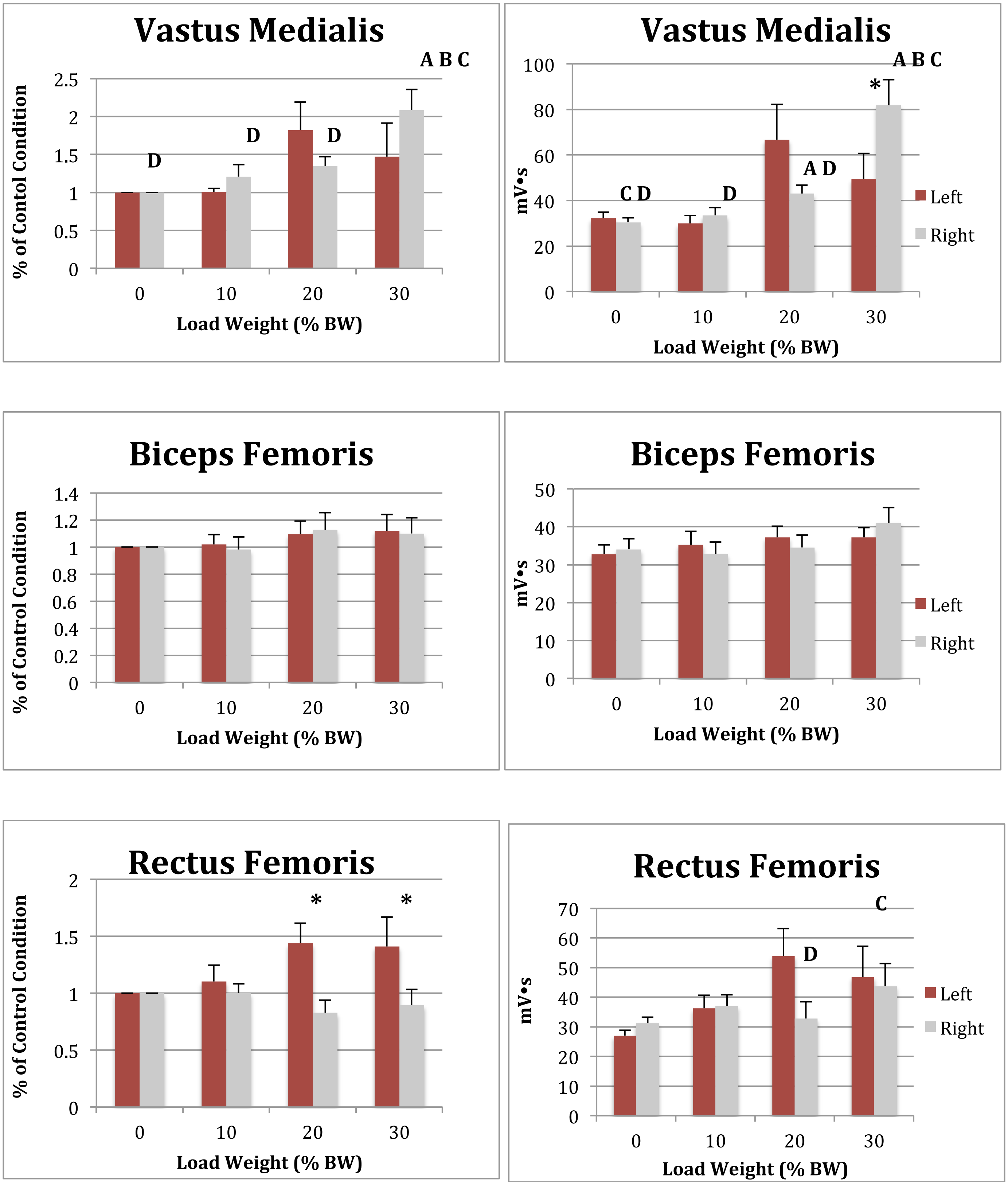
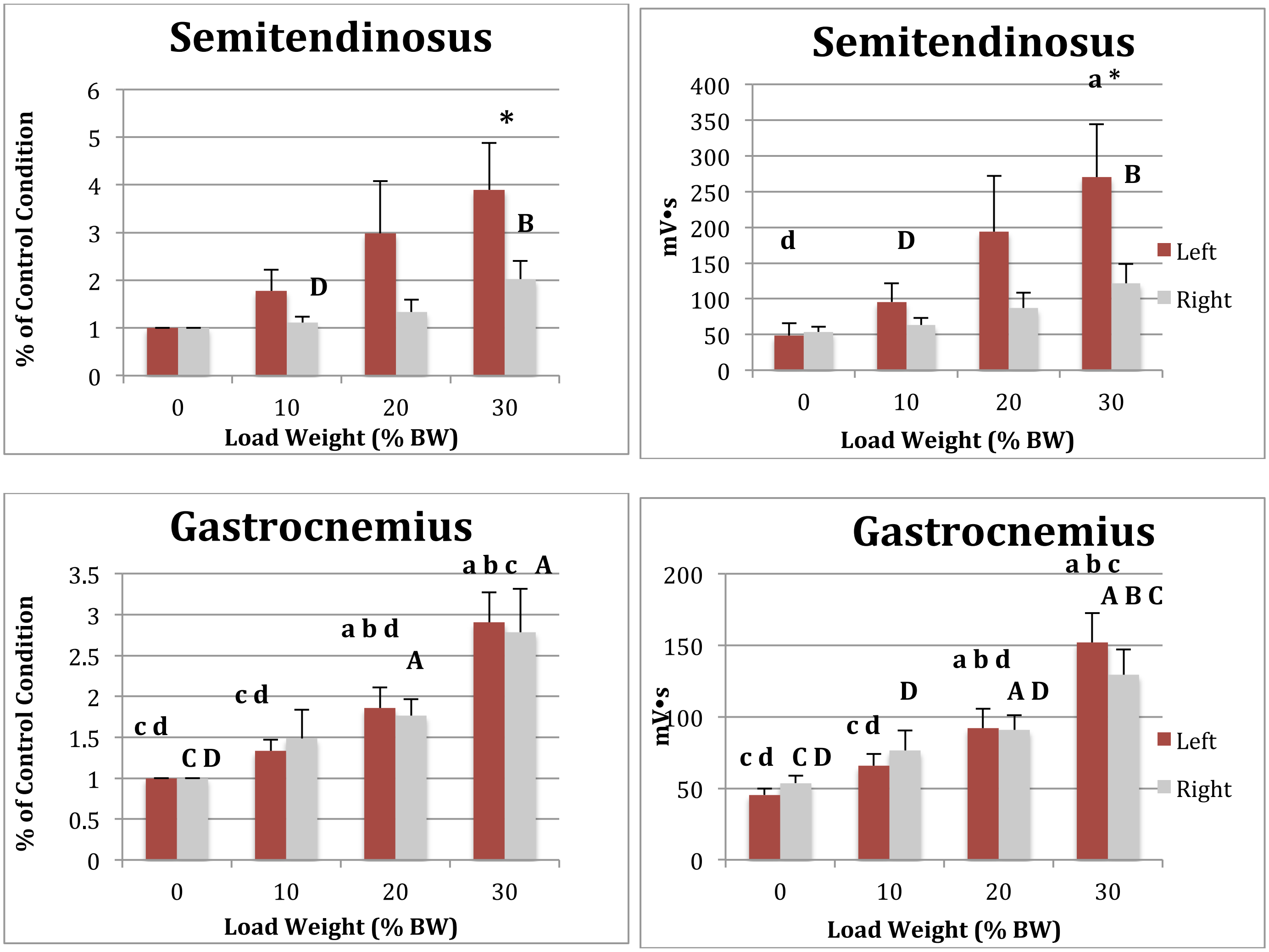


Figure 4

Peak EMG **iEMG**



The right and left BF hardly differed between the control, 10, 20, and 30 % BW conditions for peak EMG (right: 1, 0.981, 1.126, 1.1; left: 1, 1.019, 1.095, and 1.118 respectfully) and iEMG (34.061, 32.854, 34.56, 41.075). No significant increases occurred in peak or iEMG for either the left or right RF against the control.

The ST activity increased in both the right (1, 1.11, 1.329, 2.024) and left (right: 1, 1.777, 2.979, 3.894; left: 32.833, 35.245, 37.186, 37.187) with load increase, but differed significantly only in the right ST when comparing the 30% BW to the 10% BW load (P=

0.032) in the peak EMG and in the left iEMG when looking at the 30% BW to the control (P≤ 0.042).

The GAS also increased for the right (1, 1.484, 1.762, 2.782) and left (1, 1.331, 1.856, 2.903) for peak EMG and for the right (53.637, 76.27, 90.86, 129.30) and left (45.376, 65.605, 91.998, 151.9). In the right for both peak and iEMG, significance occurs from 30% BW to the control (P≤0.03) and 20% BW to the control (P≤ 0.013). The left GAS shows significance from 30% BW to Control, 10% BW, and 20% BW (P≤0.046) and at the 20% BW to Control, 10% BW, and 30% BW (P≤0.046).

Side Effects

The differences in muscle activity between the left and right, proved to show that the left side is more active than the right side. Significance takes place at peak EMG of the RF in the 20%BW (P=0.022) and the 30%BW (P=0.041), both showing to have larger peak EMG in the left. Significance in the iEMG for the same muscle was not found. The ST also showed significance at the 30% BW condition for both the peak and iEMG (P≤0.044). Again, more activity occurred for the left muscle.

Temporospatial Results

Load % BW	Stride Length (m)	p-value	Stride Width (cm)	p-value
0	1.51 ±0.03	-	10.6 ±0.5	-
10	1.46 ±0.03	0.211	11.2 ±0.7	1.0
20	1.45 ±0.03	0.117	13.1 ±0.9	0.053
30	**1.39 ±0.03 ***	**0.002**	**16.3 ±1.1 ***	**<0.001**

Table 1: Mean and standard error of stride length and width during walking with a unilateral load. Measurements are compared against the control condition of no load.

Load condition	**Single Support (%)**	**p-value**	**Double Support (%)**	**p-value**
Control	73.8 ±0.9	-	26.2 ±0.9	-
10% BW	**72.3 ±1.1 ***	**0.026**	**27.7 ±1.1 ***	**0.026**
20% BW	**70.5 ±0.8 ***	**0.001**	**29.5 ± 0.8 ***	**0.001**
30% BW	**68.9 ±0.8 ***	**<0.001**	**31.1 ±0.8 ***	**<0.001**

Table 2: Mean and standard error of support phase during walking with a unilateral load. Measurements are compared against the control condition of no load. Significant values are shown in bold and indicated with an asterisk "*". P< 0.05.

Temporospatial Effects

Previous research has shown no significant differences between left and right temporospatial parameters in unilateral load carriage when load weight is added (DeVita, Hong and Hamill, 1991). No differences were observed between left and right strides in this study as well. As a result, only the right gait cycle was used.

The average stride length, stride width, and support time of each load condition can be seen in tables 1 and 2. The stride length had shown to decrease as the load increased, with significance in the 30% BW condition when compared to all other conditions ($P \leq 0.048$). The stride width had shown to increase as load increased, with significance in the 30% BW condition when compared to all other conditions ($P \leq 0.044$). Finally, the double support increased and single support decreased as load weight was increased with the largest significant difference being from the control to 30% BW ($P<0.001$).

DISCUSSION

The purpose of this study was to examine the effects heavy unilateral load carriage has on the muscle activities of the trunk and lower limb.

Load Effects

The first hypothesis of increased peak muscle and activity with increase in load weight was supported, with a few exceptions. The muscle activities of the trunk showed no significant increases in the posterior muscles, ES and GM, while there was a significant increase in the right RA. Interestingly, these findings correlate well with studies on backpacks or other bilateral load carriage (Al-Khabbaz, Shimada, & Hasgawa, 2008; Knapik, Harman, & Reynolds, 1996; Motmans, Tomlow, & Vissers, 2006). Al-Khabbaz et al. (2008) observed an increase in hip and trunk flexion and Motmans et al. recorded an increase in RA muscle activity when standing with a load on the back (2006). The position of the hockey bag of each participant was unilateral and over the shoulder but laid slightly posterior, as opposed to directly lateral. In this study, the posterior-lateral positioning makes this unilateral type of load carriage similar to a backpack and, just like a backpack, the anterior muscles must overcome the added extensor moment caused by the posterior load. The cause for this bag position and carrying style may be because of the short, non-adjustable straps on the hockey bags that keeps the bag under the arm and rotated to the back allowing for easier transport. These features of the hockey bag are common among most hockey bags.

The muscles of the quadriceps have shown mixed results in load carriage studies (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Norman, 1979; Simpson, Munro, & Steele, 2011). In the present study, the results showed just that, with the RF showing no significant increases and the VM significantly increasing in peak and iEMG. The hamstrings responded similarly to that of previous load carriage research. The BF showed no increase in peak or activity as described by Simpson et al. (2011) and Knapik et al. (1996), while the only significant increase occurred in right ST peak EMG activity between the 10% BW and the 30% BW and iEMG increase in the left and right ST.

The left and right GAS muscle activities increased with an increasing load as seen in the literature (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Norman, 1979; Simpson, Munro, & Steele, 2011). The added load that sits slightly posterior may compel the subject to apply a countering force in the forefoot, limiting the dominant heel strike seen in unloaded walking. The forefoot walking is permitted through the activation of the gastrocnemii. The gastrocnemius also plays a role in maintaining balance and provides knee stability (Perry, 1992; Simpson, Munro, & Steele, 2011); increasing activation of this muscle suggests that the increased external load weight tests one's stability. Figure 5 highlights the muscles that significantly increased with an increasing load.

Figure 5: Muscles that significantly increased with an increased load weight in hockey bag load carriage. Muscles are: right RA, right VM, right and left ST, and right and left GAS

Side Effects

The second hypothesis that was tested was that the left would have more muscle activation when compared to the right. The results of the study support the hypothesis.

When examining the differences of muscle activities between the left and right, the data reveals its unilateral characteristics. The left side of the ST and the RF disclosed significant increases, in both peak EMG and iEMG in the ST and peak EMG in the RF when compared to the right (carrying) side. This is reflected in Motmans' study, as the non-carrying side in the rectus abdominis and the erector spinae showed significantly greater EMG activity than the carrying side (2006). Figure 6 highlights the muscles that were significantly affected by right-sided hockey bag load carriage.

Figure 6: Left muscles that significantly increased when compared to the right of the same muscle. Significant increases occurred in the left RF and the left ST.

<u>Temporospatial Effects</u>

The effects of load carriage on temporospatial parameters such as stride length; stride width and support have been well documented. The results of a shortened stride length, and wider stride width, as well as the increase of double limb support time were observed in the present study. These same results have appeared in both unilateral (Zhang, Ye, & Wang, 2010; Lee & Li, 2011) and bilateral (Knapik, Harman, & Reynolds, 1996) studies. The temporospatial changes aid in the balance of carrying a large load. The increase in stride width increases the area of the base of support and the decrease in stride length usually is the result of a slower speed (Gabell & Nayak, 1984).

Limitations

Limitations exist in this study as muscle location, activation patterns, and adipose thickness vary per person and per area and affect the surface EMG sensor. Cross talk and noise are also common in studying electromyography, although the raw data are filtered and rectified, abnormal curves may still occur (Turker, 1993).

Other limitations may be in the study design. The smooth laboratory flooring, and the Styrofoam filled bag may not be realistic to the carrier. The non-adjustable straps, although common among most hockey bags, may lie at different positions depending of the length of the upper trunk of the participant, but this was not controlled for in the present study.

Conclusion

The present study set out to examine the effects of heavy unilateral load carriage on the muscle activities of the trunk and lower limb. Observations of how each subject carried the hockey bag over their dominant shoulder and having the pack lay slightly posterior reflected in the results. The posterior-lateral load carriage method, commonly seen in hockey bag carriage, yielded results that are similar to both bilateral and unilateral load carriage studies. Increased peak EMG and iEMG in the RA, VM, ST, and GAS are indicative of bilateral load carriage and occurred as load weight increased. While greater left peak RF and ST EMG compared to the right side revealed the asymmetry of unilateral load carriage. The stride length and single support time decreased, while the stride width and double support time increased with added load weight.

More research will be needed to examine this method of load carriage and how it compares to other unilateral and bilateral methods in terms of safety. It is also recommended that ice-hockey players alternate sides when carrying their bags to and from the arena. This recommendation was also supported by DeVita on unilateral load carriage (1991).

REFERENCES

1. Al-Khabbaz, Y., Shimada, T., & Hasgawa, M. (2008). The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. *Gait & Posture , 28*, 297-3

2. Baranto, A.; Hellstrom, M.; Cederlund, C.G.; Nyman, R.; Sward (2009).Back pain and MRI changes in the thoraco-lumbar spine of top athletes in four different sports: A 15- year follow-up study. *Knee Surgery, Sports Traumatology, Arthroscopy, 17, (9), 1125-1134.*

3. Corrigan, L., Law, N., & Law, N. (2010, October). The hockey bag survey. *Not Published*. Ottawa, ON, Canada.

4. Crosbie, J., Flynn, W., & Rutter, L. (1994). Effect of side load carriage on the kinematics of gait. *Gait & Posture , 2*, 103-108.

5. DeVita, P., Hong, D., & Hamill, J. (1991). Effects of asymmetric load carrying on the biomechanics of walking. *Journal of Biomechanics , 24* (12), 1119-1129.

6. Fowler, N., Rodacki, A., & Rodacki, C. (2006). Changes in stature and spine kinematics during a loaded walking task. *Gait & Posture , 23*, 133-141.

7. Gabell, A. & Nayak, U.S.L. (1984), The effect of age on variability in gait. *Journal of Gerontology*, 39 (6).

7. Gillette, J., Stevermer, C., Miller, R., Meardon, S., & Schwab, C. (2010). The effects of age and type of carrying task on lower extremity kinematics. *Ergonomics , 53* (3), 355-364.

8. Harman, E., Han, K., Frykman, P., Johnson, M., Russell, F., & Rosenstein, M. (1992). The effects on gait timing, kinetics, and muscle activity of various loads carried on the back. *Medicine in Sports and Exercise , 24*, S129.

9. Hermens, H., Freriks, B., & Merletti, R. (1999). European recommendations for surface electromyography: Results of the seniam project.

10. Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics , 28*, 1347-1362.

11. Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs:A review of physiological, biomechanical and medical aspects. *Applied Ergonomics , 27* (3), 207-216.

12. Lee, S., & Li, J.-X. (2011). Effects of asymmetrical load carriage and high-heeled shoes on lower extremity joint kinetics in healthy young women during walking. *Master's Thesis, University of Ottawa*.

15. Motmans, R., Tomlow, S., & Vissers, D. (2006). Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics , 49* (2), 127–138.

14. Mountain, M. (2002, November). *Muscle imbalance in hockey players contributes to back pain.* Retrieved May 2011, from Hockey Training Pro: http://hockeytrainingpro.com/wordpress/2009/11/muscle-imbalance-in-hockey-players-contributes-to-back-pain/

13. Norman, R. (1979). The utility of combining EMG and mechanical work rate data in load carriage studies. *Proceedings of the 4th Congress of the international Society of Electrophysiological Kinesiology*.

16. Perry, J. Gait analysis: Normal and pathological function, 1992, Thorofare, N.J.: SLACK.

17. Simpson, K., Munro, B., & Steele, J. (2011). Backpack load affects lower limb muscle activity patterns of female hikers during prolonged load carriage. *Journal of Electromyography and Kinesiology , 21*, 782-788.

18. Smith, B., Ashton, K. M., Bohl, D., Richard, C., Metheny, J., & Klassen, S. (2006). Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. *Gait & Posture , 23*, 263-267.

20. Tilbury-Davis, D., & Hooper, R. (1999). The kinetic and kinematic e.ects of increasing load carriage upon the lower limb. *Human Movement Science , 18*, 693-700.

19. Turker, K. (1993). Electromyography: some methodological problems and issues. *Physical Therapy , 73* (10), 698-710.

21. Zhang, X. I., Ye, M., & Wang, C. (2010). Effect of unilateral load carriage on postures and gait symmetry in ground reaction force during walking. *Computer Methods in Biomechanics and Biomedical Engineering , 13* (3), 339-344.

ARTICLE 2: BAG SIZE EFFECTS ON TRUNK AND LOWER LIMB MUSCLE ACTIVITIES DURING UNILATERAL LOAD CARRIAGE OF YOUNG HEALTHY MALES

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ABSTRACT

The aim of this study was to explore the bag size effects of unilateral load carriage of up to 30% of one's body weight. Fifteen young, healthy males participated in the study. All of the participants carried the bags on their dominant right shoulder, except for one, who carried the bag on their dominant left. The dominant left shoulder carrier had his left side muscles pooled in with the right of the others. Muscle activities presented by peak electromyography (EMG) and integrate EMG (iEMG) from the left and right erector spinae, gluteus maximus, rectus abdominis, rectus femoris, vastus medialis, biceps femoris, semitendinosus, and the medial gastrocnemius were measured. Subjects walked with unilateral load carriage for a small or large ice-hockey bag with weight at 10%, 20%, and 30% of the subject's body weight as well as a control condition of no bag. A small bag (0.11 m^3) and a large bag (0.36 m^3) were used in the study. Results showed that greater muscle activity in the large bag for the right rectus femoris and the right rectus abdominis was found at the 20% and the 30% body weight load conditions for the right rectus femoris and 20% body weight for the rectus abdominis. During small bag load carriage, increases of muscle activity occurred for the right vastus medialis at the 30% bodyweight load condition. No significant differences between bag sizes were found when examining stride length and support time at a significance level of P=0.05. It was concluded that the size of the hockey bag does affect the muscle activity of the lower limbs and the trunk. However, reasons for the differences could be due to bag position on the subjects or amount of motion taking place with the bag.

INTRODUCTION

Unilateral load carriage has been shown to be more hazardous to the human body than bilateral, or backpack, load carriage (Knapik, Harman, & Reynolds, 1996). When carrying unilateral loads, the gait and posture are often altered to counter for the added weight. Motmans et al. found that the muscles of the non-carrying side were significantly greater than the carrying side (2006). Crosbie et al. learned that an increase in cadence and a decrease in velocity had occurred in unilateral load carriage when compared to normal walking (1994). This changed gait creates forces to act asymmetrically on the spinal column and lower limbs. These forces, and as a result, this type of load carriage may have high demands on the musculoskeletal system and change the kinetics and kinematics of the trunk and lower limbs. The asymmetrical forces generate tension on the muscles and tissues of the non-carrying side of the body while compressing the tissues on the carrying side.

Unilateral load carriage is commonly found in ice-hockey players carrying their equipment. It is also found that during play in hockey, participants perform repetitive or continuous forward trunk flexion. This particular movement in addition to the chronic and repetitive forward flexion with load carriage may lead to injury of the spinal column (Mountain, 2002; Baranto, Hellstrom, Cederlund, Nyman, & Sward, 2009).

In a study done by Gillette et al. (2010), small (3.8 L) and large bucket (18.9 L) sizes on kinematic measurements were compared in adults and children during unilateral load carriage and bilateral. The authors had to discard the large bucket sizes in bilateral load carriage because it was found to be too difficult for the youngest age group. For the unilateral load carriage the authors reported no significant effects or interactions of bucket size when measuring total joint range of motion and maximum joint angles of the hip, knee, and ankle. In Gillette's study the buckets were carried in the hand. The effects of load size carried unilaterally over the shoulder are still unknown.

A pre-study survey showed that out of a sample of 33 hockey players, the average size was found at 0.148 m^3 (BW), however the bags for the goaltenders and the players can vary greatly in terms of volume (Corrigan, Law, & Law, 2010). The survey also revealed that hockey bag size and hockey bag weight was not correlated, suggesting that hockey players may carry heavy loads in small bags and vice-versa.

Unilateral load carriage has been reported as being more hazardous to the human body than bilateral load carrying (DeVita, Hong, & Hamill, 1991; Motmans, Tomlow, & Vissers, 2006). The ice-hockey bags in unilateral load carriage have shown to be much larger in size and much heavier than the loads typically carried in the studies of unilateral load carriage (Corrigan, Law, & Law, 2010; Crosbie, Flynn, & Rutter, 1994; DeVita, Hong, & Hamill, 1991). Therefore, it is in the interest of this paper to investigate the trunk and lower limb muscle activity during heavy unilateral load carriage and the role of bag size. It was hypothesized that the muscles of the trunk and lower limb would increase in peak and activity in the larger hockey bag because the load is shifted further away from the subject's center of mass and more effort will be required to maintain balance.

METHODS

Hockey Bag

The hockey bags were adult bags designed for a player's ice-hockey equipment and a goalie's ice-hockey equipment. The volume of the small bag was 0.11 m^3 and the large bag had a volume of 0.36 m^3. The hockey bag straps were non-adjustable, as like most hockey bags, and so the strap length stayed the same for each participant. The short straps appear to be the reason for the congruent over-the-shoulder and on-the-back placement of the hockey bags for all participants in the study .The hockey bags were filled with styro-foam insulation to allow the bags to reveal their true volume. Designated spots, along the hockey bag's midline, were cut out of the insulation to insert metal weights.

Participants

The participants were composed of 15 male hockey players (23.4 ±2.63 years) with an average of 16.56 ±4.92 years of ice hockey experience and therefore hockey bag carriage experience. The average BMI of the participants was 24.97 and no participant in an obese weight range (BMI levels according to WHO, 2012). No injuries, musculoskeletal disorders, or any condition that would alter gait or load carriage were reported in any of the participants. All, but one of the participants carried the bag on their dominant right shoulder. For the one participant who carried his bag on his dominant left, the left gait cycle was used for analysis and pooled in with the right of the others. Also, for this one participant the left muscles were grouped with the right muscles of the other participants so that the "carrying side" and "non-carrying side" can be defined as right and left respectfully.

Prior to data collection, all participants read and signed an informed consent form approved by the University of Ottawa Ethics Committee.

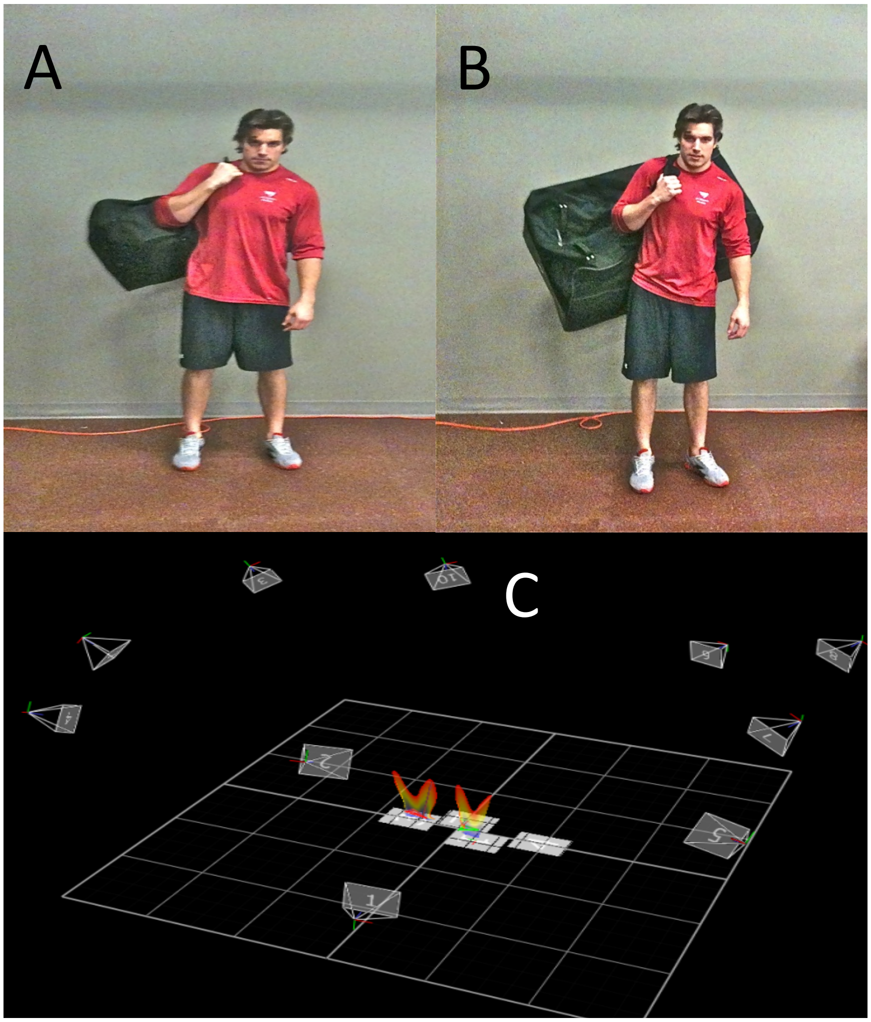
Experimental Protocol

Participants were required to wear gym sneakers, shorts and a shirt. Participants had their height and weight measured so that the bag could be adjusted to 10%, 20% and 30% of the participant's body weight (BW) and so records of the anthropometric measurements could be used for further analysis. The skin over lying the following muscles, as identified by project SENIAM and from previous unilateral and bilateral load carriage studies (Hermens, Freriks, & Merletti, 1999; Al-Khabbaz, Shimada, & Hasgawa, 2008; Motmans, Tomlow, & Vissers, 2006), were shaven and cleaned with an alcohol swab: erector spinae (ES), rectus abdominis (RA), gluteus maximus (GM), biceps femoris (BF), semitendinosus (ST), rectus femoris (RF), vastus medialis (VM), and gastrocnemius (GAS). A 16-channel electromyography (EMG) system (DS-B04, Bagnoli™-16 Desktop EMG system, Delsys Inc., Boston, MA) was set at a recording frequency of 1000 Hz and used to collect EMG activity.

Eight retro-reflective markers were placed on the left and right first toe, heel, lateral, and medial malleoli. Ten infrared, high speed, optical cameras, capturing at 100 Hz, were used to translate collected retro-reflective markers into a three-dimensional image using the VICON motion analysis system (VICON, Oxford Metrics, Oxford, UK). Four force plates (2 Bertec; 2 Kistler) set in a staggered walking position and capturing at 1000 Hz, were used along with motion analysis to aid in determining foot contact (Fig. 1).

Prior to testing, the participants were told to ignore the force plates. This was done to encourage normal stride lengths. Each participant was allowed to practice any condition and when ready would complete four trials of each load condition (10% BW, 20% BW, and 30% BW) including the control condition of walking with no bag/no load.

Participants then walked and carried a small hockey bag (0.11 m^3) and a large hockey bag (0.36 m^3) over their dominant shoulder along an 8 m path of smooth laboratory flooring. The participants were instructed to carry the bags in their normal fashion. It was observed after the study that all participants carried the bag over their dominant shoulder and resting posteriorly on the hip of their dominant carrying side (fig. 1).



<u>Figure 1</u>: A: The method in which the hockey bags were carried over the dominant shoulder, and resting posterior-laterally. **B:** Inside look of the hockey bag and the Styrofoam. **C:** Walking path over four force platforms and surrounded by 10 VICON motion analysis cameras.

DATA PROCESSING AND STATISTICAL ANALYSIS

The temporospatial variables were obtained from motion analysis. The right gait cycle was analyzed from heel-strike to heel-strike. This analyzed gait cycle was at the mid way point of the 8 m walk path and started when the subject's foot struck the force plate. Temporospatial data was then calculated using SMART Analyzer and built-in functions to measure marker-to-marker distance and determine stride length, stride width, and support time. The foot contact was determined with the help of motion analysis and force plate data.

The raw EMG data were transformed into a C3D file and imported into SMART Analyzer Software (BTS, Italy). The data were processed with a cut of frequency of 4 Hz, rectified using the temporal mean, and filtered using a single, low-pass Butterworth filter to smooth the data. The filtered EMG data were then normalized to 100% of the gait cycle and plotted as a percentage of the peak amplitude in the average of the control condition. This was done to give representations of peak muscle activity in the 10%, 20%, and 30% BW condition in comparison to the control. The integrated EMG (iEMG) was calculated from the normalized data, using the following formula in Microsoft Excel (2011):

$$\text{area} = \sum_{x=1}^{x=i} (x_{i+1} - x_i) * 1/2[f(x_{i+1}) + f(x_i)]$$

All measurements and results from the experiment are expressed as a mean with standard error (±). A two-way repeated measures analysis of variance (2-way repeated measures ANOVA) was used to examine the differences between the repeated factors of hockey bag load weight (4 levels: no load, load of 10% BW, load of 20% BW, and load of 30% BW) and hockey bag size (2 levels: small and large). When significance was found, a Bonferroni post-hoc test was performed using repeated measures t-tests. The probability of making a type-I error in all tests is presented with a P-value of <0.05. All significant data is spherical by not violating the Maulchy's Test of Sphericity. All analyses were performed using the statistical software package SPSS 20.0 for Macintosh (SPSS Inc. Chicago, IL, USA).

Data was inspected for outliers, if found they were removed. Outliers were defined as data sitting outside of 1.5 x the interquartile range. Outliers appeared in one participant, at the 30% BW conditions for the rectus abdominis, the semitendinosus, the vastus femoris, and the biceps femoris.

RESULTS

Tables 1-3 present the mean and standard error of peak EMG and iEMG of the measured muscles during walking with different bag sizes, different loads, and the statistical analysis results. Table 4 presents the temporospatial data.

The results showed no significant differences in the measurements of left and right ES, BF, ST, and GAS for the effects of bag size across all of the load conditions. Peak and iEMG increases were mixed among these muscles for larger increases in the small or large bag. Significant differences occurred in the right GM (see fig. 2). The right GM shows significantly larger values during load carriage with the small bag at the 10% BW condition in iEMG (P= 0.015). The right VM also showed significant increases (See fig. 3) in the small bag. The significance occurred at the the 30% BW level in peak EMG (P=0.044).

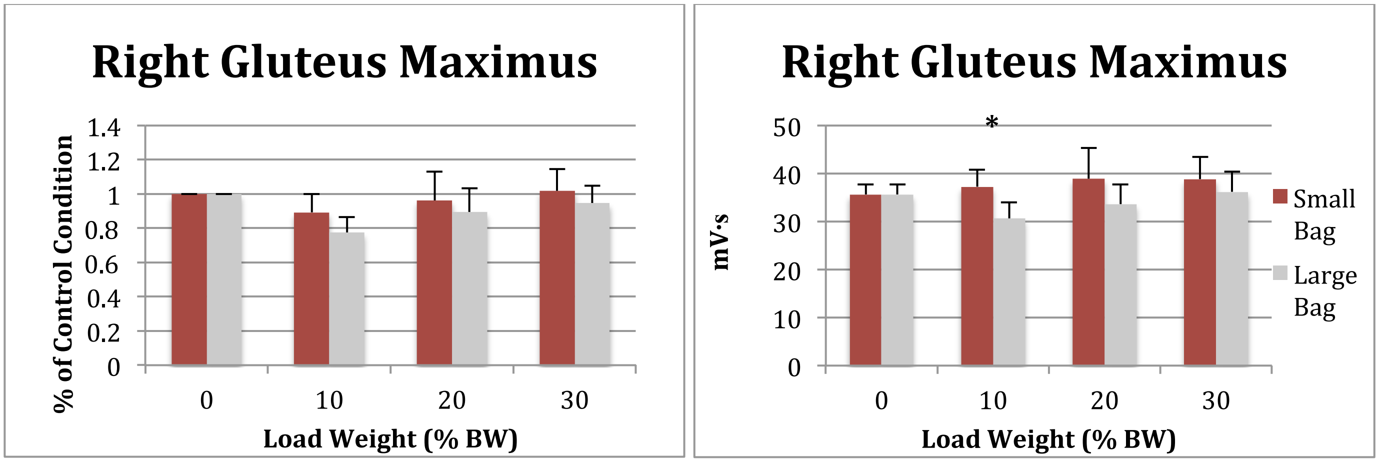
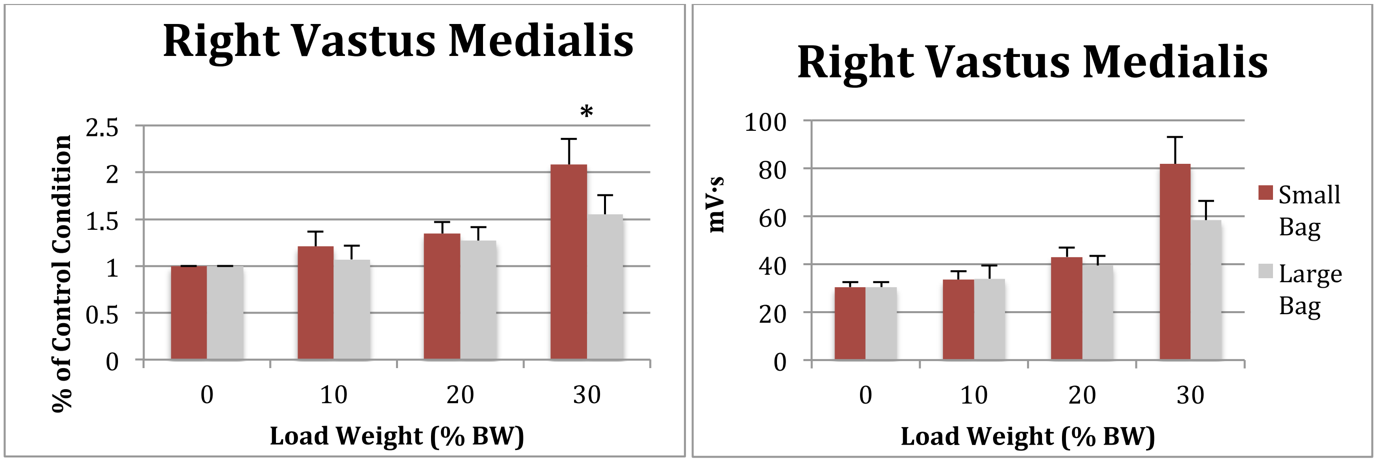


Figure 2: Peak EMG (left chart) and iEMG (right chart) of the right GM normalized to no load condition of the small and large hockey bags. Significance is shown at an alpha level of 0.05; "*" shows at which level this significance occurs.


Right Vastus Medialis

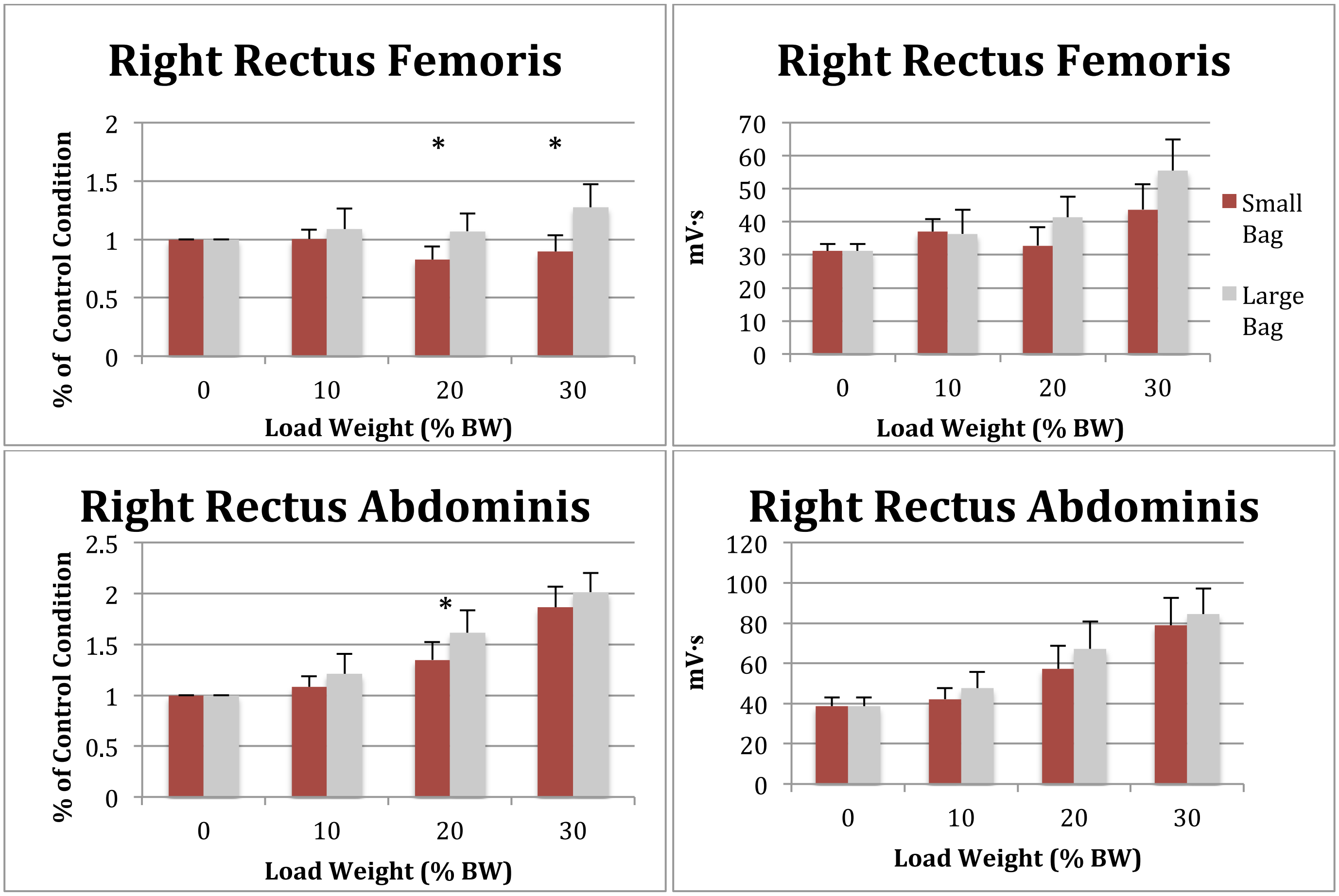
Right Vastus Medialis

<u>Figure 3</u>: Peak EMG and iEMG of the right VM normalized to no load condition of the small and large hockey bags. Significance is shown at an alpha level of 0.05; "*" shows at which level this significance occurs.

In summary, the right GM and the right VM produced significantly larger peak EMG and iEMG values for the small hockey bag. The significance occurred at the 10% BW condition for the right GM and the 30% BW load condition for the right VM.

The right RF yielded significant peak EMG increases for the large bag at the 20% BW load condition (P=0.046) and at the 30% BW load condition (P=0.03) (See fig. 5). The right RA revealed a significant peak EMG increase in the 20% BW load condition (P=0.026) (See fig. 6).

In summary, the right RF and the right RA produced larger peak and iEMG values for the large hockey bag. Significance occurs in the peak EMG at the 20% BW and 30% BW load conditions for the right RF and the 20% BW load condition for the right RA.



<u>Figure 5-6</u>: Peak EMG and iEMG of the right RF and right RA normalized to no load condition of the small and large hockey bags. Significance is shown at an alpha level of 0.05; "*" shows at which level this significance occurs.

Trunk iEMG - Size Effects

Muscle	Load (%BW)	Small bag	Large bag	P- value
RES	10	39.09 ±4.56	38.93 ±4.56	0.923
	20	39.71 ±5.09	41.38 ±5.14	0.533
	30	47.37 ±7.55	42.08 ±4.98	0.478
LES	10	34.56 ±4.12	40.27 ±7.28	0.300
	20	40.22 ±8.11	39.6 ±7.89	0.693
	30	43.61 ±7.73	45.14 ±6.85	0.748
RGM	**10**	**37.26 ±3.59**	**30.62 ±3.39**	**0.015**
	20	38.91 ±6.39	33.64 ±4.08	0.275
	30	38.84 ±4.67	36.2 ±4.18	0.535
LGM	10	33.98 ±1.60	33.35 ±2.59	0.782
	20	35.52 ±3.39	32.57 ±2.32	0.345
	30	41.62 ±6.72	37.8 ±4.07	0.549
RRA	10	42.2 ±5.42	47.66 ±8.10	0.324
	20	57.16 ±11.59	67.23 ±13.56	0.186
	30	78.95 ±13.68	84.4 ±12.88	0.254
LRA	10	44.75 ±8.92	40.35 ±8.24	0.183
	20	78.83 ±33.83	67.23 ±22.85	0.349
	30	123.25 ±53.80	97.63 ±36.81	0.179

Trunk Peak EMG - Size Effects

Muscle	Load (% BW)	Small bag	Large bag	P- value
RES	10	1.10 ±0.12	1.15 ±0.12	0.489
	20	1.13 ±0.16	1.13 ±0.11	0.980
	30	1.20 ±0.19	1.13 ±0.13	0.755
LES	10	1.07 ±0.16	1.23 ±0.18	0.174
	20	1.15 ±0.21	1.08 ±0.19	0.483
	30	1.32 ±0.28	1.28 ±0.22	0.822
RGM	10	0.89 ±0.11	0.77 ±0.09	0.194
	20	0.96 ±0.17	0.89 ±0.14	0.205
	30	1.02 ±0.13	0.95 ±0.10	0.596
LGM	10	0.94 ±0.05	0.95 ±0.07	0.839
	20	0.97 ±0.12	0.93 ±0.10	0.619
	30	1.27 ±0.30	0.96 ±0.14	0.199
RRA	10	1.08 ±0.10	1.21 ±0.12	0.494
	20	**1.35 ±0.18**	**1.61 ±0.22**	**0.026**
	30	1.86 ±0.20	2.01 ±0.19	0.388
LRA	10	1.15 ±0.15	0.92 ±0.12	0.057
	20	1.77 ±0.60	1.58 ±0.37	0.459
	30	2.50 ±0.74	2.22 ±0.57	0.144

Table 1: Mean and standard error of the integrated EMG and peak EMG measurements of the trunk. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05. Values are the total area under the peak EMG curves.

Lower limb iEMG - Size Effects

Muscle	Load (%BW)	Small bag	Large bag	P- value
RRF	10	36.96 ±3.85	36.35 ±7.22	0.913
	20	32.79 ±5.64	41.34 ±6.25	0.141
	30	43.72 ±7.64	55.51 ±9.37	0.253
LRF	10	36.17 ±4.50	45.14 ±9.08	0.288
	20	53.90 ±9.23	62.82 ±10.11	0.517
	30	46.85 ±10.37	64.03 ±15.23	0.283
RVM	10	33.50 ±3.46	33.9 ±5.44	0.930
	20	42.99 ±3.80	39.33 ±4.17	0.204
	30	81.80 ±11.25	58.25 ±8.14	0.057
LVM	10	29.90 ±3.49	39.5 ±10.44	0.344
	20	66.71 ±15.56	50.26 ±7.00	0.271
	30	49.48 ±11.23	37.88 ±6.06	0.132
RBF	10	32.85 ±3.13	31.06 ±3.34	0.459
	20	34.56 ±3.04	34.62 ±3.49	0.930
	30	41.07 ±4.00	38.88 ±3.85	0.413
LBF	10	35.24 ±3.51	34.28 ±2.85	0.727
	20	37.19 ±3.04	34.3 ±2.59	0.159
	30	37.19 ±2.55	39.61 ±3.62	0.372
RST	10	62.92 ±10.06	67.14 ±13.95	0.427
	20	86.75 ±21.57	66.53 ±11.71	0.145
	30	121.69 ±27.21	92.57 ±24.55	0.304
LST	10	95.52 ±26.43	125.60 ± 39.85	0.391
	20	193.87 ±78.31	98.84 ±21.73	0.141
	30	270.22 ±73.98	329.18 ±148.30	0.128
RGAS	10	76.27 ±13.97	70.54 ±6.94	0.621
	20	90.86 ±10.42	89.93 ±10.59	0.732
	30	129.30 ±17.80	122.18 ±15.42	0.670
LGAS	10	65.60 ±8.23	61.43 ±8.90	0.358
	20	92.00 ±13.54	94.36 ±13.29	0.623
	30	151.90 ±20.51	160.67 ±28.11	0.647

Table 2: Mean and standard error of the integrate EMG measurements of the lower limb. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05. Values are the total area under the peak EMG curves.

Lower limb Peak EMG - Size Effects

Muscle	Load (%BW)	Small bag	Large bag	P- value
RRF	10	1.00 ±0.08	1.09 ±0.18	0.532
	20	**0.83 ±0.11**	**1.07 ±0.15**	**0.046**
	30	**0.90 ±0.14**	**1.27 ±0.57**	**0.030**
LRF	10	1.10 ±0.14	1.02 ±0.20	0.715
	20	1.44 ±0.18	1.79 ±0.30	0.334
	30	1.41 ±0.26	1.88 ±0.47	0.372
RVM	10	1.21 ±0.16	1.07 ±0.15	0.495
	20	1.35 ±0.12	1.27 ±0.14	0.455
	30	**2.08 ±0.27**	**1.55 ±0.21**	**0.044**
LVM	10	1.01 ±0.05	1.08 ±0.14	0.655
	20	1.82 ±0.37	1.38 ±0.26	0.360
	30	1.47 ±0.44	1.11 ±0.22	0.201
RBF	10	0.98 ±0.09	0.95 ±0.13	0.870
	20	1.13 ±0.13	1.13 ±0.13	0.675
	30	1.10 ±0.12	1.15 ±0.14	0.584
LBF	10	1.02 ±0.07	1.13 ±0.11	0.331
	20	1.09 ±0.10	1.07 ±0.09	0.717
	30	1.12 ±0.12	1.21 ±0.11	0.320
RST	10	1.11 ±0.12	1.27 ±0.27	0.444
	20	1.33 ±0.26	1.17 ±0.15	0.449
	30	2.02 ±0.38	1.49 ±0.30	0.248
LST	10	1.78 ±0.44	2.63 ±0.86	0.210
	20	2.98 ±1.10	2.13 ±0.62	0.153
	30	3.89 ±0.98	3.25 ±1.03	0.574
RGAS	10	1.48 ±0.35	1.37 ±0.15	0.733
	20	1.76 ±0.20	1.81 ±0.22	0.626
	30	2.78 ±0.54	2.58 ±0.36	0.333
LGAS	10	1.33 ±0.14	1.38 ±0.21	0.794
	20	1.86 ±0.26	1.99 ±0.29	0.382
	30	2.90 ±0.37	3.50 ±0.64	0.244

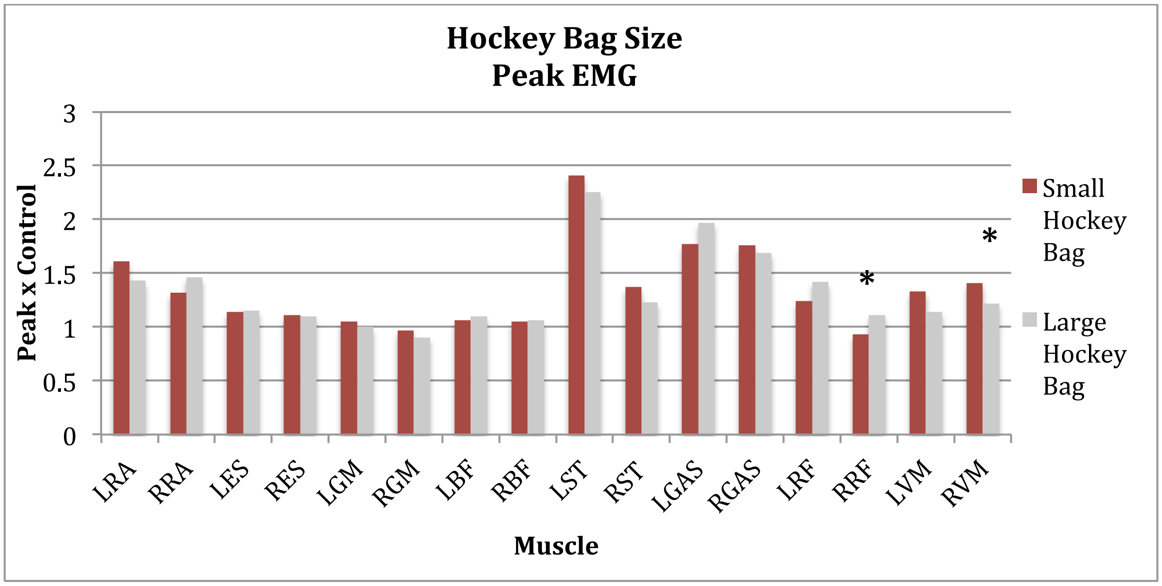
Table 3: Mean and standard error of the peak EMG measurements of the lower limb. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05.

The temporospatial mean, standard error and the corresponding p-value for the differences between the small and large bags are shown in table 4. The stride length, stride width and support time all stayed relatively the same between both sizes of bags.

Temporospatial – Size Effects

Measurement	Load (%BW)	Small Bag	Large Bag	P-value
Stride Length (m)	0	1.51±0.03	1.51 ±0.03	-
	10	1.46 ±0.03	1.46 ±0.03	0.992
	20	1.45 ±0.03	1.45 ±0.03	0.959
	30	1.39 ±0.03	1.39 ±0.03	0.920
Stride Width (cm)	0	10.6 ±0.5	10.6 ±0.5	-
	10	11.2 ±0.7	13.2 ±1.2	0.655
	20	13.1 ±0.9	13.6 ±1.1	0.635
	30	16.3 ±1.1	14.6 ±1.0	0.228
Single Support (% gait cycle)	0	73.8 ±0.9	73.8 ±0.9	-
	10	72.3 ±1.1	72.1 ±1.0	0.571
	20	70.5 ±0.8	70.8 ±0.8	0.533
	30	68.9 ±0.8	68.7±0.8	0.749
Double Support (% gait cycle)	0	26.2 ±0.9	26.2 ±0.9	-
	10	27.7 ±1.1	27.9 ±1.0	0.571
	20	29.5 ±0.8	29.2 ±0.8	0.533
	30	31.1 ±0.8	31.3 ±0.8	0.749

Table 4: Mean and standard error of stride length, stride width, and support phase during walking with a two different sizes of unilateral loads.



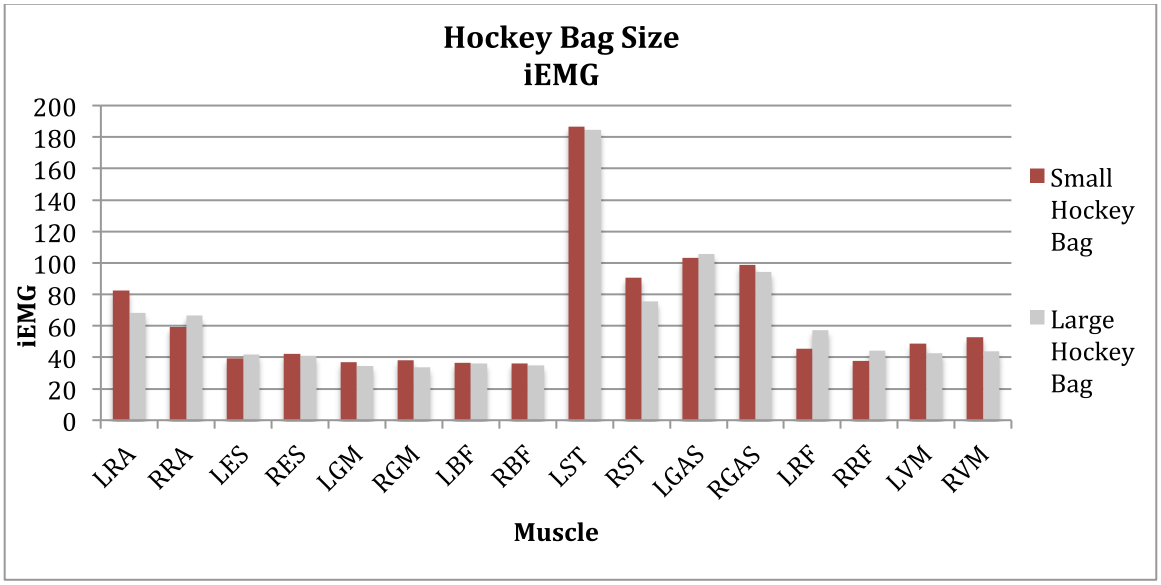


Figure 8: Mean peak EMG and iEMG of the small and large hockey bags at the 30% BW load condition. Significance is shown with an "*". $P<0.05$.

DISCUSSION

The aim of the present study was to examine the size effects of the hockey bag in unilateral load carriage on the muscle activities of the trunk and lower limbs. Most load carriage studies contain bags that are small in size, usually about the size of a backpack or duffle bag, this study filled the research gaps of the influence of carriage of small and large ice hockey bags on muscle activity of the trunk and lower limbs.

Only one study that explored the influence of container sizes on the kinematics of the lower limbs in unilateral load carriage was found, which was reported by Gillette et al. (2010). The authors reported no significant main effect in the difference between large (18.9 L) and small (3.8 L) bucket sizes when observing the kinematics around the hip, knee, and ankle. In Gillette's study, no measure of muscle activity was recorded.

In a study done by Simpson et al. (2010), on the load position influences on muscle activity during walking with load carriage in female hikers, the high load position exhibited a decrease in gastrocnemius iEMG when compared to the medium (P=0.005) and low load position (P= 0.02). The pack stayed in the same location on each participant but the experimenters were able to adjust the bag's center of mass (CoM) by shifting the weight vertically. The low load was aligned with the lumbar vertebrae (L1-L5), the medium load was aligned with the thoracic vertebrae T7-T12, and the high load was aligned with the thoracic vertebrae at the T1-T6 level. In the present study, the small hockey bag was located approximately at the medium position of the back and the large hockey bag was at the medium-low position. Unlike Simpson's study, the position of the bag was not recorded for, the strap length was different between the two sizes, and the center of mass of the bag was, more than likely, different between the two sizes. Simpson et al. reported that the differences were small and suggested that load position does not elicit significant gait modifications.

In the present study, as previously mentioned, the large bag would hang slightly lower than the small bag. This was due to the non-adjustable shoulder strap being shorter in the small bag and longer for the large bag. Similar to the results by Simpson et al., the right GAS showed greater peak and iEMG in the large, lower positioned bag, when compared to the small, higher sitting bag. However, the results were not statistically significant and the left (non-carrying side) showed increase in the GAS for the small bag. In the present study, the significant increases for iEMG and peak EMG occurred in the small bag for the right GM and the right VM, while increases in peak EMG occurred in large bag load carriage for the right RA and the right RF. The significant iEMG values for the right GM were relatively small and occurred only at the 10% BW load condition.

The right RA and right RF are significantly greater in the large bag for the 20% BW (right RF and right RA) and the 30% BW (right RF). This increasing trend of anterior muscle groups such as the trunk flexor (RA) and hip flexor (RF), indicating a forward leaning posture, may be the reason for the increased peak EMG during the large bag carriage. The large bag hangs lower on the posterior-lateral side of the subject, when compared to the small bag; it therefore generates a larger extensor moment that the anterior muscles have to overcome. Similarly, Simpson's study also conveyed increased forward lean with the lower positioned bag and a more upright posture with the higher positioned load.

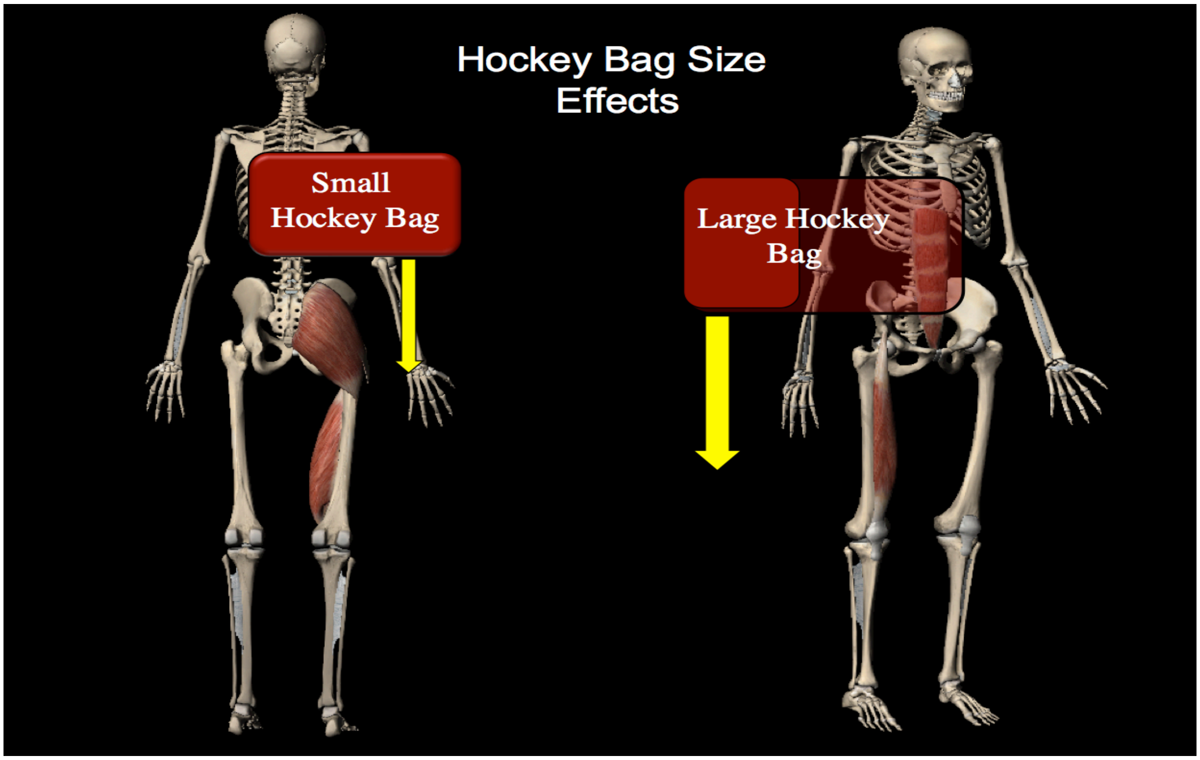


Figure 9: Significance increases in iEMG and peak EMG are shown for load carriage of the small bag and the large bag. The yellow vector demonstrates the theoretical larger force acting down in the larger bag. Muscles involved in flexion (hip and trunk) are greater in the large bag and muscles involved in extension (hip and knee) are greater for the small bag.

The temporospatial data between the small and large bag sizes were very comparable. The only significance was found in stride width and at the 10% BW load condition; a wider distance for the larger bag. Due to the small load condition (10% BW) and the values between bag sizes for the 10% load condition being so close (Small bag: 11.2±0.7; Large bag: 13.2 ±1.2), it is likely that this significance occurred because of chance.

Limitations

A limitation to this study would the inability to control bag position for each participant and still have the participants carry it in their normal fashion, the hockey bags used in this study, just like most hockey bags on the market, contain un-adjustable shoulder straps. A consequence of this was the possibility of the bag's sitting at different locations for each subject as the height changes between participants. Another limitation is found in the make-up of the load. Styrofoam created the bag to be formed much like a block and not so much like the bags used by the participants where the bag is not uniform in size or center of mass.

Limitations occur during the placement of EMG sensors and markers for recording the temporospatial measurements. Muscle tone, amount of subcutaneous adipose and location vary among each participant and can affect results (Turker, 1993).

Conclusion

The present study aimed to understand the relationship of the muscles of the trunk and lower limb on the size of the load in walking during unilateral load carriage. Carriage of the large hockey bag resulted in increased peak EMG of the RF and the RA. Carriage of the small hockey bag produced increased peak EMG of the VM and increased iEMG of the GM. Perhaps due to its longer shoulder straps, the larger bag would sit lower on the subjects when compared to the small bag. An increased activation of the trunk flexors (RA) and hip flexors (RF) results.

It is concluded that the differences between the small and large bags in unilateral hockey bag load carriage need to be further researched with exact bag position measurements to determine the results between the bag sizes. The size of the hockey bag in unilateral load carriage alters the relative position of the bag on the carrier and therefore affects the muscles of the trunk and lower limbs.

REFERENCES

1) Baranto, A., Hellstrom, M., Cederlund, C., Nyman, R., & Sward. (2009). Back pain and MRI changes in the thoraco-lumbar spine of top athletes in four different sports: A 15-year follow-up study. *Knee Surgery, Sports Traumatology, Arthroscopy , 17* (9), 1125-1134.

2) Corrigan, L., Law, N., & Law, N. (2010, October). The hockey bag survey. *Not Published* . Ottawa, ON, Canada.

3) Crosbie, J., Flynn, W., & Rutter, L. (1994). Effect of side load carriage on the kinematics of gait. *Gait & Posture , 2*, 103-108.

4) Gillette, J., Stevermer, C., Miller, R., Meardon, S., & Schwab, C. (2010). The effects of age and type of carrying task on lower extremity kinematics. *Ergonomics , 53* (3), 355-364.

5) Hermens, H., Freriks, B., & Merletti, R. (1999). European recommendations for surface electromyography: Results of the seniam project.

6) Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs:A review of physiological, biomechanical and medical aspects. *Applied Ergonomics , 27* (3), 207-216.

7) Komi, P.V., Kaneko, M., & Aura, O. (1987). EMG activity of the leg extensor muscles with special reference to mechanical efficiency in concentric and eccentric exercise. *International Journal of Sports Medicine, 8* (suppl), 22-29.

8) Lee, S., & Li, J.-X. (2011). Effects of asymmetrical load carriage and high-heeled shoes on lower extremity joint kinetics in healthy young women during walking. *Master's Thesis, University of Ottawa* .

9) Mackie, H., Legg, S., & Hedderley, D. (2003). Comparison of four different backpacks intended for school use. *Applied Ergonomics , 34*, 257-264.

10) Motmans, R., Tomlow, S., & Vissers, D. (2006). Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics , 49* (2), 127–138.

11) Mountain, M. (2002, November). *Muscle imbalance in hockey players contributes to back pain.* Retrieved May 2011, from Hockey Training Pro: http://hockeytrainingpro.com/wordpress/2009/11/muscle-imbalance-in-hockey-players-contributes-to-back-pain/

12) Simpson, K., Munro, B., & Steele, J. (2011). Backpack load affects lower limb muscle activity patterns of female hikers during prolonged load carriage. *Journal of Electromyography and Kinesiology , 21*, 782-788.

13) Smith, B., Ashton, K. M., Bohl, D., Richard, C., Metheny, J., & Klassen, S. (2006). Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. *Gait & Posture , 23*, 263-267.

14) Turker, K. (1993). Electromyography: some methodological problems and issues. *Physical Therapy , 73* (10), 698-710.

CHAPTER 4: RESULTS

Means, standard errors and the p-values are shown in tables 4-16 for the load effects (temporospatial, small bag peak EMG, large bag peak EMG, small bag iEMG, and large bag iEMG), side effects (trunk peak EMG, lower limb peak EMG, trunk iEMG, and lower limb iEMG), and hockey bag size effects (temporospatial, trunk peak EMG, lower limb peak EMG, trunk iEMG, and lower limb iEMG). Bar graphs in figures 12-18 show the mean and standard errors in small and large hockey bag load carriage of peak EMG- trunk, peak EMG – lower limb, iEMG- trunk, and iEMG – lower limb.

Table 3: Table of abbreviations

Muscle	Abbreviation
Rectus Abdominis	RA
Erector Spinae	ES
Gluteus Maximus	GM
Biceps Femoris	BF
Semitendinosus	ST
Medial Gastrocnemius	GAS
Rectus Femoris	RF
Vastus Medialis	VM

Load Effects

Temporospatial

Condition	Bag Size	Control	10% BW	P- value	20% BW	P- value	30% BW	P- value
Stride Length (m)	Small	1.51 ±0.03	1.46 ±0.03	0.211	1.45 ±0.03	0.117	**1.39 ±0.03**	**0.002**
	Large	1.51 ±0.03	**1.46 ±0.03**	**0.008**	**1.45 ±0.03**	**0.017**	**1.39 ±0.03**	**0.001**
Stride Width (cm)	Small	10.6 ±0.5	11.2 ±0.7	1.000	13.1 ±0.9	0.053	**16.3 ±1.1**	**0.000**
	Large	10.6 ±0.5	13.2 ±1.2	0.110	13.6 ±1.1	0.118	**14.6 ±1.0**	**0.024**
Double support (%)	Small	26.2 ±0.9	**27.7 ±1.1**	**0.026**	**29.5 ±0.8**	**0.001**	**31.1 ±0.8**	**0.000**
	Large	26.2 ±0.9	**27.9 ±1.0**	**0.000**	**29.2 ±0.8**	**0.000**	**31.3 ±0.8**	**0.000**

Table 4: Mean and standard error of stride length, stride width, and double support time during walking with a small (0.11 m^3) and large (0.36 m^3) unilateral load and the comparison results to the control condition (0% BW). Significance is shown in bold at a alpha level of $P<0.05$.

Small – Peak EMG

Muscle	10% BW	P- value	20% BW	P- value	30% BW	P- value
RES	1.10 ±0.12	1.000	1.13 ±0.16	1.000	1.20 ±0.19	1.000
LES	1.07 ±0.16	1.000	1.15 ±0.21	1.000	1.32 ±0.28	1.000
RGM	0.89 ±0.11	1.000	0.96 ±0.17	1.000	1.02 ±0.13	1.000
LGM	0.94 ±0.05	1.000	0.97 ±0.12	1.000	1.27 ±0.30	1.000
RRA	1.08 ±0.10	1.000	1.35 ±0.18	0.415	**1.86 ±0.20**	**0.005**
LRA	1.15 ±0.15	1.000	1.77 ±0.60	1.000	2.50 ±0.74	0.366
RRF	1.00 ±0.08	1.000	0.83 ±0.11	0.859	0.90 ±0.14	1.000
LRF	1.10 ±0.14	1.000	1.44 ±0.18	0.169	1.41 ±0.26	0.819
RVM	1.21 ±0.16	1.000	1.35 ±0.12	0.084	**2.08 ±0.27**	**0.008**
LVM	1.01 ±0.05	1.000	1.82 ±0.37	0.248	1.47 ±0.44	1.000
RBF	0.98 ±0.09	1.000	1.13 ±0.13	1.000	1.10 ±0.12	1.000
LBF	1.02 ±0.07	1.000	1.09 ±0.10	1.000	1.12 ±0.12	1.000
RST	1.11 ±0.12	1.000	1.33 ±0.26	1.000	2.02 ±0.38	0.100
LST	1.78 ±0.44	0.601	2.98 ±1.10	0.562	3.89 ±0.98	0.062
RGAS	1.48 ±0.35	1.000	**1.76 ±0.20**	**0.013**	**2.78 ±0.54**	**0.030**
LGAS	1.33 ±0.14	0.190	**1.86 ±0.26**	**0.030**	**2.90 ±0.37**	**0.001**

Large – Peak EMG

Muscle	10% BW	P- value	20% BW	P- value	30% BW	P- value
RES	1.15 ±0.12	1.000	1.13 ±0.11	1.000	1.13 ±0.13	1.000
LES	1.23 ±0.18	1.000	1.08 ±0.19	1.000	1.28 ±0.22	1.000
RGM	0.77 ±0.09	0.142	0.89 ±0.14	1.000	0.95 ±0.10	1.000
LGM	0.95 ±0.07	1.000	0.93 ±0.10	1.000	0.96 ±0.14	1.000
RRA	1.21 ±0.20	1.000	1.61 ±0.22	0.090	**2.01 ±0.19**	**0.001**
LRA	0.92 ±0.12	1.000	1.58 ±0.37	0.858	2.22 ±0.57	0.309
RRF	1.09 ±0.18	1.000	1.07 ±0.15	1.000	1.27 ±0.20	1.000
LRF	1.02 ±0.20	1.000	1.79 ±0.30	0.114	1.88 ±0.47	0.492
RVM	1.07 ±0.15	1.000	1.27 ±0.14	0.483	1.55 ±0.21	0.108
LVM	1.08 ±0.14	1.000	1.38 ±0.26	0.957	1.11 ±0.22	1.000
RBF	0.95 ±0.13	1.000	1.13 ±0.13	1.000	1.15 ±0.14	1.000
LBF	1.13 ±0.11	1.000	1.07 ±0.09	1.000	1.21 ±0.11	0.428
RST	1.27 ±0.27	1.000	1.17 ±0.15	1.000	1.49 ±0.30	0.737
LST	2.63 ±0.86	0.477	2.13 ±0.62	0.522	3.25 ±1.03	0.283
RGAS	1.37 ±0.15	0.156	**1.81 ±0.22**	**0.014**	**2.58 ±0.36**	**0.004**
LGAS	1.38 ±0.21	0.582	**1.99 ±0.29**	**0.026**	**3.50 ±0.64**	**0.009**

Table 5: Mean and standard error of peak EMG in the measured muscles during walking with a small (0.11 m^3) and large (0.36 m^3) unilateral load and the comparison to the control condition (0% BW). Significance is shown in bold at an alpha level of $P<0.05$.

Small – iEMG

Muscle	Control	10% BW	P- value	20% BW	P- value	30% BW	P- value
RES	39.11 ±3.06	39.09 ±4.56	1.000	39.71 ±5.09	1.000	47.37 ±7.55	0.864
LES	32.82 ±2.20	34.56 ±4.12	1.000	40.22 ±8.11	1.000	43.61 ±7.73	0.795
RGM	35.64 ±2.06	37.26 ±3.59	1.000	38.91 ±6.39	1.000	38.84 ±4.67	1.000
LGM	36.50 ±1.89	33.98 ±1.60	1.000	35.52 ±3.39	1.000	41.62 ±6.72	1.000
RRA	38.66 ±4.24	42.20 ±5.42	1.000	57.16 ±11.59	0.250	**78.95 ±13.68**	**0.010**
LRA	34.37 ±3.20	44.75 ±8.92	0.786	78.83 ±33.83	1.000	123.25 ±53.80	0.630
RRF	31.21 ±2.04	36.96 ±3.85	0.764	32.79 ±5.64	1.000	43.72 ±7.64	0.961
LRF	27.02 ±1.75	36.17 ±4.50	0.353	53.90 ±9.23	0.071	46.85 ±10.37	0.336
RVM	30.43 ±2.06	33.50 ±3.46	1.000	**42.99 ±3.80**	**0.005**	**81.80 ±11.25**	**0.002**
LVM	32.17 ±2.70	29.90 ±3.49	1.000	66.71 ±15.56	0.101	49.48 ±11.23	0.371
RBF	34.06 ±2.80	32.85 ±3.13	1.000	34.56 ±3.29	1.000	41.07 ±4.00	0.152
LBF	32.83 ±2.46	35.24 ±3.51	1.000	37.19 ±3.04	0.541	37.19 ±2.55	0.951
RST	53.61 ±7.29	62.92 ±10.06	0.427	86.75 ±21.57	0.521	121.69 ±27.21	0.050
LST	48.25 ±17.61	95.52 ±26.43	0.467	193.87± 78.31	0.478	**270.22± 73.98**	**0.042**
RGAS	53.64 ±5.00	76.27 ±13.97	0.766	**90.86 ±10.42**	**0.010**	**129.30± 17.80**	**0.004**
LGAS	45.38 ±4.24	**65.60 ±8.23**	**0.025**	**92.00 ±13.54**	**0.004**	**151.90± 20.51**	**0.000**

Table 6: Mean and standard error of iEMG in the measured muscles during walking with a small (0.11 m^3) unilateral load and the comparison to the control condition (0% BW). Significance is shown in bold at an alpha level of P<0.05.

Large – iEMG

Muscle	Control	10% BW	P- value	20% BW	P- value	30% BW	P- value
RES	39.11 ±3.06	38.93 ±4.56	1.000	41.38 ±5.14	1.000	42.08 ±4.98	1.000
LES	32.82 ±2.20	40.27 ±7.28	1.000	39.60 ±7.89	1.000	45.14 ±6.85	0.319
RGM	35.64 ±2.05	30.62 ±3.39	0.443	33.64 ±4.08	1.000	36.20 ±4.18	1.000
LGM	36.50 ±1.89	33.35 ±2.59	1.000	32.57 ±2.32	1.000	37.80 ±4.07	1.000
RRA	38.66 ±4.24	47.66 ±8.10	0.606	67.23 ±13.56	0.117	**84.40 ±12.88**	**0.002**
LRA	34.37 ±3.20	40.35 ±8.24	1.000	67.23 ±22.85	0.765	97.63 ±36.81	0.519
RRF	31.21 ±2.04	36.35 ±7.22	1.000	41.34 ±6.25	0.868	55.51 ±9.37	0.150
LRF	27.02 ±1.75	45.14 ±9.08	0.336	**62.82 ±10.11**	**0.015**	64.03 ±15.23	0.144
RVM	30.43 ±2.06	33.90 ±5.44	1.000	39.33 ±4.17	0.225	**58.25 ±8.14**	**0.014**
LVM	32.17 ±2.70	39.50 ±10.44	1.000	50.26 ±7.00	0.110	37.88 ±6.06	0.890
RBF	34.06 ±2.80	31.06 ±3.34	1.000	34.62 ±3.49	1.000	38.88 ±3.85	0.799
LBF	32.83 ±2.46	34.28 ±2.85	1.000	34.30 ±2.59	1.000	39.61 ±3.62	0.562
RST	53.61 ±7.29	67.14 ±13.95	0.943	66.53 ±11.71	0.434	92.57 ±24.55	0.646
LST	48.25 ±17.61	125.60 ±39.85	0.383	98.84 ±21.73	0.083	329.18 ±148.30	0.461
RGAS	53.64 ±5.00	70.54 ±6.94	0.058	**89.93 ±10.59**	**0.012**	**122.18± 15.42**	**0.001**
LGAS	45.38 ±4.24	61.43 ±8.90	1.000	**94.36 ±13.29**	**0.011**	**160.67± 28.11**	**0.004**

Table 7: Mean and standard error of iEMG in the measured muscles during walking with a large (0.36 m^3) unilateral load and the comparison results to the control condition (0% BW). Significance is shown in bold at an alpha level of $P<0.05$.

Side Effects

Trunk Peak EMG - Side Effects

Bag Size	Muscle	Load (%BW)	Left	Right	P- value
Small	ES	10	1.07 ±0.16	1.10 ±0.12	0.758
		20	1.15 ±0.21	1.13 ±0.16	0.909
		30	1.32 ±0.28	1.20 ±0.19	0.566
Large	ES	10	1.07 ±0.16	1.15 ±0.12	0.493
		20	1.15 ±0.21	1.13 ±0.11	0.919
		30	1.32 ±0.28	1.13 ±0.13	0.549
Small	GM	10	0.94 ±0.05	0.89 ±0.11	0.618
		20	0.97 ±0.12	0.96 ±0.17	0.957
		30	1.27 ±0.30	1.02 ±0.13	0.368
Large	GM	10	0.95 ±0.07	0.77 ±0.09	0.506
		20	0.93 ±0.10	0.89 ±0.14	0.834
		30	0.96 ±0.14	0.95 ±0.10	0.927
Small	RA	10	1.15 ±0.15	1.08 ±0.10	0.643
		20	1.77 ±0.60	1.35 ±0.18	0.432
		30	2.50 ±0.74	1.86±0.20	0.319
Large	RA	10	0.92 ±0.12	1.21±0.12	0.186
		20	1.58 ±0.37	1.61±0.22	0.925
		30	2.22 ±0.57	2.01±0.19	0.701

Table 8: Mean and standard error of the peak EMG measurements of the trunk. P-value levels are shown for the statistical comparison between the left and right sides of the muscle for carriage of both the small and large hockey bag. Significance is shown in bold at P<0.05. Values are normalized to the peak EMG during the control of walking without a bag or load (Control=1).

Lower limb Peak EMG - Side Effects

Bag Size	Muscle	Load (%BW)	Left	Right	P- value
Small	**RF**	10	1.10 ±0.14	1.00 ±0.08	0.589
		20	**1.44 ±0.18**	**0.83 ±0.11**	**0.022**
		30	**1.41 ±0.26**	**0.90 ±0.14**	**0.041**
Large	**RF**	10	1.02 ±0.20	1.09 ±0.18	0.801
		20	**1.79 ±0.30**	**1.07 ±0.15**	**0.028**
		30	1.88 ±0.47	1.27 ±0.57	0.233
Small	VM	10	1.01 ±0.05	1.21 ±0.16	0.251
		20	1.82 ±0.37	1.35 ±0.12	0.232
		30	1.47 ±0.44	2.08 ±0.27	0.147
Large	VM	10	1.08 ±0.14	1.07 ±0.15	0.968
		20	1.38 ±0.26	1.27 ±0.14	0.764
		30	1.11 ±0.22	1.55 ±0.21	0.206
Small	BF	10	1.02 ±0.07	0.98 ±0.09	0.899
		20	1.09 ±0.10	1.13 ±0.13	0.350
		30	1.12 ±0.12	1.10 ±0.12	0.607
Large	BF	10	1.13 ±0.11	0.95 ±0.13	0.412
		20	1.07 ±0.09	1.13 ±0.13	0.202
		30	1.21 ±0.11	1.15 ±0.14	0.964
Small	**ST**	10	1.78 ±0.44	1.11 ±0.12	0.113
		20	2.98 ±1.10	1.33 ±0.26	0.089
		30	**3.89 ±0.98**	**2.02 ±0.38**	**0.044**
Large	**ST**	10	2.63 ±0.86	1.27 ±0.27	0.064
		20	2.13 ±0.62	1.17 ±0.15	0.102
		30	**3.25 ±1.03**	**1.49 ±0.30**	**0.035**
Small	GAS	10	1.33 ±0.14	1.48 ±0.35	0.576
		20	1.86 ±0.26	1.76 ±0.20	0.729
		30	2.90 ±0.37	2.78 ±0.54	0.813
Large	GAS	10	1.38 ±0.21	1.37 ±0.15	0.942
		20	1.99 ±0.29	1.81 ±0.22	0.505
		30	3.50 ±0.64	2.58 ±0.36	0.135

Table 9: Mean and standard error of the peak EMG measurements of the lower limb P-value levels are shown for the statistical comparison between the left and right sides of the muscle for carriage of both the small and large hockey bag. Significance is shown in bold at $P<0.05$. Values are normalized to the peak EMG during the control of walking without a bag or load (Control=1).

Trunk iEMG - Side Effects

Bag Size	Muscle	Load (%BW)	Left	Right	P- value
Small	ES	0	32.82 ±2.20	39.11 ±3.06	0.053
		10	34.56 ±4.12	39.09 ±4.56	0.366
		20	40.22 ±8.11	39.71 ±5.09	0.945
		30	43.61 ±7.73	47.37 ±7.55	0.543
Large	ES	0	32.82 ±2.20	39.11 ±3.06	0.053
		10	40.27 ±7.28	38.93 ±4.56	0.847
		20	39.6 ±7.89	41.38 ±5.14	0.825
		30	45.14 ±6.85	42.08 ±4.98	0.566
Small	GM	0	36.5 ±1.89	35.64 ±2.05	0.713
		10	33.98 ±1.60	37.26 ±3.59	0.383
		20	35.52 ±3.39	38.91 ±6.39	0.503
		30	41.62 ±6.72	38.84 ±4.67	0.645
Large	GM	0	36.5 ±1.89	35.64 ±2.05	0.713
		10	33.35 ±2.59	30.62 ±3.39	0.417
		20	32.57 ±2.32	33.64 ±4.08	0.768
		30	37.8 ±4.07	36.2 ±4.18	0.615
Small	RA	0	34.37 ±3.20	38.66 ±4.24	0.140
		10	44.75 ±8.92	42.2 ±5.42	0.660
		20	78.83 ±33.83	57.16 ±11.59	0.379
		30	123.25 ±53.80	78.95 ±13.68	0.311
Large	RA	0	34.37 ±3.20	38.66 ±4.24	0.140
		10	40.35 ±8.24	47.66 ±8.10	0.267
		20	67.23 ±22.85	67.23 ±13.56	1.000
		30	97.63 ±36.81	84.4 ±12.88	0.632

Table 10: Mean and standard error of the integrate EMG measurements of the trunk. P-value levels are shown for the statistical comparison between the left and right muscles in carriage of the small and large hockey bag. Significance is shown in bold at P<0.05. Values are the total area under the peak EMG curves.

(next page)

Table 11: Mean and standard error of the integrate EMG measurements of the lower limbs. P-value levels are shown for the statistical comparison between the left and right muscles (P<0.05)

Lower limb iEMG - Side Effects

Bag Size	Muscle	Load (%BW)	Left	Right	P- value
Small	RF	0	27.02 ±1.75	31.21 ±2.04	0.107
		10	36.17 ±4.50	36.96 ±3.85	0.894
		20	53.90 ±9.23	32.79 ±5.64	0.086
		30	46.85 ±10.37	43.72 ±7.64	0.763
Large	RF	0	27.02 ±1.75	31.21 ±2.04	0.107
		10	45.14 ±9.08	36.35 ±7.22	0.498
		20	62.82 ±10.11	41.34 ±6.25	0.050
		30	64.03 ±15.23	55.51 ±9.37	0.628
Small	VM	0	32.17 ±2.70	30.43 ±2.06	0.605
		10	29.90 ±3.49	33.50 ±3.46	0.491
		20	66.71 ±15.56	42.99 ±3.80	0.134
		30	49.48 ±11.23	81.80 ±11.25	0.610
Large	VM	0	32.17 ±2.70	30.43 ±2.06	0.605
		10	39.5 ±10.44	33.9 ±5.44	0.626
		20	50.26 ±7.00	39.33 ±4.17	0.238
		30	37.88 ±6.06	58.25 ±8.14	0.061
Small	BF	0	32.83 ±2.46	34.06 ±2.80	0.644
		10	35.24 ±3.51	32.85 ±3.13	0.860
		20	37.19 ±3.04	34.56 ±3.04	0.814
		30	37.19 ±2.55	41.07 ±4.00	0.140
Large	BF	0	32.83 ±2.46	34.06 ±2.80	0.644
		10	34.28 ±2.85	31.06 ±3.34	0.253
		20	34.3 ±2.59	34.62 ±3.49	0.279
		30	39.61 ±3.62	38.88 ±3.85	0.594
Small	**ST**	0	48.25 ±17.61	53.61 ±7.29	0.262
		10	95.52 ±26.43	62.92 ±10.06	0.103
		20	193.87 ±78.31	86.75 ±21.57	0.057
		30	**270.22 ±73.98**	**121.69 ±27.21**	**0.030**
Large	ST	0	48.25 ±17.61	53.61 ±7.29	0.262
		10	125.60 ± 39.85	67.14 ±13.95	0.137
		20	98.84 ±21.73	66.53 ±11.71	0.225
		30	329.18 ±148.30	92.57 ±24.55	0.094
Small	GAS	0	45.38 ±4.24	53.64 ±5.00	0.078
		10	65.60 ±8.23	76.27 ±13.97	0.391
		20	92.00 ±13.54	90.86 ±10.42	0.931
		30	151.90 ±20.51	129.30 ±17.80	0.263
Large	GAS	0	45.38 ±4.24	53.64 ±5.00	0.078
		10	61.43 ±8.90	70.54 ±6.94	0.185
		20	94.36 ±13.29	89.93 ±10.59	0.711
		30	160.67 ±28.11	122.18 ±15.42	0.126

Size Effects

Temporospatial – Size Effects

Measurement	Load (%BW)	Small Bag	Large Bag	P-value
Stride Length (m)	0	1.51±0.03	1.51 ±0.03	-
	10	1.46 ±0.03	1.46 ±0.03	0.992
	20	1.45 ±0.03	1.45 ±0.03	0.959
	30	1.39 ±0.03	1.39 ±0.03	0.920
Stride Width (cm)	0	10.6 ±0.5	10.6 ±0.5	-
	10	11.2 ±0.7	13.2 ±1.2	0.655
	20	13.1 ±0.9	13.6 ±1.1	0.635
	30	16.3 ±1.1	14.6 ±1.0	0.228
Single Support (% gait cycle)	0	73.8 ±0.9	73.8 ±0.9	-
	10	72.3 ±1.1	72.1 ±1.0	0.571
	20	70.5 ±0.8	70.8 ±0.8	0.533
	30	68.9 ±0.8	68.7±0.8	0.749
Double Support (% gait cycle)	0	26.2 ±0.9	26.2 ±0.9	-
	10	27.7 ±1.1	27.9 ±1.0	0.571
	20	29.5 ±0.8	29.2 ±0.8	0.533
	30	31.1 ±0.8	31.3 ±0.8	0.749

Table 12: Mean and standard error of the temporospatial measurements. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05.

Trunk Peak EMG - Size Effects

Muscle	Load (% BW)	Small	Large	P- value
RES	10	1.10 ±0.12	1.15 ±0.12	0.489
	20	1.13 ±0.16	1.13 ±0.11	0.980
	30	1.20 ±0.19	1.13 ±0.13	0.755
LES	10	1.07 ±0.16	1.23 ±0.18	0.174
	20	1.15 ±0.21	1.08 ±0.19	0.483
	30	1.32 ±0.28	1.28 ±0.22	0.822
RGM	10	0.89 ±0.11	0.77 ±0.09	0.194
	20	0.96 ±0.17	0.89 ±0.14	0.205
	30	1.02 ±0.13	0.95 ±0.10	0.596
LGM	10	0.94 ±0.05	0.95 ±0.07	0.839
	20	0.97 ±0.12	0.93 ±0.10	0.619
	30	1.27 ±0.30	0.96 ±0.14	0.199
RRA	10	1.08 ±0.10	1.21 ±0.12	0.494
	20	**1.35 ±0.18**	**1.61 ±0.22**	**0.026**
	30	1.86 ±0.20	2.01 ±0.19	0.388
LRA	10	1.15 ±0.15	0.92 ±0.12	0.057
	20	1.77 ±0.60	1.58 ±0.37	0.459
	30	2.50 ±0.74	2.22 ±0.57	0.144

Table 13: Mean and standard error of the peak EMG measurements of the trunk. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05.

Lower limb Peak EMG - Size Effects

Muscle	Load (%BW)	Small	Large	P- value
RRF	10	1.00 ±0.08	1.09 ±0.18	0.532
	20	**0.83 ±0.11**	**1.07 ±0.15**	**0.046**
	30	**0.90 ±0.14**	**1.27 ±0.57**	**0.030**
LRF	10	1.10 ±0.14	1.02 ±0.20	0.715
	20	1.44 ±0.18	1.79 ±0.30	0.334
	30	1.41 ±0.26	1.88 ±0.47	0.372
RVM	10	1.21 ±0.16	1.07 ±0.15	0.495
	20	1.35 ±0.12	1.27 ±0.14	0.455
	30	**2.08 ±0.27**	**1.55 ±0.21**	**0.044**
LVM	10	1.01 ±0.05	1.08 ±0.14	0.655
	20	1.82 ±0.37	1.38 ±0.26	0.360
	30	1.47 ±0.44	1.11 ±0.22	0.201
RBF	10	0.98 ±0.09	0.95 ±0.13	0.870
	20	1.13 ±0.13	1.13 ±0.13	0.675
	30	1.10 ±0.12	1.15 ±0.14	0.584
LBF	10	1.02 ±0.07	1.13 ±0.11	0.331
	20	1.09 ±0.10	1.07 ±0.09	0.717
	30	1.12 ±0.12	1.21 ±0.11	0.320
RST	10	1.11 ±0.12	1.27 ±0.27	0.444
	20	1.33 ±0.26	1.17 ±0.15	0.449
	30	2.02 ±0.38	1.49 ±0.30	0.248
LST	10	1.78 ±0.44	2.63 ±0.86	0.210
	20	2.98 ±1.10	2.13 ±0.62	0.153
	30	3.89 ±0.98	3.25 ±1.03	0.574
RGAS	10	1.48 ±0.35	1.37 ±0.15	0.733
	20	1.76 ±0.20	1.81 ±0.22	0.626
	30	2.78 ±0.54	2.58 ±0.36	0.333
LGAS	10	1.33 ±0.14	1.38 ±0.21	0.794
	20	1.86 ±0.26	1.99 ±0.29	0.382
	30	2.90 ±0.37	3.50 ±0.64	0.244

Table 14: Mean and standard error of the peak EMG measurements of the lower limbs. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05. Values are normalized to the peak EMG during the control of walking without a bag or load (Control=1).

Trunk iEMG - Size Effects

Muscle	Load (%BW)	Small	Large	P- value
RES	10	39.09 ±4.56	38.93 ±4.56	0.923
	20	39.71 ±5.09	41.38 ±5.14	0.533
	30	47.37 ±7.55	42.08 ±4.98	0.478
LES	10	34.56 ±4.12	40.27 ±7.28	0.300
	20	40.22 ±8.11	39.6 ±7.89	0.693
	30	43.61 ±7.73	45.14 ±6.85	0.748
RGM	**10**	**37.26 ±3.59**	**30.62 ±3.39**	**0.015**
	20	38.91 ±6.39	33.64 ±4.08	0.275
	30	38.84 ±4.67	36.2 ±4.18	0.535
LGM	10	33.98 ±1.60	33.35 ±2.59	0.782
	20	35.52 ±3.39	32.57 ±2.32	0.345
	30	41.62 ±6.72	37.8 ±4.07	0.549
RRA	10	42.2 ±5.42	47.66 ±8.10	0.324
	20	57.16 ±11.59	67.23 ±13.56	0.186
	30	78.95 ±13.68	84.4 ±12.88	0.254
LRA	10	44.75 ±8.92	40.35 ±8.24	0.183
	20	78.83 ±33.83	67.23 ±22.85	0.349
	30	123.25 ±53.80	97.63 ±36.81	0.179

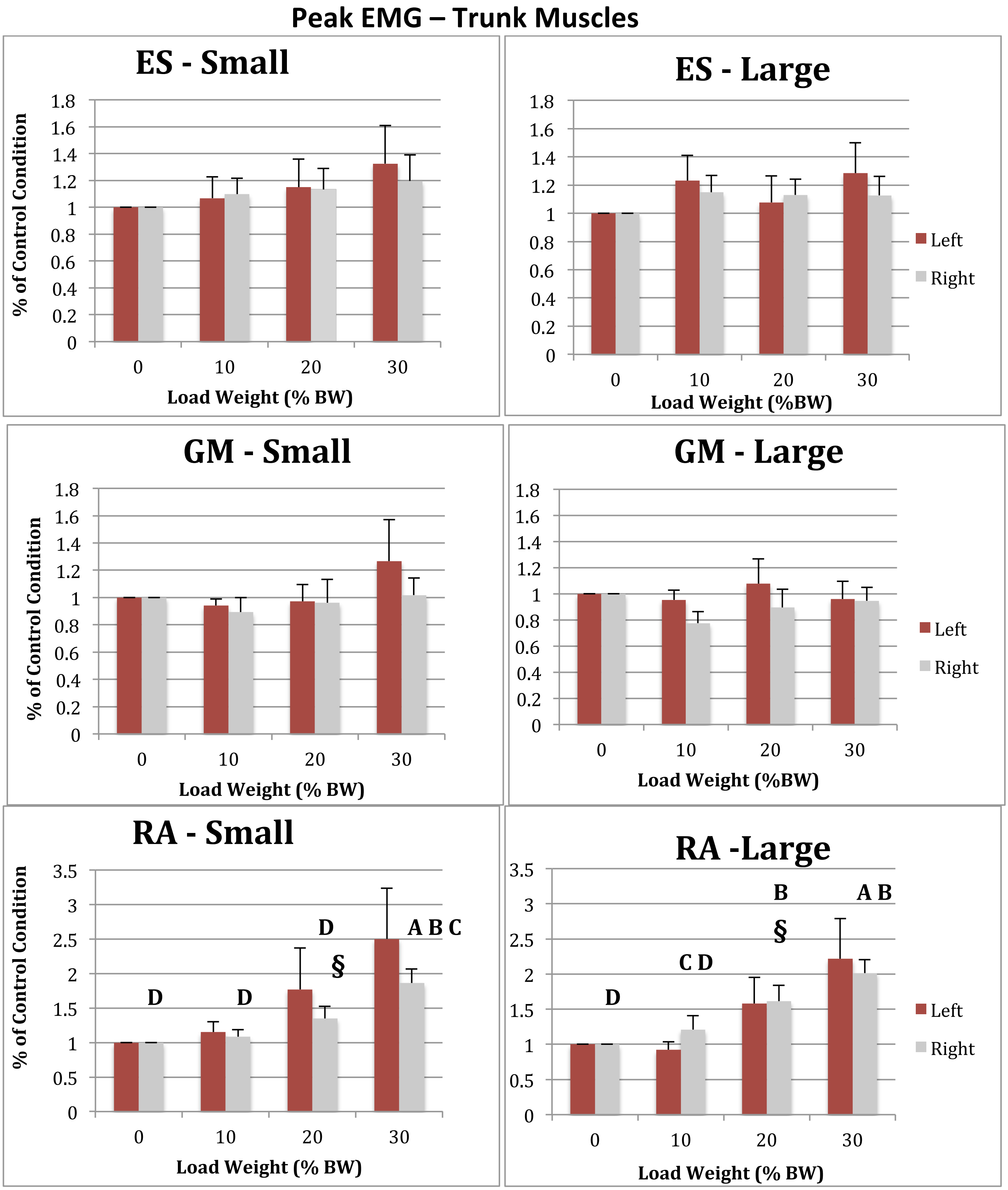
Table 15: Mean and standard error of the integrate EMG measurements of the trunk. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05. Values are the total area under the peak EMG curves.

Lower limb iEMG - Size Effects

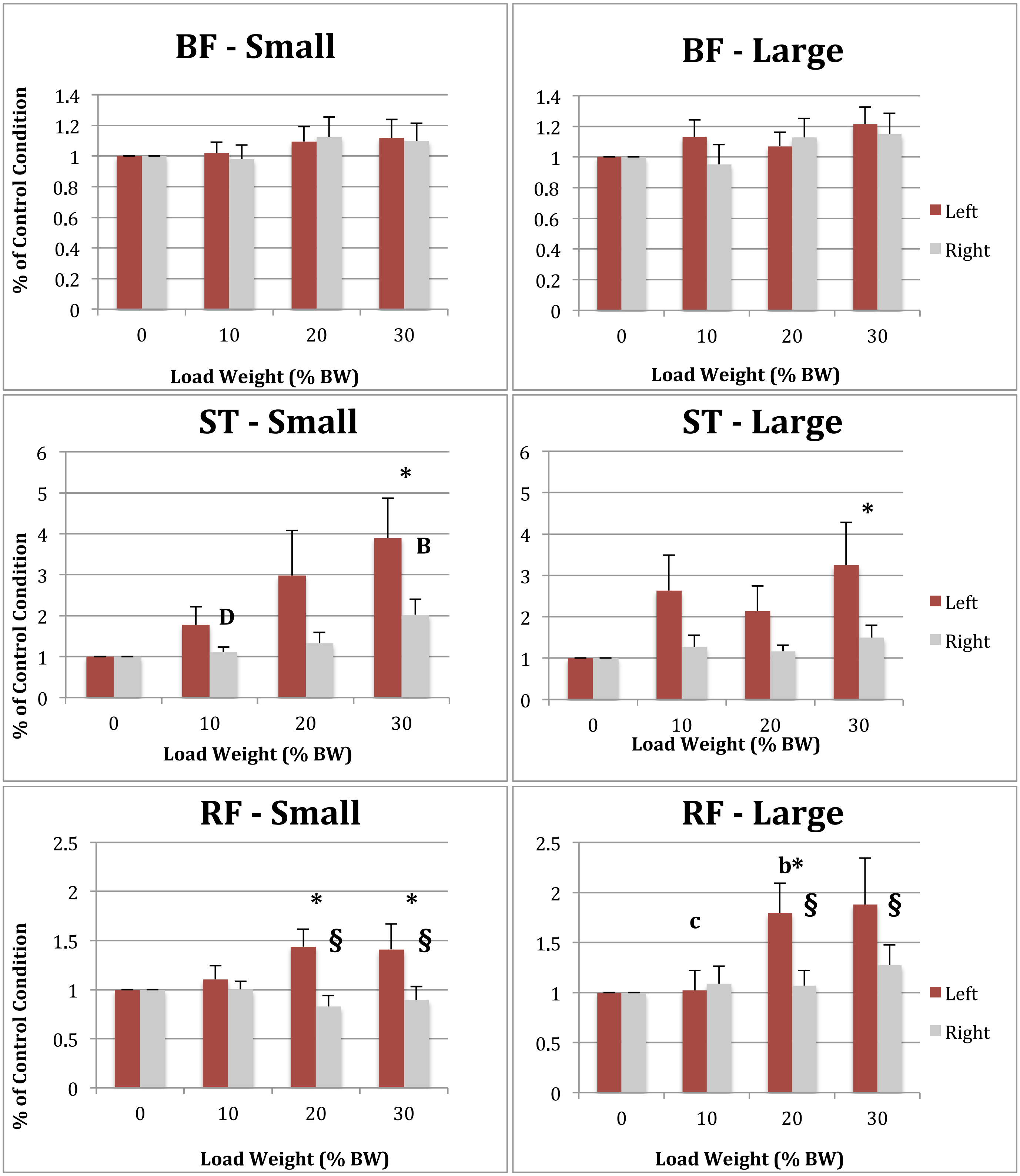
Muscle	Load (%BW)	Small	Large	P- value
RRF	10	36.96 ±3.85	36.35 ±7.22	0.913
	20	32.79 ±5.64	41.34 ±6.25	0.141
	30	43.72 ±7.64	55.51 ±9.37	0.253
LRF	10	36.17 ±4.50	45.14 ±9.08	0.288
	20	53.90 ±9.23	62.82 ±10.11	0.517
	30	46.85 ±10.37	64.03 ±15.23	0.283
RVM	10	33.50 ±3.46	33.9 ±5.44	0.930
	20	42.99 ±3.80	39.33 ±4.17	0.204
	30	81.80 ±11.25	58.25 ±8.14	0.057
LVM	10	29.90 ±3.49	39.5 ±10.44	0.344
	20	66.71 ±15.56	50.26 ±7.00	0.271
	30	49.48 ±11.23	37.88 ±6.06	0.132
RBF	10	32.85 ±3.13	31.06 ±3.34	0.459
	20	34.56 ±3.04	34.62 ±3.49	0.930
	30	41.07 ±4.00	38.88 ±3.85	0.413
LBF	10	35.24 ±3.51	34.28 ±2.85	0.727
	20	37.19 ±3.04	34.3 ±2.59	0.159
	30	37.19 ±2.55	39.61 ±3.62	0.372
RST	10	62.92 ±10.06	67.14 ±13.95	0.427
	20	86.75 ±21.57	66.53 ±11.71	0.145
	30	121.69 ±27.21	92.57 ±24.55	0.304
LST	10	95.52 ±26.43	125.60 ± 39.85	0.391
	20	193.87 ±78.31	98.84 ±21.73	0.141
	30	270.22 ±73.98	329.18 ±148.30	0.128
RGAS	10	76.27 ±13.97	70.54 ±6.94	0.621
	20	90.86 ±10.42	89.93 ±10.59	0.732
	30	129.30 ±17.80	122.18 ±15.42	0.670
LGAS	10	65.60 ±8.23	61.43 ±8.90	0.358
	20	92.00 ±13.54	94.36 ±13.29	0.623
	30	151.90 ±20.51	160.67 ±28.11	0.647

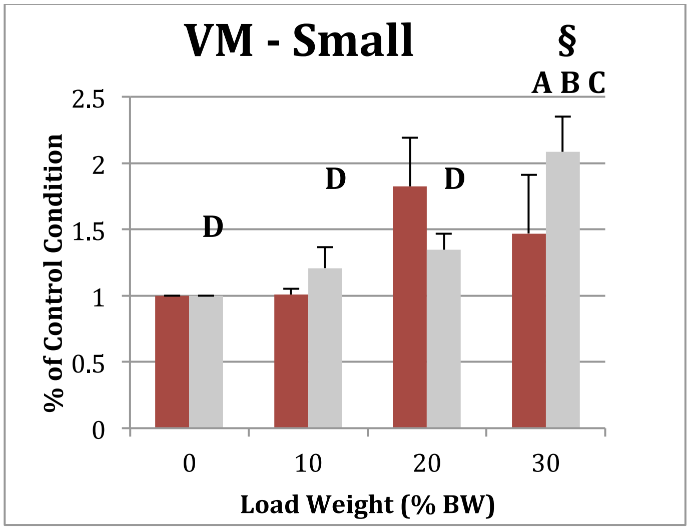
Table 16: Mean and standard error of the integrate EMG measurements of the lower limb. P-value levels are shown for the statistical comparison between the small and large hockey bag. Significance is shown in bold at P<0.05. Values are the total area under the peak EMG curves.

Figure 12-18: Bar graphs of the mean and standard error Peak EMG and iEMG are shown below for the muscles of the trunk and lower limb. Significance is shown at an alpha level of 0.05; "A" vs. right Control; "B" vs. right 10% BW; "C" vs. right 20% BW; "D" vs. right 30% BW ("a", "b" "c", and "d" are for left side). "*" denotes significance between left and right sides. "§" denotes significance between small and large bags



Peak EMG – Lower Limb

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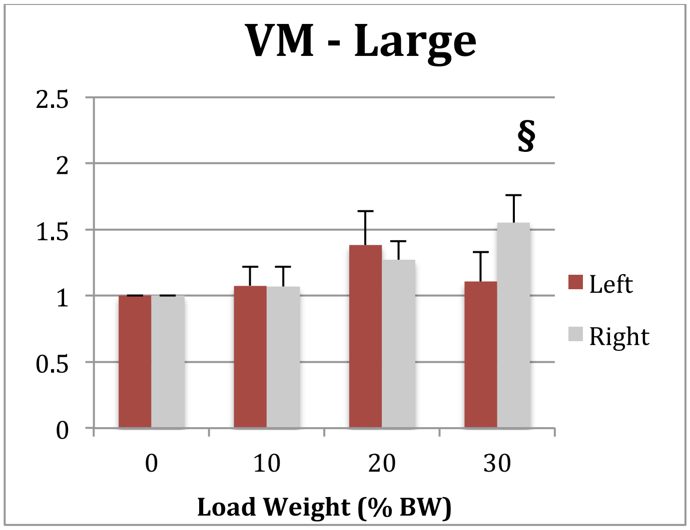
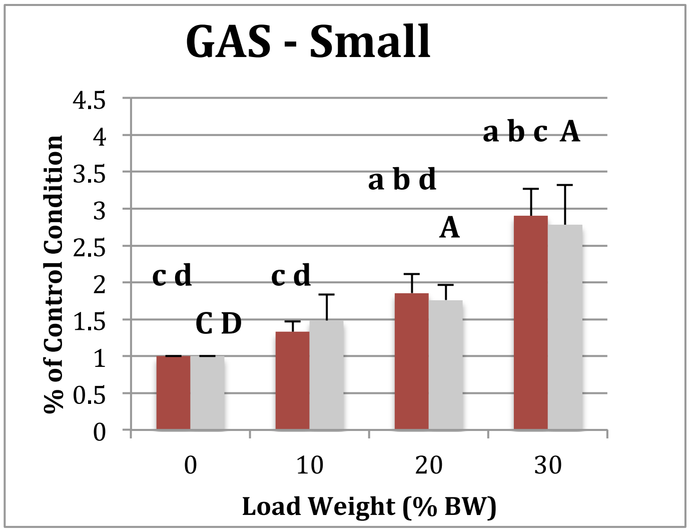
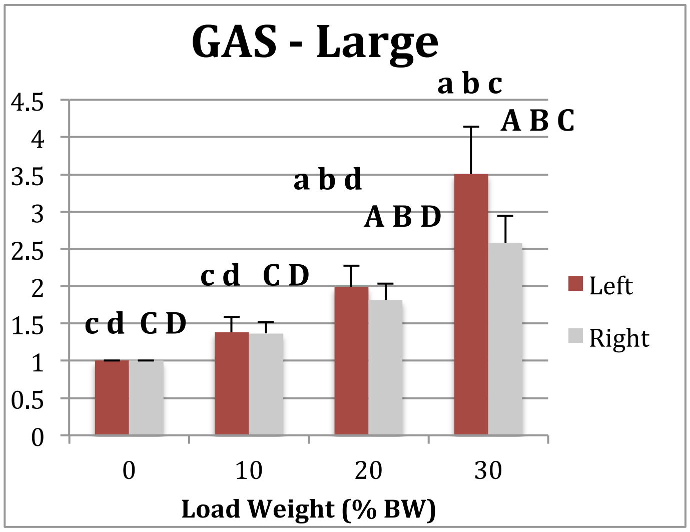
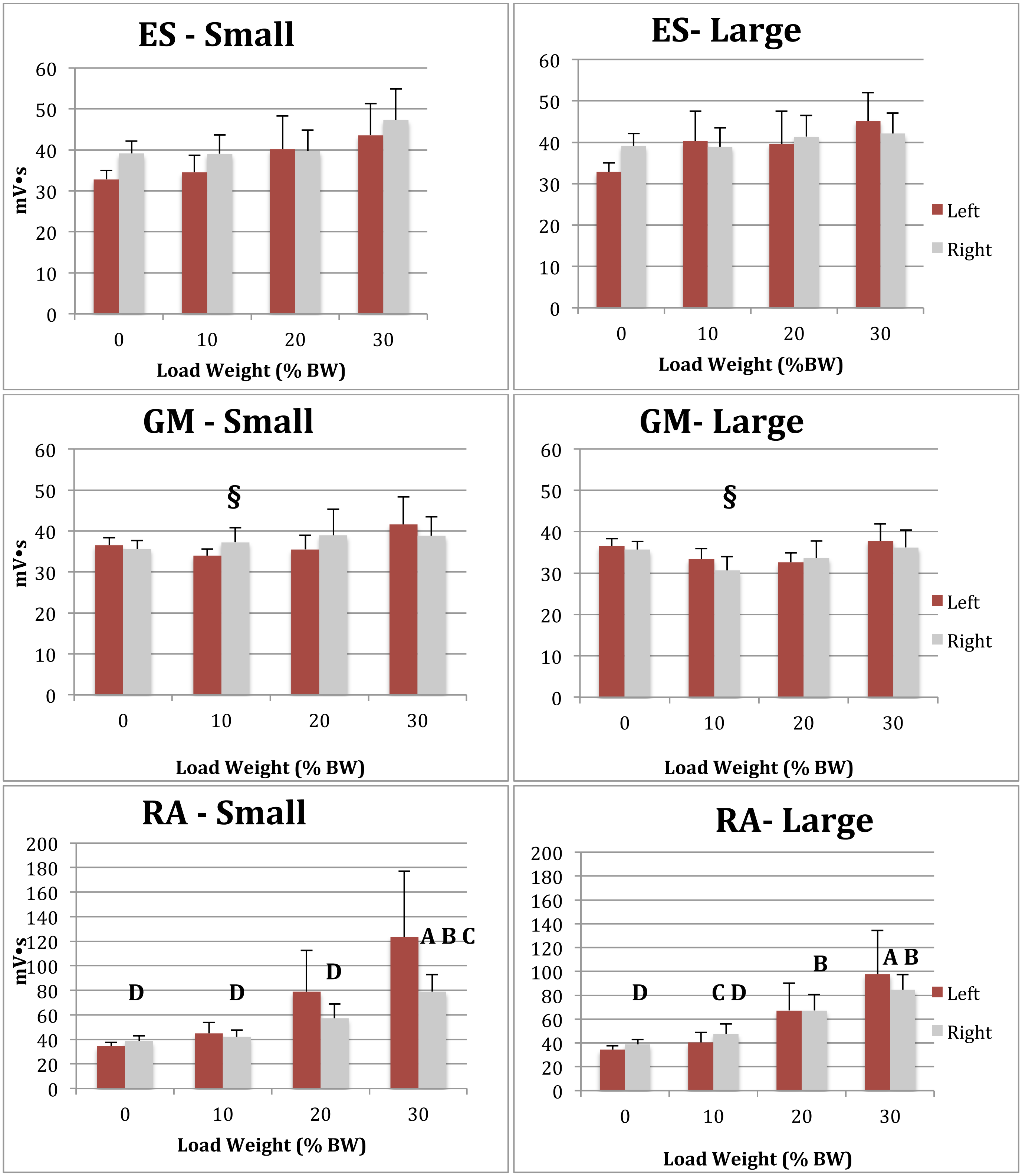
§
A B C
D
D
D
2.5
2
1.5
1
0.5
0
% of Control Condition
0
10
20
30
Load Weight (% BW)


VM - Large
§
2.5
2
1.5
1
0.5
0
0
10
20
30
Load Weight (% BW)
Left
Right

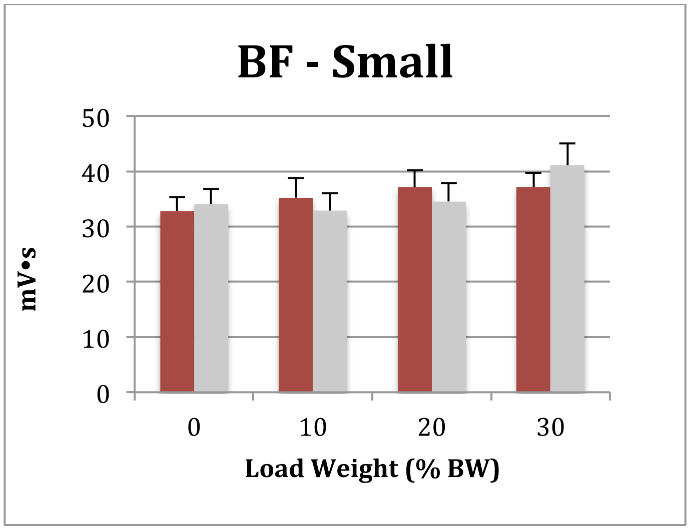

GAS - Small
a b c A
a b d
A
c d
c d
C D
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
% of Control Condition
0
10
20
30
Load Weight (% BW)

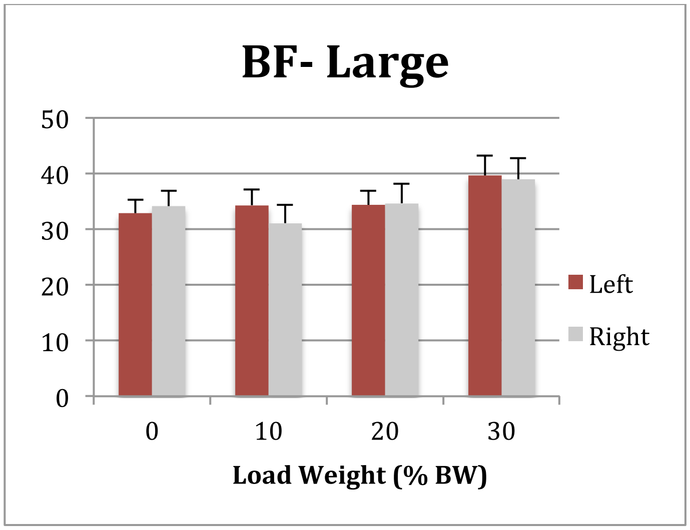

GAS - Large
a b c
A B C
a b d
A B D
c d C D
c d C D
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
Load Weight (% BW)
Left
Right

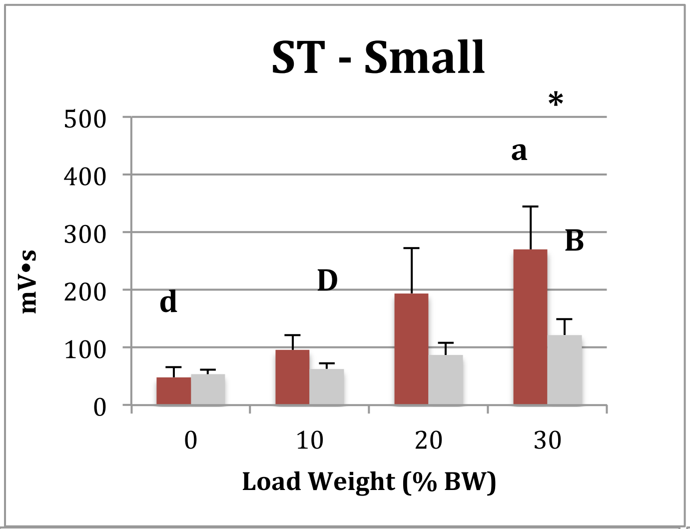
iEMG – Trunk Muscles

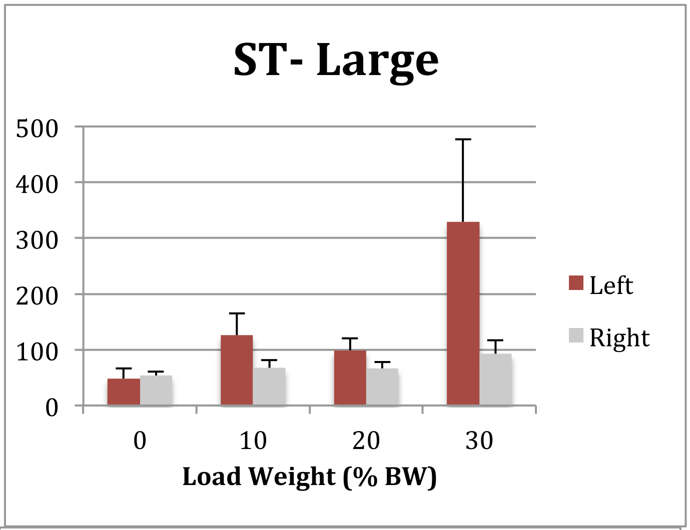


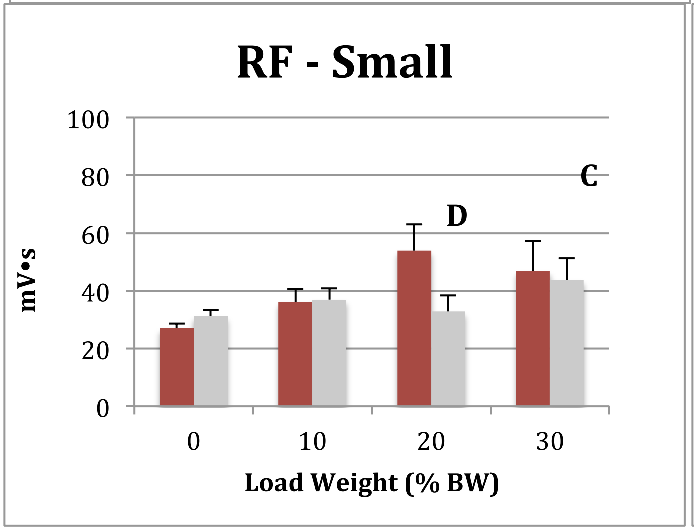
iEMG – Lower Limb

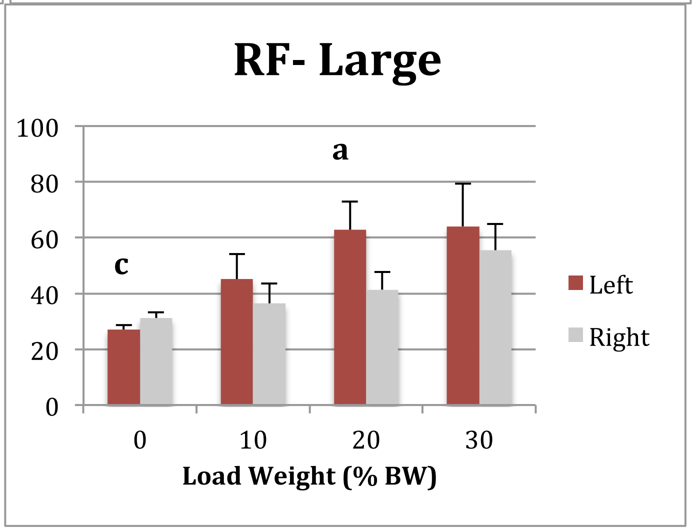


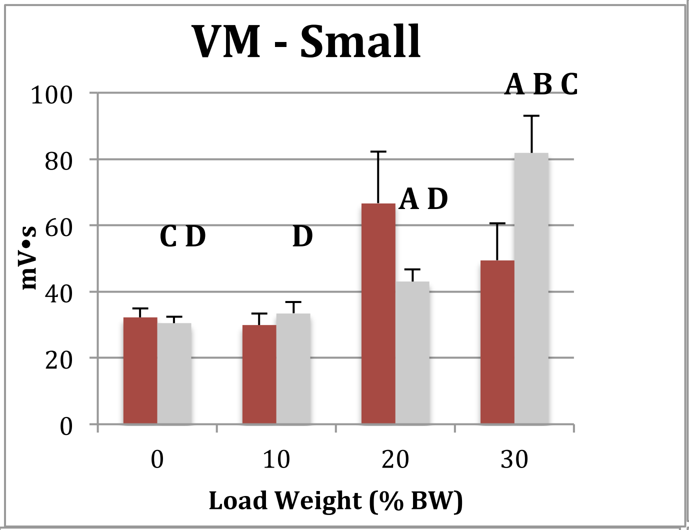


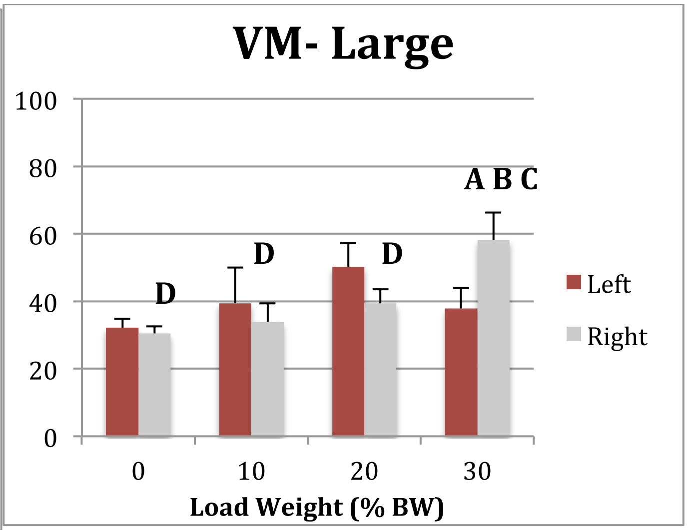


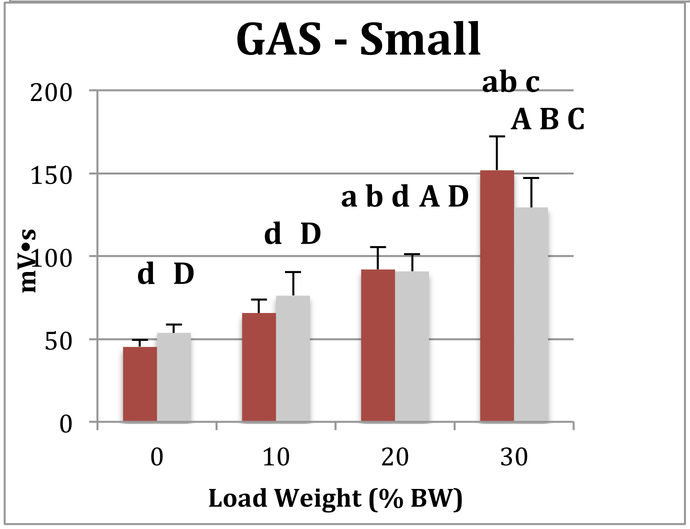


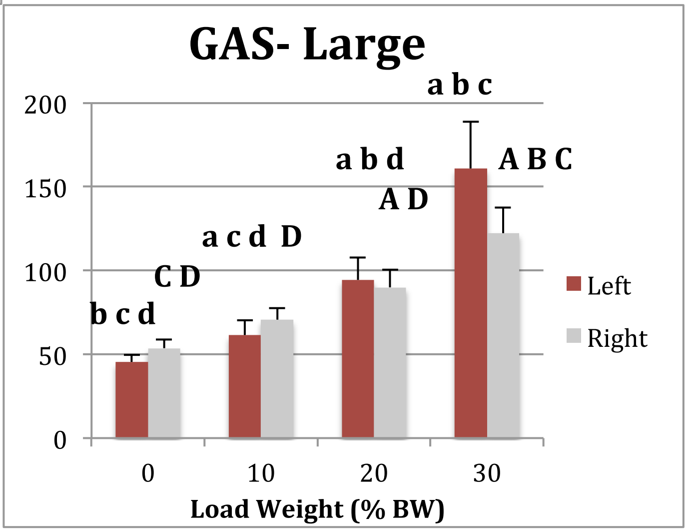





VM - Small
mV•s
100
80
60
40
20
0
0
10
20
30
Load Weight (% BW)
C D
D
A D
A B C


VM- Large
100
80
60
40
20
0
0
10
20
30
Load Weight (% BW)
D
D
D
A B C
Left
Right


GAS - Small
mV•s
200
150
100
50
0
0
10
20
30
Load Weight (% BW)
d D
d D
a b d A D
ab c
A B C


GAS- Large
200
150
100
50
0
0
10
20
30
Load Weight (% BW)
b c d
C D
a c d D
a b d
A D
a b c
A B C
Left
Right

CHAPTER 5: GENERAL DISCUSSION

The current study examined the effect of variations in the size and mass of hockey bag load carriage on the stride length, stride width, support time, and the muscle activities of the trunk and lower limbs during walking.

Temporospatial variables

In the present study, and consistent with the literature, the participants showed a significantly ($P<0.02$) shorter stride length across the increasing load conditions in both the small and the large bags of the 30% BW load condition when compared to the control (small and large: Control: 1.51± 0.03m; 10% BW: 1.46± 0.03m; 20% BW: 1.45±0.03; and 30% BW: 1.39± 0.03m). There have been some mixed and insignificant findings in previous unilateral and bilateral load carriage studies on stride length and load weight (DeVita, Hong, & Hamill, 1991; Goh, Thambyah, & Bose, 1998; Lee & Li, 2011; Singh & Koh, 2009). However, most studies on load carriage, both bilateral and unilateral have shown a decrease in stride length with load weight (Crosbie, Flynn, & Rutter, 1994; Zhang, Ye, & Wang, 2010; Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Martin & Nelson, 1986; An, Yoon, & Yoo, 2010). In the present study, only the right limb was analyzed for stride length. Results by Crosbie (1994) and DeVita (1991) showed no significant differences between left and right stride length in unilateral load carriage and values indicate there may not have been a major change between the left and right stride in the present study.

The stride width in hockey bag load carriage significantly increased in both the small and large hockey bags ($P<0.024$) when comparing the 30% BW load condition to the control (sig. differences occur from Control [10.6±0.5cm] to 30%BW small bag [16.3±1.1cm] and

30%BW large bag [14.6±1.0cm]. This corresponds with previous research in bilateral and unilateral load carriage (Crosbie, Flynn, & Rutter, 1994; Zhang, Ye, & Wang, 2010).

Support time had increased in double support phase and decreased in single support phase with the heavier load in small and large hockey bag load carriage. Both hockey bag sizes with each load condition (10%BW, 20%BW, and 30%BW) produced significantly longer double support phases when compared to the control (sig. differences occur from Control [double support time: 26.2±.09%] to 10%BW small [27.7±1.1%]; 10%BW large [27.9±1.0%], 20%BW small [29.5±0.8%]; 20%BW large [29.2±0.8%], 30%BW small [31.1±0.8%]; 30%BW large [31.3±0.8%]). Results for support time is mixed in previous studies, some showing no significance (DeVita, Hong, & Hamill, 1991; Lee & Li, 2011), but the bulk of the studies have seen significant increases in double support time (Ozgul, Akalan, Kuchimov, Uyger, Temelli, & Polat, 2011; Birrell & Haslam, 2010; Singh & Koh, 2009; Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Demura, Demura, & Shin, 2010).

The increased double support time and stride width, and decreased single support time and stride length seen in unilateral hockey bag load carriage, are the biomechanical adjustments done to maintain stability and reduce the chances of falling (Pohl, Lloyd, & Ferber, 2010). The temporospatial measurements tend to intensify as the load weight increased.

Electromyography Vs. Load

A) *Rectus Abdominis*

RA activity increased in both the left and right sides with significant increases only occurring on the right side for peak EMG and iEMG in both the small and large hockey bags. Although, the left RA did not show significance at the alpha level of 0.05, the mean values for peak and iEMG were greater than the right in the 30% BW load condition. The 30% BW condition in the right RA showed a significant increase against all other conditions (P<0.05). Motmans et Al. found that the RA activity in the unilateral loaded condition (15% BW) was not significantly different than the control condition (no load). There are several explanations as to why the RA activity was significantly larger in the present study compared to being insignificant in Motmans study. First, it may have been because of the mass of the load. Motmans used 15% BW, whereas the present study found significance at the 30% BW load. Second, Motmans examined the participants in static standing. In the present study, the participants are walking forward, usually associated with a forward lean in load carriage studies (Simpson, Munro, & Steele, 2011). Lastly, the position of the load may play a factor. In Motmans' study, participants had the bag over the shoulder and across the body, positioned directly on the hip. The present study had the hockey bag in the more posterior position, much like a backpack. In the bilateral, backpack studies, the RA muscles show significant increases to compensate for the tension placed on the anterior muscles as the result of a posterior load (Motmans, Tomlow, & Vissers, 2006; Al-Khabbaz, Shimada, & Hasgawa, 2008).

B) Erector Spinae

No significant changes occurred in the left or right ES as a result of increasing load in small or large bag unilateral load carriage. Similar findings are found in bilateral studies, the ES has no significant increase (Cook & Neumann, 1987) and in some cases, are significantly lower than the control (Bobet & Norman, 1984; Motmans, Tomlow, & Vissers, 2006). Again this may reflect the positioning of the hockey bag load. In it's posterior-lateral location on the subjects, the hockey bag is akin to many backpacks.

C) Gluteus Maximus

Much like the ES, the GM showed no significant increase at any of the loaded conditions in either the small or large hockey bags. Little evidence in previous studies exists on the EMG activity of the gluteus maximus. The insignificant results for this muscle suggest that much like the erector spinae, active hip extension, via the GM is not an integral part of hockey bag load carriage.

D) Knee Flexors (Biceps Femoris & Semitendinosus)

Increased load weight resulted in large increases in muscle activities of both sides of the ST (small bag 30% BW; LST: 3.89 ±0.98 and RST: 2.02 ±0.38) and little change to the BF (small bag 30% BW; LBF: 1.12 ±0.12 and RBF: 1.10 ±0.12). Due to small changes in the BF and large variation around the mean in the ST, significance was only found in iEMG of the left ST during small bag load carriage (significant when comparing the 30% BW condition to the control, P=0.042) and in the right ST for the 30% BW load against the 10% BW. The high measurements for the ST peak and iEMG are unknown. Possible causes may be cross talk with underlying muscles or poor connectivity of the EMG sensor to the skin (Mirka, 1991).

Recent research in bilateral load carriage reveals that heightened muscle activity may be present in the hamstrings (Simpson, Munro, & Steele, 2011). However past studies have concluded that there is no significance in the hamstring muscle activities during walking with load carrying (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Knapik, Harman, & Reynolds, 1996).

E) Gastrocnemius

Significant increases in peak EMG and iEMG occurred in both GAS and at each load increment and for both sizes of hockey bags. This result parallels with the literature. Simpson et al. reported increased iEMG of the gastrocnemius in backpackers carrying loads of up to 40%BW (2010). It has been well documented in the bilateral studies that peak EMG of the GAS increases (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992; Norman, 1979) but no studies on the muscle activity of the gastrocnemius could be found for unilateral load carriage.

F) Knee Extensors (Rectus Femoris & Vastus Medialis)

The RF on the right and left sides showed no significant change in peak EMG or iEMG in either the small bag or large bag with load increase. The VM muscles of both sides increased in peak EMG and iEMG, with significance found only in the right VM when compared to the control (30% BW in small bag for peak EMG [P=0.008], 20%BW [P=0.005] and 30%BW[P=0.002] for iEMG, and 30%BW large bag in iEMG [P=0.014]). Like the ST of the hamstrings, the VM showed some inconsistence among participants in terms of the muscle activation patterning. In this case, it could have been from cross talk with the RF.

Ghori and Luckwill noticed significant muscle prolongation in the unloaded side of the vastus lateralis when they studied the effects of unilateral loading (Ghori & Luckwill, 1985). In a bilateral load carriage study, Simpson et al. revealed significant peak activation in the vastus lateralis with increasing load (2011). Other studies have shown mix results, either no significance (Harman, Han, Frykman, Johnson, Russell, & Rosenstein, 1992)or significant increase (Norman, 1979).

Electromyography Vs. Carrying Side

In the present study, significantly greater peak EMG and iEMG for the left sides of the RF and ST compared to the right side at the 30% BW load condition occur ($P<0.05$). Also, increased peak EMG, although not significant, was found to be greater in the left when compared to the right of all muscles excluding the VM for the 30% load condition of both the small and large hockey bags.

Similarly, the literature in unilateral load carriage show significant differences between right and left, carrying and non-carrying, muscles. Increases in the peak EMG of the left, non-carrying side have occurred for the vastus lateralis, semimembranosus, gluteus medius, rectus abdominis, and erector spinae in unilateral load carriage examination (Ghori & Luckwill, 1985; Motmans, Tomlow, & Vissers, 2006; Cook & Neumann, 1987).

In bilateral load studies, few, if any, significant differences between the left and right limbs have been reported.

Hockey Bag Size

No significant differences occurred between the two bag sizes for stride length, stride width, and support time.

The right RA and right RF showed significantly larger peak EMG in the large bag compared to the small bag for the 20% load condition and the 30% load condition for the right RF ($P<0.046$). While the right VM had significantly larger peak EMG values for the small bag in the 30% BW load condition ($P=0.044$). Significant iEMG increases for the right GM ($P=0.015$) occurred for the 10% BW load condition in the small bag compared to the large bag.

To further understand the results of hockey bag size in this study, we must look at each muscle's function. The RF is a bi-articular muscle, having the function of knee extension and also hip flexion. The RA's main function is to flex the trunk. Both of the right sides of these muscles have significantly greater activation for the large bag. The small bag showed larger muscle activation for the GM (a hip extensor) and the VM (knee extensor). An explanation for having larger hip and trunk flexor activity for the large bag may be due to its placement on the subjects. All subjects carried the hockey bags in the same manner, which was over the shoulder and resting on the back. This carriage technique was most likely due to the hockey bag’s short, non-adjustable straps. The large bag in the study, however, had longer straps and would hang a bit lower on the subjects back than the smaller bag. In a study by Simpson et Al. on the vertical load position during load carriage (2010), female hikers showed a significantly smaller trunk angle when carrying a load placed lower on the back ($P<0.05$), indicating greater trunk flexion (Simpson, Munro, & Steele, 2011).

The large bag hangs lower on the subject creating an extensor moment in the hip and trunk. An added effort by the hip and trunk flexors is the result. The load position and amount of asymmetry are different for the small and large bags. These differences occur due to the non-adjustable straps and as a result affect the muscle activities of the trunk and lower limbs.

CHAPTER 6: LIMITATIONS

Limitations in this study include the makeup of the hockey bag load. Styrofoam was used to generate the hockey bag's true volume. For many hockey players this may be unnatural as the hockey bag normally contains flexible equipment that can bend around the carrier's trunk. The hockey bag has non-adjustable straps, making the two sizes of hockey bags positioned at different places on the participants. The non-adjustable straps also limit the researchers to control for the position between participants. However, the non-adjustable straps are characteristic of the hockey bags on the market.

Walking on smooth laboratory flooring also poses as a limitation. Realistically, carriers are walking over gravel, bumps, and sometimes snow and ice.

Limitations of the EMG set-up and lying over skin can change the activity recorded by the device. The EMG sensors for the semitendinosus and vastus medialis may have produced some errors, as large values were reported. Cross talk is suspected to be the cause of this (Turker, 1993).

CHAPTER 7: CONCLUSION

The purpose of the present study was to explore the effects of carrying a hockey bag with different load and different size on the temporospatial measurements and on the trunk and lower limb muscle activities. The study reveals that hockey bag load carriage may be different than unilateral and bilateral load carriage. The hockey bag is carried over one shoulder, as seen in a unilateral style. But, the hockey bag is placed more posterior than the athletic duffle bags studied in unilateral studies, which is carried lying over the hip. In this way, the hockey bag is similar to the bilateral backpack. More investigation is needed to determine which style of unilateral load carriage may be considered safer.

Males in the 18-30 year age group are the ones who are more likely to carry hockey bags in this fashion and walk further distances to the local arenas. Many, if not all, of the unilateral load carriage study's, have used athletic duffle bags with weight as much as 20% of the body weight of the participants. The hockey bag has been shown to be as heavy as 33% of one's body weight (Corrigan, Law, & Law, 2010).

In the present study, stride length and single support time has been shown to decrease and stride width and double support time increased with load weight in hockey bag load carriage ($P<0.05$). Significant increases ($P<0.05$) in peak EMG occur with 20% BW and 30% BW load weight in the following muscles in both small and large hockey bag load carriage: right rectus abdomininis, right and left gastronemius, right semitendinosus, and the right vastus medialis. Significant increases in integrated EMG occur with 20% BW and 30% BW load weight in the following muscles during small and large hockey bag load carriage: right rectus abdominis, right and left gastrocnemius, left semitendinosus, and right vastus medialis.

Significant differences in left and right sides were found in the rectus femoris and semitendinosus. The left sides of these muscles were greater in EMG when compared to the right.

The findings of increased activity of the rectus abdominis and no change of the erector spinae are similar to many bilateral studies studying the same muscles (Knapik, Harman, & Reynolds, 1996; Motmans, Tomlow, & Vissers, 2006; Simpson, Munro, & Steele, 2011). While the increases in the non-carrying, left-sided muscles show larger peak and iEMG activity than the right-sided muscles are representative of many unilateral load carriage studies (Motmans, Tomlow, & Vissers, 2006; Smith, Ashton, Bohl, Richard, Metheny,

& Klassen, 2006). It is suggested by the researchers that the posterior-lateral position of the hockey bag in load carriage creates the results to be similar to the both types of load carriage.

Hockey bag size showed significant differences ($P<0.05$) in the right rectus abdominis and the right rectus femoris at the 30% BW load condition, showing an increase in the large hockey bag. While the right vastus medialis showed higher integrated EMG in the small bag when compared to the large bag. The researchers of the present study propose that this result may have occurred due to the large hockey bag being positioned slightly lower on the subjects, when compared to the small bag. This lower position of the large hockey bag would create a greater extensor moment around the trunk/hip. The increased activity of the trunk/hip flexors (as shown in the significant peak EMG increases of the right RA and right RF) would allow the body to maintain posture. Significance was found for bag size at the 10% BW load condition. Increased right gluteus maximus iEMG occurred during the 10% BW load condition. Hockey bag size effects the muscles of the trunk and lower limb, most likely due to their difference in amount of asymmetry and its position when carried.

It is recommended that young hockey players alternate the shoulder they use during hockey bag load carriage to avoid asymmetrical muscle fatigue (DeVita, Hong, & Hamill, 1991). Hockey players should also choose bags that stay close to the body's center of mass to avoid excessive rotation around the hip and trunk and have adjustable straps.

Future research should investigate the influences of posterior-lateral load carriage on joint biomechanics of the trunk and lower limb and how the gait and posture of young hockey players may be affected by the heavy loads applied after walking for relatively long distances and on different surfaces.

REFERENCES

Al-Khabbaz, Y., Shimada, T., & Hasgawa, M. (2008). The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. *Gait & Posture , 28*, 297-302.

An, D.-H., Yoon, J.-Y., & Yoo, W.-G. (2010). Comparisons of the gait parameters of young Korean women carrying a single-strap bagnhs_496 87..93. *Nursing and Health Sciences , 12*, 87-93.

Andersson, G. (1999). Epidemiological features of chronic lowback pain. *The Lancet , 354* (9178), 581-585.

Baranto, A., Hellstrom, M., Cederlund, C., Nyman, R., & Sward. (2009). Back pain and MRI changes in the thoraco-lumbar spine of top athletes in four different sports: A 15-year follow-up study. *Knee Surgery, Sports Traumatology, Arthroscopy , 17* (9), 1125-1134.

Benoit, D., Lamontagne, M., Cerulli, G., & Liti, A. (2003). The clinical significance of electromyography normalisation techniques in subjects with anterior cruciate ligament injury during treadmill walking. *Gait & Posture , 18*, 56-63.

Birrell, S., & Haslam, R. (2010). The effect of load distribution within military load carriage systems on the kinetics of human gait. *Applied Ergonomics , 41*, 585-590.

Birrell, S., & Hooper, R. (2007). Initial subjective load carrying injury data collected with interviews and questionnaires. *Military Medicine , 172* (3), 306-311.

Bobet, J., & Norman, R. (1984). Effects of load placement on back muscle activity in load carriage. *European Journal of Applied Physiology , 53*, 71-75.

Chansirinukor, W., Wilson, D., Grimmer, K., & Dansie, B. (2001). Effects of backpacks on students: Measurement of cervical and shoulder posture. *Australian Journal of Physiotherapy , 47*, 110-116.

Choi, H., Hwang, S., Choi, H., Kim, Y., & Yi, C. (2007). Joint moments and centre of body mass according to the weight of side load carriage in walking. *Medical Physics and Biomedical Engineering , 14* (5), 2856-2859.

Cook, T., & Neumann, D. (1987). The effects of load placement on the EMG activity of the low back muscles during load carrying by men and women. *Ergonomics , 30* (10), 1413-1423.

Corrigan, L., Law, N., & Law, N. (2010, October). The hockey bag survey. *Not Published* . Ottawa, ON, Canada.

Crosbie, J., Flynn, W., & Rutter, L. (1994). Effect of side load carriage on the kinematics of gait. *Gait & Posture , 2*, 103-108.

Dalen, A., Nilsson, J., & Thorstensson, A. (1978). *Factors influencing a prolonged foot march.* FOA Report C50601-H6, Karolinska Institue, Stockholm.

De Luca, C. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics , 13* (2), 135-163.

Demura, T., Demura, S.-I., & Shin, S. (2010). Comparison of gait properties during level walking and stair ascent and descent with varying loads. *Health , 2* (12), 1372-1376.

DeVita, P., Hong, D., & Hamill, J. (1991). Effects of asymmetric load carrying on the biomechanics of walking. *Journal of Biomechanics , 24* (12), 1119-1129.

Dolan, P., & Adams, M. (2001). Recent advances in lumbar spinal mechanics and their significance for modelling, *Clinical Biomechanics*, *16* (1), S8-S16.

Erdfelder, E., Paul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behaviour Research Methods, Instruments, & computers* .

Fergenbaum, M. (2007). Development of safety limits for load carriage in adults. *School of Rehabilitation Therapy* .

Flloyd, W., & Silver, P. (1951). Function of the erector spinae in flexion of the trunk. *Lancet , 1*, 133-134.

Fowler, N., Rodacki, A., & Rodacki, C. (2006). Changes in stature and spine kinematics during a loaded walking task. *Gait & Posture , 23*, 133-141.

Gabell, A., & Nayak, U. (1984). The effect of age on variability in gait. *Journal of Gerontology , 39* (6), 662-666.

Ghori, G., & Luckwill, R. (1985). Responses of the lower limb to load carrying in walking man. *EUROPEAN JOURNAL OF APPLIED PHYSIOLOGY AND OCCUPATIONAL PHYSIOLOGY , 54* (2), 145-150.

Gillette, J., Stevermer, C., Miller, R., Meardon, S., & Schwab, C. (2010). The effects of age and type of carrying task on lower extremity kinematics. *Ergonomics , 53* (3), 355-364.

Goh, J.-H., Thambyah, A., & Bose, K. (1998). Effects of varying backpack loads on peak forces in the lumbosacral spine during walking. *Clinical Biomechanics , 1*, S26-S31.

Hale, C., Colemon, F., & Karpovich, P. (1953). Trunk inclination in carrying low and high packs of various weights. *U.S. Army Quartermaster Research and Development Division, Enviornmental Protection Division* .

Harman, E., Han, K., Frykman, P., Johnson, M., Russell, F., & Rosenstein, M. (1992). The effects on gait timing, kinetics, and muscle activity of various loads carried on the back. *Medicine in Sports and Exercise , 24*, S129.

Hermens, H., Freriks, B., & Merletti, R. (1999). European recommendations for surface electromyography: Results of the seniam project.

HF boards. (2009). *Hockey bag recomendations?* . Retrieved May 2011, from HF Boards: http://hfboards.com/archive/index.php/t-667539.html

Hockey Canada. (2010). *About hockey Canada: Player registration*. Retrieved April 18, 2011, from Hockey Canada: http://www.hockeycanada.ca/index/ci_id/23952/la_id/1.htm

Hong, Y., Li, J.-X., & Tik-Pui Fong, D. (2008). Effect of prolonged walking with backpack loads on trunk. *Journal of Electromyography and Kinesiology , 18*, 990-996.

Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics , 28*, 1347-1362.

Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs:A review of physiological, biomechanical and medical aspects. *Applied Ergonomics , 27* (3), 207-216.

Knapik, J., Reynolds, K., Staab, J., Vogel, J., & Jones, B. (1992). Injuries associated with strenuous road marching. *Military Medicine , 157*, 64-70.

Komi, P.V., Kaneko, M., & Aura, O. (1987). EMG activity of the leg extensor muscles with special reference to mechanical efficiency in concentric and eccentric exercise. *International Journal of Sports Medicine, 8* (suppl), 22-29.

Leardini, A., Chiari, L., Della Croce, U., & Cappozzo. (2005). Human movement analysis using stereophotogrammetry. Part 3: Soft tissue artifact assessment and compensation. *Gait & Posture , 21* (2), 212-225.

Lee, S., & Li, J.-X. (2011). Effects of asymmetrical load carriage and high-heeled shoes on lower extremity joint kinetics in healthy young women during walking. *Master's Thesis, University of Ottawa*.

LeVeau, B., & Bernhardt, D. (1984). Developmental biomechanics: Effect of forces on growth, development, and maintenance of the human body. *Physical Therapy , 64*, 1874-1882.

Mackie, H., Legg, S., & Hedderley, D. (2003). Comparison of four different backpacks intended for school use. *Applied Ergonomics , 34*, 257-264.

Martin, P., & Nelson, R. (1986). The effect of carried loads on the walking patterns of men and women. *Ergonomics , 29*, 1191-1202.

McGill, S. (1997). The biomechanics of low back injury: : Implications on current practice in industry and the clinic. *Journal of Biomechanics , 30* (5), 465-475.

McNabb, C. (n.d.). *Player development initiation.* Retrieved from Hockey Canada: http://www.hockeycanada.ca/index/php/ci_id/18766/la_id/1.htm/

Mirka, G. (1991). The quantification of EMG normalization error. *Ergonomics , 34* (3), 343-352.

Motmans, R., Tomlow, S., & Vissers, D. (2006). Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics , 49* (2), 127–138.

Mountain, M. (2002, November). *Muscle imbalance in hockey players contributes to back pain.* Retrieved May 2011, from Hockey Training Pro: http://hockeytrainingpro.com/wordpress/2009/11/muscle-imbalance-in-hockey-players-contributes-to-back-pain/

Must, A., & Strauss, R. (1999). Risks and consequences of childhood and adolescent obesity. *Interantional Journal of Obesity Related Metabolic Disorders , 23*, S2-11.

Norkin, C., & Leangie, P. (1992). *Joint Structure and Function: Acomprehensive analysis, 2nd ed.* Philadelphia, P.A.: F.A. Davis Company.

Norman, R. (1979). The utility of combining EMG and mechanical work rate data in load carriage studies. *Proceedings of the 4th Congress of the international Society of Electrophysiological Kinesiology*.

O'Shea, O., Bettany-Satikov, J., & Warren, J. (2006). Same-sided and cross body load carriage on 3-D back shape in young adults. *Research into Spinal Deformities , 5*.

Ozgul, B., Akalan, E., Kuchimov, S., Uyger, F., Temelli, Y., & Polat, M. (2011). During asymmetrical backpack loading: Is unloaded side of body segments truly unloaded? *Journal of Biomechanics , 44*, ee1-e21.

Pascoe, D., Pascoe, D., Wang, Y., Shim, D.-M., & Kim, C. (1997). Influence of carrying book bags on gait cycle and posture of youths. *Ergonomics , 40*, 631-641.

Perez, C. (2000). *Chronic back problems among workers.* Statistics Canada: Health Reports.

Pohl, B., Lloyd, C., & Ferber, R. (2010). Can the reliability of three-dimensional running kinematics be imporved using functional joint methodology? *Gait & Posture , 32*, 559-563.

Rousseau, P., Post, A., & Hoshizaki, T. (2009). The effects of impact management materials in ice hockey helmets on head injury criteria. *Journal of Sports Engineering and Technology , 4*, 223.

Simpson, K., Munro, B., & Steele, J. (2011). Backpack load affects lower limb muscle activity patterns of female hikers during prolonged load carriage. *Journal of Electromyography and Kinesiology , 21*, 782-788.

Singh, T., & Koh, M. (2009). Effects of backpack load position on spatiotemporal parameters and trunk forward lean. *Gait & Posture , 1*, 49-53.

Smith, B., Ashton, K. M., Bohl, D., Richard, C., Metheny, J., & Klassen, S. (2006). Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. *Gait & Posture , 23*, 263-267.

Smith, B., Roan, M., & Lee, M. (2010). The effect of evenly distributed load carrying on lower body gait dynamics for normal weight and overweight subjects. *Gait & Posture , 32*, 176-180.

St. Michael's Hospital. (2011, March 16). *Injuries rise sharply in minor hockey after bodychecking rules relaxed: Study.* Retrieved April 18, 2011, from Science Newsline: http://www.sciencenewsline.com/medicine/2011031613000037.html

Taylor, W., Ehrig, R., Duda, G., Schell, H., Seebeck, P., & Heller, M. (2005). On the influence of soft tissue coverage in the determination of bone kinematics using skin markers. *Journal of Orthopedic Research , 23*, 726-734.

Tilbury-Davis, D., & Hooper, R. (1999). The kinetic and kinematic e.ects of increasing load carriage upon the lower limb. *Human Movement Science , 18*, 693-700.

Weekes, D. (2005). *The big book of hockey trivia.* Vancouver, B.C.: Greystone Books- A division of Douglas & McIntyre Ltd.

Zhang, X. I., Ye, M., & Wang, C. (2010). Effect of unilateral load carriage on postures and gait symmetry in ground reaction force during walking. *Computer Methods in Biomechanics and Biomedical Engineering , 13* (3), 339-344.

APPENDIX

Appendix A: Consent Form & Questionnaire

Université d'Ottawa • University of Ottawa

Faculté des sciences de la santé
École des sciences de l'activité physique

Faculty of Health Sciences
School of Human Kinetics

Consent Form

Title of the study: THE EFFECT OF HOCKEY BAG LOAD CARRIAGE ON THE MUSCLE ACTIVITIES OF THE TRUNK AND LOWER LIMBS OF HEALTHY YOUNG MALES DURING GAIT

Research Supervisor: Jing Xian Li, PhD
Associate Professor
School of Human Kinetics, Faculty of Health Science

Primary Investigator: Liam Corrigan, B.Sc.
Master Candidate
Human Movement Biomechanics Laboratory

INVITATION TO PARTICIPATE:
I am invited to participate in the abovementioned research testing conducted by Dr. Jing Xian Li of the School of Human Kinetics, Faculty of Health Sciences, University of Ottawa and her student Mr. Liam Corrigan. I understand this research is Liam Corrigan's master's thesis research project. The research is entitled "The effect of hockey bag load carriage on the muscle activities of the trunk and lower limbs of healthy young males during gait." The purpose of the research is to study gait with unilateral hockey bag load carriage by examining a) walking on level ground with4 different loads of hockey bag and with two different sized hockey bags b) walking with hockey bag load carriage in stair initiation during stair ascent and stair descent under 4 load conditions.

PURPOSE OF THE STUDY:
I understand that the purpose of this study is to examine the effects of heavy one-sided loading (hockey bag) on the muscle activity of the trunk and lower limbs. To

understand the impact of asymmetrical hockey bag carrying, in terms of the hockey bag mass, hockey bag volume, and stair climbing on muscle activity during walking.

ELIGIBILITY:
To be able to participate in this study, I must be between ages of 18 to 30. I must not suffer from any neuromuscular disorders or musculoskeletal injuries and have normal movement capacity.

PARTICIPATION:
I will complete a form about my biography and exercise habits, and musculoskeletal disorders. The study involves one session of measurements. It will last approximately 2 hours during which my movement of ground walking, and upstairs and downstairs walking with a hockey bag of different weight and size will be recorded using video cameras. And my muscle activity in trunk and lower limbs will be recorded.
I will perform at least a total of 45 trials of short distance walking (approximately 8 m) for 15 conditions of hockey bag load carriage at the Human Movement and Biomechanics Laboratory (he above mentioned address). The conditions include

- **level walking** with a hockey bag of 0%, 10%, 20%, and 30% of my body weight (these conditions, aside from the 0% condition, will be repeated twice; once with a smaller hockey bag and once with a larger hockey bag),
- **stair ascent initiation (3 steps)** with a hockey bag of 0%, 10%, 20%, and 30% of my body weight, and **stair descent initiation (3 steps)** with a hockey bag of 0%, 10%, 20%, and 30% of my body weight.

I will complete a questionnaire regarding my hockey experience, partake in anthropometric measurements that will include taking my body height and weight, and, if in congruence, sign this consent form before partaking in the above-mentioned research.

RISKS:
My participation in this study will entail you to have small portions of your legs palpated so that the researcher can properly place the EMG (electromyography) sensors. These areas of my legs will also be wiped down with alcohol swabs; if I am allergic to alcohol then these areas can also be wiped down with water and a cloth. There is a possibility that I may experience mild skin irritation from the tape used to attach the muscle sensors and reflective markers. This irritation is similar to that experienced with a bandage and typically lasts only a short while.

Prior to commencing the tests, maximum voluntary contractions of certain muscle groups (quadriceps, hamstrings, calves, gluteus maximus, muscles of the lower back, and muscles of the lower abdominals), will be needed in order to normalize data to the participant's maximal force.
The pushing and pulling movements that I will be asked to perform to maximally perceived effort have no more risks than most common daily activities. To ensure that I do not pull a muscle during these movements, adequate warm-up on a stationary bike will first be conducted. In this study I will entail the carrying of heavy loads asymmetrically and walking on level flooring as well as stair ascent and descent, and this may cause me to feel stress on some of the muscles and joints.

Fatigued muscles following the study session may also occur but stretching at the end of the session upon your request may be provided.

Every effort will be made to minimize the above risks. I am also encouraged to notify the researchers if any discomfort is experienced anytime during the session.

DISADVANTAGES OF PARTICIPATING:
I understand the primary disadvantage of participation will be the time required to complete data collection.

BENEFITS:
I will not personally benefit from this study but my participation will help explain how muscles contribute to carrying a load asymmetrically through hockey bag load carriage. Data collected will also help in contributing to the advancement of scientific knowledge of loaded gait.

CONFIDENTIALITY AND ANONYMITY:
I understand that records of my participation in this study will be kept confidential. All documents will be identified only by code number, which will include my date of participation. Hard copies will be kept in a locked cabinet at the Human Movement and Biomechanics Laboratory. This data will be kept for a maximum of 15 years before being destroyed, starting from the date of thesis submission. I will not be identified by name in any reports of the completed study. No records bearing my name or date of birth will leave the premises of the University of Ottawa. The information in this study will be used for a Master's thesis and may be used for a future study. All investigators mentioned at the beginning of this consent form will have access to the data collected from this study.

VOLUNTARY PARTICIPATION:
I am free to refuse participation and, if I choose to participate, I can withdraw from the study at any time for any reason.

CONSENT:
I declare that I understand this project, the nature and degree of my participation and possible disadvantages and risks listed in this consent form. I have had the opportunity to ask all my questions concerning the different aspects of the study and have received responses to my satisfaction.

I voluntarily agree to participate in this study.

If I withdraw from the study, I want that:
_______ the data gathered from me until the time of withdrawal be destroyed.
_______ the data gathered from me until the time of withdrawal be nonetheless used for the study despite my withdrawal.

I agree that Dr. Jing Xian Li can keep my name and telephone number for contact me for any future study that she may be carrying out.

Yes ________ **No________**

There are two copies of this consent from one of which is for me to keep.

Consent Form

____
Name of Participant

_________________________ _________________________
Signature of Participant Date

_________________________ _________________________
Signature of Researcher Date

Université d'Ottawa • University of Ottawa
Faculté des sciences de la santé
École des sciences de l'activité physique
Faculty of Health Sciences
School of Human Kinetics

Hockey Bag Study- Questionnaire
University of Ottawa

1. Name of participant:

   ____

2. Email (optional):

   ____

3. Age of participant:

   ____

4. Position in hockey:

   ____

5. How do you normally carry your hockey bag?:

   ____

6. Which side do you carry your hockey bag on?:

   ____

7. In any given week, how many times do you play hockey? _________
8. In the past year, how many months have you been playing hockey?:

   ______

9. How many years have you been playing hockey?:

   ____

10. Why don't you use a wheeled hockey bag or bilateral (back pack style) hockey bag?:

    ____

____

11. On a given hockey day, how far are you carrying your hockey bag (include both to and from the arena)?:

___________________________________(m)

12. What is your dominant hand i) in writing ii) in hockey?

i)_______________

ii)_______________

13. Have you had any sprains or bone fractures in the past 6 months or any other neurological or physical impairment that may affect the load carriage in this study?____

14. Comments/Notes:__________________________________

____

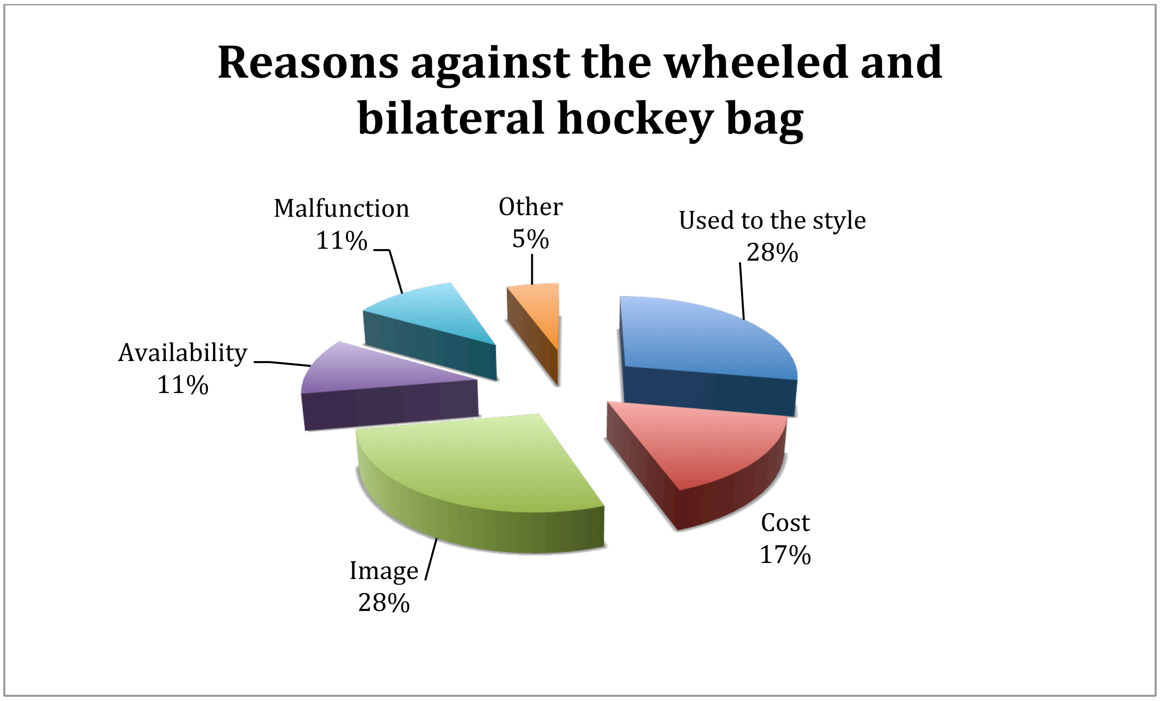
(Laboratory Data)

Body Weight: ___________Kg 10%=______

Body Height: ____________cm 20%=______

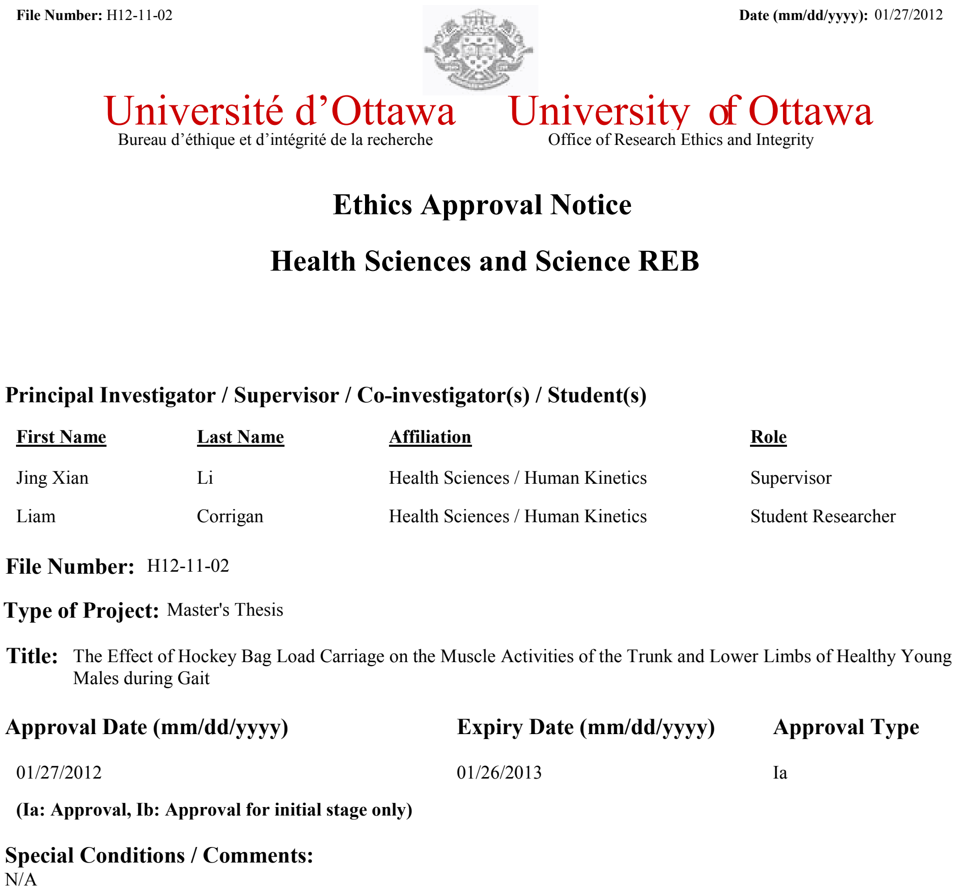
30%=______

Appendix B: Questionnaire Results



<u>Figure 22:</u> A pie chart revealing the variety of responses given from the participants as to why they do not use a wheeled hockey bag.

Appendix C: Ethics Approval



File Number: H12-11-02

Date (mm/dd/yyyy): 01/27/2012

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Ethics Approval Notice

Health Sciences and Science REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

First Name	Last Name	Affiliation	Role
Jing Xian	Li	Health Sciences / Human Kinetics	Supervisor
Liam	Corrigan	Health Sciences / Human Kinetics	Student Researcher

File Number: H12-11-02

Type of Project: Master's Thesis

Title: The Effect of Hockey Bag Load Carriage on the Muscle Activities of the Trunk and Lower Limbs of Healthy Young Males during Gait

Approval Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
01/27/2012	01/26/2013	Ia

(Ia: Approval, Ib: Approval for initial stage only)

Special Conditions / Comments:
N/A