

BIOMECHANICAL ASSESSMENT OF PACED AND MAXIMAL EFFORT  
REPETITIVE SYMMETRICAL LIFTING IN CANADIAN SOLDIERS – A SEX  
COMPARISON

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## **Abstract**

This study examined the sex related differences of neuromuscular and biomechanical effects of paced and maximal effort performance during a short duration military lifting evaluation. Thirty-one Canadian soldiers participated in the Canadian Armed Force's sandbag lift component of the FORCE evaluation twice, by pacing the task and by performing the task at maximum effort. Fifteen women and sixteen men were studied to determine differences in sex. The participant's biomechanical and neuromuscular effects were recorded with an Inertial Measurement Unit (IMU) motion sensor system by XSENS, and surface electromyography electrodes (sEMG). The maximal effort lifting task overall resulted in lesser values of cross correlation, and more exaggerated joint angles. Maximal effort lifting required more EMG activity than paced lifting. Women required more trunk motion and EMG activity compared to men. There are significant differences in how women and men apply lifting approaches and adjust to paced and maximal effort lifting tasks.

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# Table of Contents

<b>ABSTRACT</b> .....	<b>II</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>III</b>
<b>LIST OF TABLES</b> .....	<b>VIII</b>
<b>LIST OF FIGURES</b> .....	<b>X</b>
<b>LIST OF APPENDICES</b> .....	<b>XII</b>
<b>1.0 INTRODUCTION</b> .....	<b>1</b>
BACKGROUND .....	1
SIGNIFICANCE OF THE RESEARCH.....	2
INCENTIVIZED LIFTING IN THE CAF .....	4
LIFTING AND ASSOCIATED INJURY RISK.....	5
LIFTING TECHNIQUE .....	5
EFFECTS OF FATIGUE ON LIFTING (PACED VS NON-PACED) .....	7
SEX DIFFERENCES IN LIFTING TECHNIQUE.....	8
CONCLUSION .....	10
<b>2.0 PILOT STUDY</b> .....	<b>11</b>
OBJECTIVE .....	11
METHODS.....	11
RESULTS .....	13
DISCUSSION AND LIMITATIONS .....	16
<b>3.0 METHODS</b> .....	<b>18</b>

PARTICIPANTS .....	18
PROTOCOL.....	18
Lifting Setup .....	18
PRE-DATA COLLECTION MEASUREMENTS .....	21
INSTRUMENTATION .....	21
Electromyography.....	21
Motion Capture .....	26
Familiarization .....	28
The Lifting Task.....	29
DATA ANALYSIS .....	30
Outcome Measures.....	30
EMG Data Analysis .....	30
Kinematic Data Analysis.....	31
STATISTICAL ANALYSIS .....	33
<b>4.0 RESULTS .....</b>	<b>35</b>
PRE-COLLECTION MEASUREMENTS .....	35
MAIN EFFECT OF LIFT ON MUSCLE ACTIVITY .....	36
Main Effect of Lift on Mean EMG .....	37
Main Effect of Lift on Max EMG.....	37
MAIN EFFECT OF LIFT ON JOINT ANGLES.....	38
Main Effect of Lift on Joint Angles at Lift Initiation .....	39
Main Effect of Lift on Joint Angles at Lift Placement.....	39
MAIN EFFECT OF SEX ON MUSCLE ACTIVITY.....	40

Main Effect of Sex on Mean EMG .....	41
Main Effect of Sex on Max EMG .....	41
MAIN EFFECT OF SEX ON JOINT ANGLES.....	41
Main Effect of Sex on Joint Angles at Lift Initiation .....	42
Main Effect of Sex on Joint Angles at Lift Placement.....	42
SIGNIFICANT INTERACTION EFFECTS.....	42
CROSS CORRELATION FINDINGS .....	44
Cross Correlation Findings (Women) .....	44
Cross Correlation Findings (Men) .....	45
PERCENT CHANGE FINDINGS.....	46
Percent Change Findings for Lift Style.....	46
Percent Change Findings for Sex .....	47
<b>5.0 DISCUSSION .....</b>	<b>49</b>
THE MAIN EFFECT OF LIFT.....	49
THE MAIN EFFECT OF SEX .....	51
CROSS CORRELATION .....	54
PERCENT CHANGE (EARLY VS LATE).....	55
LIMITATIONS .....	57
SIGNIFICANCE OF RESULTS .....	59
FUTURE DIRECTIONS.....	61
<b>6.0 CONCLUSION.....</b>	<b>62</b>
SIGNIFICANCE & IMPLICATIONS .....	62

**7.0 APPENDICES .....65**

**REFERENCES .....74**

**CURRICULUM VITAE**

## List of Tables

<b>Table 4. 1:</b> Men and Women Anthropometric Measurements $\pm$ Standard Deviation.....	35
<b>Table 4. 2:</b> Main effect of Lift (Paced vs Max) on Muscle Activity (Mean EMG and Max EMG) at the Anterior Deltoid, Supraspinatus, Bicep Brachii, Erector Spinae (T9), Multifidous (L3), Vastus Lateralis, Bicep Femoris, and Gastrocnemius.....	36
<b>Table 4. 3:</b> Main effect of Lift (Paced vs Max) on Joint Angle (at Lift Initiation and Lift Placement) for the Hip, Knee, Shoulder, Elbow, and L5/S1. ....	38
<b>Table 4. 4:</b> Main effect of Sex (Men vs Women) on Muscle Activity (Mean EMG and Max EMG) at the Anterior Deltoid, Supraspinatus, Bicep Brachii, Erector Spinae (T9), Multifidous (L3), Vastus Lateralis, Bicep Femoris, and Gastrocnemius.....	40
<b>Table 4. 5:</b> Main effect of Sex (Men vs Women) on Joint Angle (at Lift Initiation and Lift Placement) for the Hip, Knee, Shoulder, Elbow, and L5/S. ....	41
<b>Table 4. 6:</b> Significant Interaction Effects for Main effect of Lift (Paced and Max) and sex (Men and Women) on Joint Angles with indicated Lift Style, Lift Phase, and Post Hoc Significance. ....	42
<b>Table 4. 7:</b> Women Cross Correlation findings represented as a coefficient comparing early vs late lifts of Paced tests (PC), and Max tests (MC), as well as across tests (Paced vs Max; PMC). Women Lag frames (% of time) indicated comparing early vs late lifts of Paced test (PL), Max test (ML), as well as across tests (Paced vs Max; PML). ....	44
<b>Table 4. 8:</b> Men Cross Correlation findings represented as a coefficient comparing early vs late lifts of Paced tests (PC), and Max tests (MC), as well as across tests (Paced vs Max; PMC). Men Lag frames (% of time) indicated comparing early vs late lifts of Paced test (PL), Max test (ML), as well as across tests (Paced vs Max; PML).....	45

**Table 4. 9:** Percent Change Values (Early 5 reps vs Late 5 reps) of EMG activity (Mean and Max) for Lift style (Paced and Max)..... 46

**Table 4. 10:** Percent Change Values (Early 5 reps vs Late 5 reps) of Joint Angles for Lift style (Paced and Max)..... 46

**Table 4. 11:** Percent Change Values (Early 5 reps vs Late 5 reps) of EMG activity (Mean and Max) for Sex (Women and Men)..... 47

**Table 4. 12:** Percent Change Values (Early 5 reps vs Late 5 reps) of Joint Angles for Lift style (Paced and Max)..... 48

## List of Figures

<b>Figure 2. 1:</b> Lifting Station Set-up .....	12
<b>Figure 2. 2:</b> EMG electrode and IMU participant setup .....	13
<b>Figure 2. 3:</b> Global Segment Coordinate System Reference of XSENS .....	14
<b>Figure 2. 4:</b> Global and Local Coordinate Frames of XSENS.....	14
<b>Figure 2. 5:</b> First rep of max effort lift test vs last rep of max effort lift test.....	15
<b>Figure 2. 6:</b> Raw % Maximum voluntary contraction of bicep during maximal effort lifting test .....	15
<b>Figure 2. 7:</b> First rep of paced lift test vs last rep of paced lift test.....	16
<b>Figure 3. 1:</b> Design and build of research equipment used to replicate the SBL test. ....	20
<b>Figure 3. 2:</b> EMG electrode placement for the vastus lateralis on an active Canadian soldier.....	22
<b>Figure 3. 3:</b> Examples from the SENIUM guidelines (biceps brachii and medial gastrocnemius). .....	23
<b>Figure 3. 4:</b> Order of MVC testing with general joint positioning .....	25
<b>Figure 3. 5:</b> Bicep Femoris MVC test on participant at Canadian Forces Base Gaagetown Fitness Center.....	26
<b>Figure 3. 6:</b> Anthropometrics measured (XSENS Manual) .....	27
<b>Figure 3. 7:</b> IMU sensor placement (participant vs. digital model) (Roetenberg, Luinge, and Slycke 2009).....	28
<b>Figure 3. 8:</b> Timeline of data collection.....	28

**Figure 3. 9:** Trigger to send 5V signal through EMG software to indicate placement of the lifting task..... 30

**Figure 3. 10:** Picture taken during paced lifting task of a Canadian soldier research participant..... 31

**Figure 4. 13:** A: Shoulder Angle, B: Elbow Angle, C: L5/S1 Angle, D: Hip Angle, E: Knee Angle..... 45

# List of Appendices

**Appendix 7. 1:** Participant Consent Form..... 65

**Appendix 7. 2:** Information Sheet..... 67

**Appendix 7. 3:** Get Active Questionnaire..... 70

## **1.0 Introduction**

Many sex comparison studies have explored relative lifting load as opposed to absolute. Evaluating lifting technique and muscular changes in this context provides insight into biomechanical variance, onset of fatigue, and the significance of sex during the two lifting approaches. The Canadian Armed Forces (CAF) requires the successful annual completion of a battery of fitness standards, which includes the Sandbag Lift (SBL) occupational standard evaluation. The SBL test can be performed in a paced manner (30 lifts in a 210 second period) or to enhance individual fitness score, the lifts can be completed with maximal effort (30 lifts completely as quickly as possible). The purpose of this study was to analyze sex related differences in lifting technique of a paced and maximal effort lifting task. The comparison of lifting technique will include a kinematic analysis of joints and segments, and neuromuscular demand on several upper and lower extremity and trunk muscles. Common lifting guidelines often do not consider sex, and there is limited literature on kinematic/neuromuscular differences between short duration paced and maximal effort (ME) lifting.

### **Background**

The SBL test is one of four components of the 'Fitness for Operational Requirements of CAF Employment' (FORCE) evaluation. During the evaluation, the member is to lift a 20kg sand bag 30 times, in less than three and a half minutes. CAF members are motivated to aim higher than the minimal standards as incentivized performance is encouraged (Gagnon et al. 2015). There are bronze, silver, gold, and platinum incentivization levels that are based on the performance results of a member relative to the individual's age and sex (Spivock, 2015).

All members (men and women) of the CAF are required to complete this bona-fide occupational requirement. A study done by Lindbeck and Kjellberg, (2001) concluded that lifting/work technique should be considered separately in men and women. In addition to other physiological differences between men and women, significant differences in strength and power have been noted particularly in the upper body as men have shown stronger (Bartolomei et al. 2021). Moreover, women may be at increased risk for back injuries when repeatedly lifting absolute load of 15kg or higher (Plamondon et al. 2014). Therefore, it is important to understand how both sexes accommodate biomechanically to lifting an absolute load with maximal effort, compared to pacing the lifting task.

### **Significance of the Research**

It is meaningful to analyze the coordination differences between the two styles of lifts (paced and maximal effort) as intersegmental coordination is significant in determining a lifter's safe functioning (Hsiang and McGorry, 1997). Research has shown that if the lifter experiences fatigue in the extensor muscles, maintenance of spinal stability is negatively impacted (Sparto et al. 1997). Since extreme fatigue has been correlated to variations in trunk movements and muscular activities (Kazemi et al. 2021), it is crucial to discern the amount of fatigue accumulated in the context of this occupational testing. This research provides a better understanding of the kinematic and neuromuscular impact during the two lifting styles. This study will also serve as the first biomechanical assessment of the FORCE evaluation.

The gap in the literature is the sex specific exploration of potential lower back risk with short duration lifting performed at maximal effort. This study can be used as

information to consider prior to implementation of exercise interventions or practical guidance for men and women of the CAF preparing for the SBL test.

The study explored the following two aims: 1) Determine the modification in lifting technique, and muscle exertion associated with performing the standardized CAF SBL test at a paced and maximal effort; and 2) determine whether there are sex related differences in lifting technique.

Lifting technique throughout this document will be operationally defined by exploring:

1. Differences in upper extremity, trunk and lower extremity joint angles at both lift initiation and sandbag placement.
2. Joint coordination related to cross correlation of the lifting envelope between shoulder, trunk and knee angle motions.

The following research hypotheses will be explored:

1. The maximal effort lifting task will result in differences in joint angles when compared to the paced task at lift initiation and lift placement.
2. Higher muscle activation will be required during the maximal effort lifting task compared to the lifting task over the duration of the task.
3. Lifting technique will require more lower extremity (hip, and knee) and trunk motion (L5/S1) for women participants to complete the lifting task compared to the men.
4. The muscle activity will be different between men and women performing the lifting tasks over the duration of the task.

## **Incentivized Lifting in the CAF**

It is well understood that the development of occupational fitness standards should provide a rationale for decision making processes (Tipton, Milligan, and Reilly 2013). The FORCE evaluation minimal standards were created based on operational performance of six common military tasks, and to predict success on the Common Military Task Fitness Evaluation (CMTFE) (Stockbrugger et al. 2018). The tasks are as follows: escape to cover, pickets and wire carry, sandbag fortification, picking and digging, vehicle extrication, stretcher carry. Physiological demands that could limit successful operational completion of the above mentioned tasks were isolated, simulated in a gym environment, and the FORCE evaluation was created (T. J. Reilly, Blacklock, and Newton 2012).

The recently introduced incentive program includes a set of individual/group rewards and an estimation of maximal oxygen uptake value after completion of the FORCE evaluation (Gagnon et al. 2015). These tools primarily serve as a health indication of CAF members, and secondarily encourages maximal performance while completing their annual test (Gagnon et al. 2015). A novel study completed by Laframboise et al. 2018 has allowed an estimation of VO<sub>2</sub> max data to be calculated from the FORCE evaluation based on sex, age, anthropometrics, and performance on the test battery. Spivock 2015 outlines the implementation of an incentivized FORCE evaluation. Spivock, (2015) also makes mention to the benefit of the reward system in place for higher achieving members, as a member that scores silver and above will receive rewards (ball cap, joggers, etc). He also indicates motivational benefits for under achieving members as slight improvement in their scores will help achieve unit recognition of incentive level.

Reilly et al., (2016) found that lean body mass rather than sex would influence performance on military task simulations, but also suggested that sex differences in form and efficiency while considering speed and load should be explored at greater length in future research. This research will provide insight into sex differences during an incentivized occupational standard lifting task.

### **Lifting and associated Injury Risk**

The National Institute for Occupational Safety and Health (NIOSH) has set maximum acceptable disc compression guidelines of 3500N and maximum acceptable energy expenditure guidelines of 2.2-4.7kcal/min (Waters et al. 1993). “Repetitive lifting tasks lasting 1 h or less should not require workers to exceed 50% of the 9.5 kcal/min baseline maximum aerobic capacity value” (Waters et al. 1993). Although these guidelines are practical for many workplace tasks, there seems to be limited data on practical guidelines for lifting tasks lasting less than 5 minutes.

NIOSH defines the standard lifting location at a vertical height of 75cm, and a horizontal displacement of 25cm (Waters et al. 1993). NIOSH has indicated that the maximum recommended weight for lifting (RWL) at standard lifting location under optimal conditions should be 23kg (Waters et al. 1993). The SBL test requires participants to lift a 20kg sandbag (three kg below the NIOSH load constant), from floor to 1m (25 cm higher than standard lifting location), in a maximal effort manor.

### **Lifting Technique**

We will be operationally defining lifting technique by joint angles and patterns, and neuromuscular patterns. Often, a squat technique is encouraged to members prior to participating in the SBL. However, regardless of the preferred lifting technique,

increased injury risk may be present when attempting to integrate a different lifting style than what the member is accustomed to (Straker 2003). Burgess-Limerick, (2003) also suggests that general lifting education should be provided to individuals, as opposed to the recommendation of one style of lift. When considering numerous recommended lifting techniques, the use of a wide stance and flat back resulted in less compression on the spine (Anderson and Chaffin 1986). However, Anderson and Chaffin, (1986) did note that this was only advantageous compared to the stoop technique if feet are in a wide stance and lifting load above the knees (which would be the case during the SBL test).

It is acknowledged that a squat style of lifting elicits greater oxygen consumption when compared to a stoop, although lesser perceived low-back exertion (Hagen, Hallen, and Harms-Ringdahl, 1993). Straker, (2003) found that a stoop technique is less fatiguing, a squat technique results in less spinal compression, and a semi squat technique is also a good option. The erector spinae has been found to have highest muscular activity regardless of lifting style, while squat style has higher vastus lateralis activity and lower bicep femoris activity when compared to a stoop style of lift (Hagen, Hallen, and Harms-Ringdahl, 1993).

Maintaining slight lordosis of the lumbar spine while lifting has been encouraged during lifting tasks for many years. Conversely, new research has shown that flexed lumbar spine postures are correlated to higher strength and efficiency (Mawston et al. 2021). To stabilize the spine more efficiently, abdominal activities must increase to maintain equilibrium during kinetic/kinematic disturbances and reduce risk of musculoskeletal injuries (MSKI) (Granata and Orishimo, 2001). This study also suggests

that women may experience increased fatigue, greater muscle recruitment, and reduced external stability when compared to men during similar lifting tasks. A study by Vijaywargiya, Bhiwapurkar, and Thirugnanam (2022), suggested to keep maximum accepted lifting weight at 15kg when lifting from floor to ear to avoid MSKI in symmetrical lifting tasks. This study also showed that loading rate linearly increased after waist level.

### **Effects of Fatigue on Lifting (paced vs non-paced)**

The NIOSH lifting equation assumes 15 minutes of continuous lifting and suggests independent task analysis of lifting tasks that involve high-speed lifting (lifting that is not performed within a two-four second time frame) (Waters et al. 1993). Marras et al. (1993) measured lifting rates per hour and its association to lower back pain development. A 90% risk factor rate for development of lower back pain was associated with 295 lifts/hour in this study. This would average out to less than five lifts per minute. The paced occupational requirement of the SBL test requires members to perform seven lifts per minute on average, and high scoring individuals complete all 30 lifts within one minute. Of course, it is well documented that moderate to heavy loads, and moderate to high repetitions is beneficial for muscular hypertrophy (Kraemer and Ratamess 2004). Considering this information, one might conclude that performing one set of 30 sandbag lifts may not pose significant risk. However, ultimately load tolerance of the tissue will determine the injury outcome of an event (Bahr 2005). Furthermore, maximum lifting measures are ideally performed without straining or becoming out of breath (Snook and Ciriello 1991), which is a common occurrence during the SBL.

When two lifts per minute is compared to eight lifts per minute lateral shear, anteroposterior shear, and compression loads increase (Davis et al. 2002). Recent research on fatigue and lifting had participants lift repetitively in a paced manor to exhaustion, with relative load set at 10% of lifting capacity (Kazemi et al. 2021). In this study, participants adjusted lifting technique as fatigue accumulated, and compressive force ( $F_c$ ) at L5/S1 disk were affected by the repetitive lifting. Dolan and Adams (1998) inferred that repetitive lifting causes fatigue in the erector spinae muscles. These researchers also found that peak bending moment acting on the lumbar spine increased due to increased lumbar flexion throughout 100 lifts of 10kg, paced, from floor to waist.

### **Sex Differences in Lifting Technique**

It has been well documented that men and women have many physiological differences. During a conventional deadlift, men produce higher power compared to women (Jones et al. 2016). A study that measured hamstring activity during lower body resistance exercises showed that women were less able to activate the hamstrings, and more able to activate the quadriceps (Ebben 2009). Women have a larger percentage of type one muscle fibers which may attribute to increased endurance and less fatigue compared to men (Wüst et al. 2008; Côté, 2012), specifically in the erector spinae muscles (Mannion et al. 1997). Marras, Davis, and Jorgensen, (2003) found that although spinal compression was overall higher in men as the lifting pattern originated from the lumbar spine as opposed to the hips, women were at increased risk for injury due to lower spinal compression tolerance while lifting in “fixed” circumstances. This study also showed that spinal load was very similar between sexes when lifting height was normalized to subject anthropometry.

Sex influenced loadings of the spine when comparing paced lifting tasks by as much as 17% (two vs eight lifts per minute) (Davis et al. 2002). As lifting load increases from 6kg to 12kg, Martinez et al. (2019) found that the glenohumeral joint contributes less to the task for women when compared to men when lifting from hip to eye level. Women lifting an absolute load (15kg) from one pallet to another, when compared to men, displayed a less synchronized motion that was initiated with the knees, which increases risk for back injuries (Plamondon et al. 2014). Similar inter-joint coordination patterns were observed in women in a study done by Plamondon et al. (2017) when lifting relative load (to strength) as well (10kg load for women, 15kg load for men). In this study women's sequential lifting technique was again changed from a flexed squat lift to a stoop and participants were close to full lumbar flexion at peak resultant moment (PRM). These two studies suggest that sequential lifting patterns may not be due to load only and could suggest differences in technique between sexes, and that women may be putting large stresses on the lumbar spine during fatiguing lifting tasks. Fischer et al. (2015) found that lifting technique of men and women altered equivalently as fatigue accumulated during exposure to a prolonged lifting task that is defined in relative terms. In this study, changes in lower limb kinematics were not documented. The researchers however deduced that men and women adopted a position that required more forward lean as fatigue accumulated. Lower grip and upper body strength of women could contribute to the adoption of semi squat lifting pattern as opposed to a stoop (Eger and Stevenson 2004). Higher leg and back strength has been correlated to more synchronized hip-back inter-joint coordination in women (Yehoyakim et al. 2016).

In a study done by Tingelstad et al. (2016) it was concluded that no body mass bias exists in the Common Military Task Fitness Evaluation (CMTFE) and that total

performance on the CAF military physical fitness test is dependent on physical fitness rather than morphology. It was indicated that performing a biomechanical analysis on technique used, may prove beneficial when further correlating performance with morphology. This research contributes to this analysis by examining lifting technique in Canadian soldiers and its relation to sex.

## **Conclusion**

The importance of our research study is highlighted by the limited literature on acute maximal effort lifting while considering sex. Pilot work was completed to gain insight on kinematic and kinetic changes while lifting at maximal effort. Our project helps to contribute to the literature on this research topic.

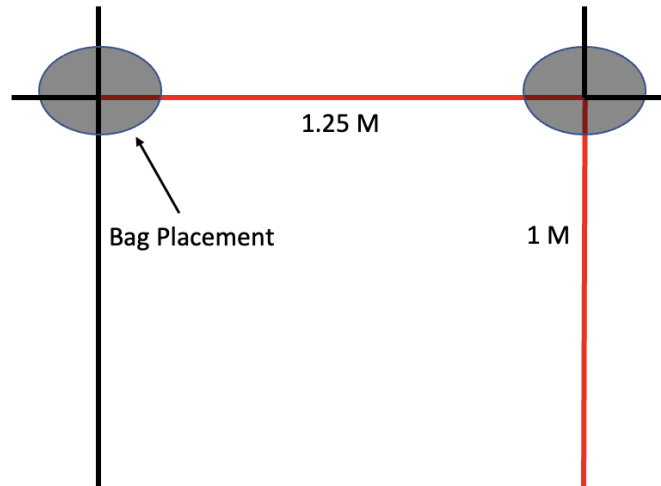
## **2.0 Pilot Study**

### **Objective**

The objective of the pilot work administered was to determine appropriate experimental design and evaluate kinematic/kinetic differences between paced and maximal effort symmetrical lifting while considering sex. Unfortunately, there were no women volunteers tested. Regardless, methods were trialed, and data was collected to give the researchers insight on potential kinematic and neuromuscular changes required prior to proceeding with the proposal. The assessment was made with an inertial measurement unit motion tracking system, electromyography, and force plates.

### **Methods**

Three participants performed the SBL test. Participants completed a proper warm up before lifting a calibrated 20kg sandbag 30 times in a paced and maximal effort manor. The bag was lifted and pressed against a wall with control at a height of 1 meter. Once the bag had contacted the wall, the participant dropped the bag to the floor prior to shuffling laterally to the referenced lifting site and lifting another bag while adhering to the same protocol. The paced test consisted of one lift per seven seconds for three minutes and 30 seconds (a total of 30 lifts). During the maximal effort test, the participant was directed to lift the bags as fast as possible until the 30 lifts were completed. If the participant did not lift the bag to the indicated lifting height, the participant was informed that the lift was not counted. The participant had freedom to choose their preferred lifting style and was not given any recommendations for optimal performance.



**Figure 2. 1:** *Lifting Station Set-up*

Surface electromyography (EMG) electrodes (sampling rate of 1024 Hz) were used to measure percent of maximum voluntary contraction (%MVC) and assess muscle activity and fatigue. The electrodes were placed on the following muscles: rectus femoris, vastus lateralis, biceps femoris, erector spinae at T9 & L3, gastrocnemius, biceps brachii, and the anterior deltoid. MVC testing was administered by the researcher as described in the research methodology. The participant was given two minutes of rest before the maximum voluntary contraction was repeated (Cardoso, Cardenas, and Albert 2021). Body hair was shaved, and the skin was abraded using paper towel, and wiped with alcohol swabs prior to the placement of electrodes (Courbalay et al. 2017). Electrodes were pre-gelled and Hypafix tape was used to secure the electrodes (Cardoso, Cardenas, and Albert 2021).

Inertial Measurement Unit (IMU) motion sensors by XSENS were used during the test to measure kinematic coordination differences between the two styles of lifts. Sensors were placed on the feet, lower and upper legs, pelvis, sternum, shoulders, upper

and forearms, hands, and head. Anatomical landmarks were measured and inputted into the software prior to calibration. The motion sensor equipment was placed on the participant and did not disrupt the EMG equipment. Motion sensors from the XSENS were affixed to participants with the provided XSENS straps which wrap around the site of sensor placement. The straps and sensors were further be secured to the participants with heavy duty tape.

An additional pilot test was administered while using force transducers. The participant performed a squat, stoop, and semi squat lift. Ground reaction force data was measured to indicate directional criteria comparatively.

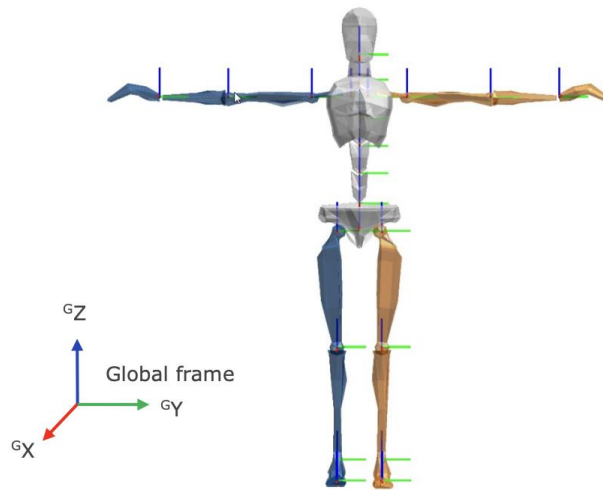


*Figure 2. 2: EMG electrode and IMU participant setup*

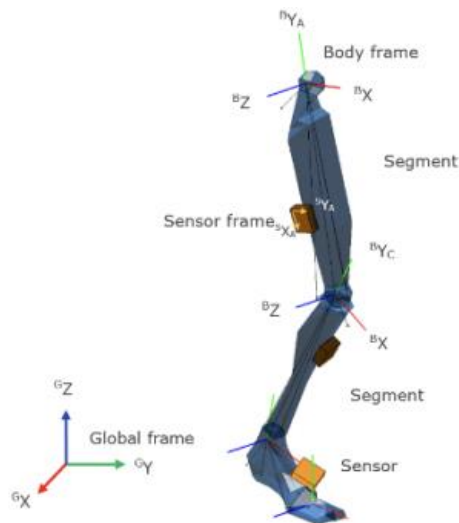
## **Results**

Joint angle data was used to determine coordination patterns at the beginning and at the end of paced and maximal effort lifting and evaluate the differences. For the

purposes of this pilot work, only flexion and extension angles were assessed. EMG was also used to display neuromuscular activity during the two lifting tasks.



**Figure 2. 3:** Global Segment Coordinate System Reference of XSENS



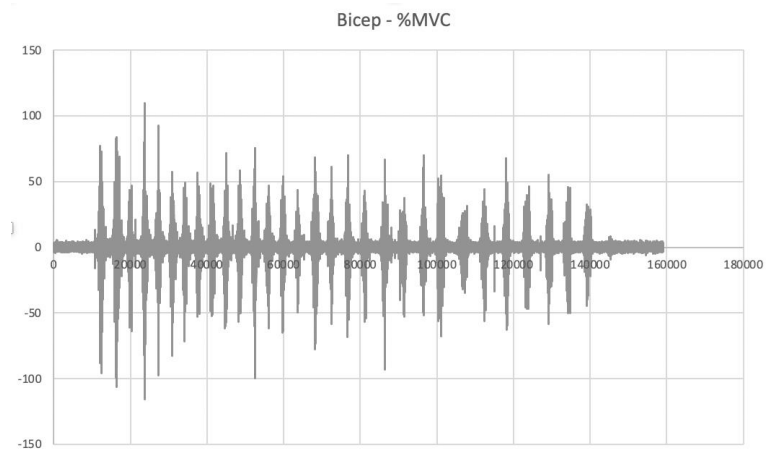
**Figure 2. 4:** Global and Local Coordinate Frames of XSENS

One of the participants began the paced test with a lumbar flexion angle of less than two degrees between joints L4 & L3. During the participant's maximal effort test, L3/L4 flexion began higher and remained throughout the 30 lifts (from approximately

four degrees to approximately 6.5 degrees). Max EMG activity of the bicep brachii decreased throughout the maximal effort testing. The pictures below visually show the participant adopting a more stoop lifting approach at the end of the test when compared to the beginning.



*Figure 2. 5: First rep of max effort lift test vs last rep of max effort lift test*



*Figure 2. 6: Raw % Maximum voluntary contraction of bicep during maximal effort lifting test*

Another participant began the paced lifting task with a higher degree of L5/S1 joint flexion (over 15 degrees), but quickly decreased this flexion angle after the fifth lift. The participant was able to maintain less than 10 degrees of L5/S1 joint flexion for 22 of the remaining 25 lifts. However, after the participant completed the first 5 lifts of the maximal effort test, 18 of the remaining 25 were below 10 degrees.



*Figure 2. 7: First rep of paced lift test vs last rep of paced lift test*

Participant three showed consistent flexion range in his right knee when comparing the two lifting tasks, however he had much less knee extension overall while performing the maximal effort lifting. This points to the participant maintaining more consistent knee flexion, and consequently performing the maximal effort test with a more consistent squat lifting approach.

## **Discussion and Limitations**

The findings in the pilot work informed the final protocol for thesis research. Efficiently recognizing lifts during the testing was a problem during our pilot work. We lacked understanding of the timing of the lifts, so have decided to implement a timing

button that will be triggered with the sandbag at the top of each lift. Ideally, our data is marked as the participant lifts the bag to accurately evaluate the entirety of the lift.

All pilot participants were strong men. We were unable to evaluate any differences between men and women because of this. Using EMG and IMU software simultaneously led to an excess of data recorded prior to and after lifting tests. This was problematic while compiling data for pilot work, however, assistant researchers ensured prompt initiation and completion of recording on equipment during research trials.

During the first pilot tests, one of the hand motion capture sensors fell off the participant in the middle of maximal effort testing. Although not detrimental to relevant kinematic data for this project – the event distracted the participant, and they stopped suddenly before being instructed to continue. After this test, hand IMU was secured with tape for all other participants. We employed this tactic during research trials as well.

Furthermore, %MVC was measured by use of the highest independent value recorded during the maximum voluntary contraction. We recognize how this may result in an inaccurate MVC reading and will instead measure the MVC by taking the average value during a selected timeframe. Lastly, rectus femoris muscle activity was measured however, we decided to replace this selection with measurement of the supraspinatus muscle. We recognized that the rectus femoris was not providing a significant amount of additional insight due to neuromuscular activity being measured at the vastus lateralis already. The measurement of the supraspinatus will allow us to take a closer look at the stabilization and elevation of the shoulder girdle during the lifts.

## **3.0 Methods**

### **Participants**

Sixteen men and fifteen women, all members of the CAF, were recruited for this study. A briefing note was sent to the base commander to inform them of the research being carried out at 5CDSB. Participants volunteered to partake in the study after receiving an email from the researcher outlining the study. All members were medically cleared to partake in the FORCE evaluation by a physician, and completed informed consent forms, and a detailed statement of understanding prior to participation. Participants had no current diagnosis of injury, or chronic disease. Ethics approval was acquired from the University of New Brunswick's research ethics board. Trials were held at the fitness center of Canadian Forces Base Gaagetown.

### **Protocol**

Our study required 50% of the participants to perform the maximal effort test first, followed by the paced test. The other 50% of the participants completed the paced test first, followed by the maximal effort test. Rest intervals were 20 minutes in between each lifting task to ensure appropriate recovery.

### ***Lifting Setup***

To replicate the lifting task of the FORCE evaluation for the Canadian Armed Forces, a lifting station was custom built. This station included taped indication of how high to lift the sandbag, as well as where to place feet while lifting. The participant started directly behind one of the sandbags, so that the taped line on the floor was

positioned between their feet. When the lifting task began, the participant lifted a sandbag up to the horizontally positioned line marked one metre from the floor. At least half of the sandbag had to be over the line. If the sandbag was positioned vertically, the entire sandbag had to clear the horizontal line. The participant could grab both sides of the bag, including the pigtail. The participant could also use their knee to assist with lifting the sandbag. The sandbag could then be released to the floor prior to shuffling to the next bag. This process was repeated for a total of thirty lifts by alternating between the two bags (shuffling left to right). Triggers were placed above the lift placement line strategically to ensure that half of the bag was placed above the line, while making firm contact with the trigger. The triggers sent a 5V signal through the EMG software to mark lift placement when the bag was pressed against them, and light up when contacted. The back of the lifting station included a four-foot by eight-foot sheet of plywood, secured to two wooden pallets. The entire station was supported by two support legs made with two-by-fours. To further support the system, two sandbags were draped over the ends to ensure minimal movement throughout the task. To inhibit forward and backward shifting of the lifting station, another two sandbags were draped on top of the structure. Power and signal cords to the triggers were hidden behind the lifting structure.



*Figure 3. 1: Design and build of research equipment used to replicate the SBL test.*

## **Pre-Data Collection Measurements**

Participants were asked to attend one data collection session where they would perform both lifting tasks. Consent forms were administered, and the participant reviewed all information with the researcher. Anthropometric data was collected on each participant prior to testing. Height and weight were recorded in centimeters and kilograms respectively by using a calibrated Global Industrial digital physician scale, while the participant did not have shoes on. Hand length and breadth was recorded in centimeters by using measuring tape, and shoe size and age were also acquired.

## **Instrumentation**

To compare biomechanical and neuromuscular differences between the two lifting styles, the following equipment was used during data collection:

1. Bortec Octopus AMT8-channel electromyography (EMG) (Bortec Biomedical Ltd., Calgary AB, [www.bortec.ca](http://www.bortec.ca)) to assess neuromuscular activity of several upper and lower limb musculature as well as trunk muscles.
2. Inertial Measurement Unit (IMU) Motion Tracking system by XSENS ([xsens.com](http://xsens.com)), to assess joint angles and lifting kinematics of lower and upper limbs and trunk.
3. Entrance survey of measured body anthropometrics including height (cm), weight (kg), hand length (cm), hand breadth (cm), shoe size and age.

## ***Electromyography***

Neuromuscular activity of indicated musculature in the following paragraph, was measured using sEMG electrodes. Body hair was shaved, and the skin abraded using

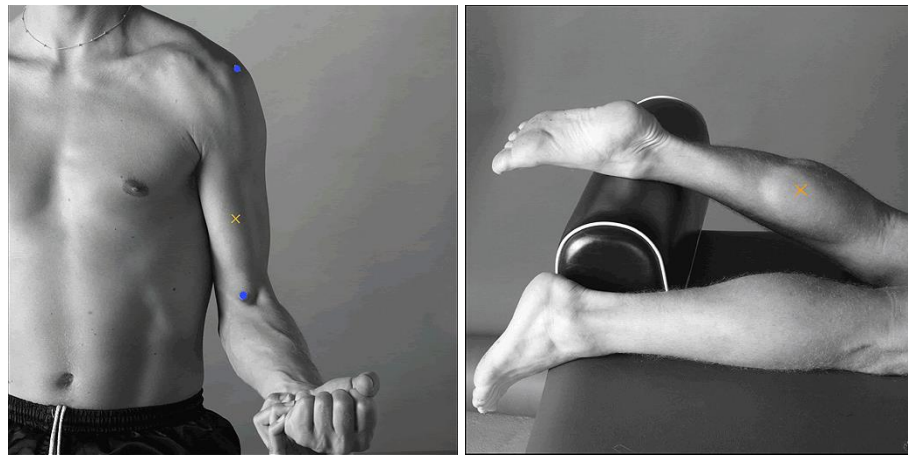
paper towel, and wiped with alcohol swabs prior to the placement of electrodes (Courbalay et al. 2017). The electrodes were placed unilaterally (left) on the skin of the following muscles while adhering to the guidelines by the Surface Electromyography for the Non-Invasive Assessment of Muscle (SENIAM): supraspinatus, vastus lateralis, biceps femoris, erector spinae at T9, multifidous at L3, gastrocnemius, bicep brachii, and the anterior deltoid. Electrodes were placed parallel to the muscle fibers after pinpointing placement location with a surface marker (Vera-Garcia, Moreside, and McGill 2010). All electromyography signal data was collected at 1024 samples per second and the raw signal was band pass filtered from 10-1000 Hz.



**Figure 3. 2:** *EMG electrode placement for the vastus lateralis on an active Canadian soldier.*

The medial gastrocnemius sensor was placed on the most prominent bulge of this muscle. The anterior deltoid sensor was placed one finger width anterior and distal to the acromion. The biceps brachii sensor was placed on the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit. The sensor for the vastus lateralis was placed at 2/3 on the line from the anterior spina iliaca superior to the lateral

side of the patella. The rectus femoris sensor was placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella. The bicep femoris sensor was placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. The erector spinae sensor was placed two-finger width lateral from spinous process at T9. The multifidus sensor was placed on the midline between the caudal top posterior spina iliaca superior and the interspace between L1 and L2 at the level of the L5 spinous process.

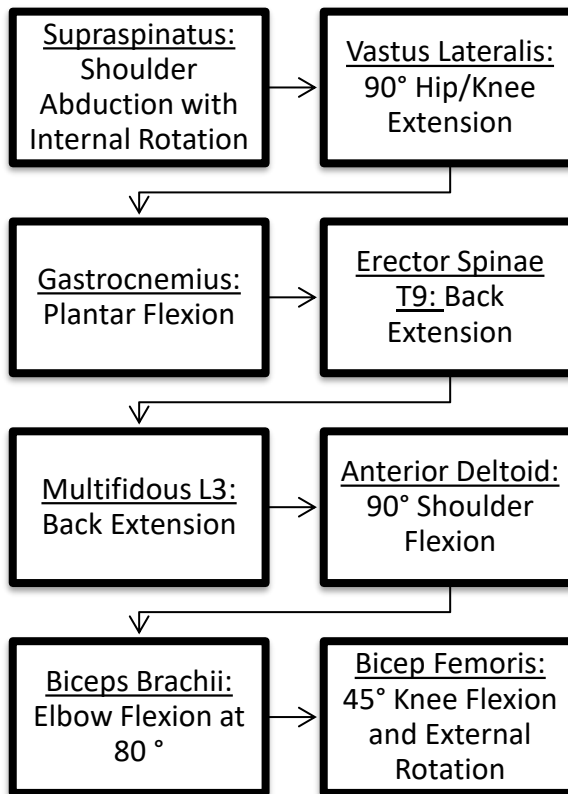


**Figure 3. 3:** Examples from the SENIUM guidelines (*biceps brachii* and *medial gastrocnemius*).

Hypafix tape was used to secure the electrodes in place. Electrodes were pre-gelled and placed over the belly of the muscle while alligator clips will be used to connect to electrode leads.

The maximum voluntary contraction of the supraspinatus was assessed while the participant completed shoulder abduction with internal rotation (empty can) (Boettcher, Ginn, and Cathers 2008). Measurement of the vastus lateralis was measured while the participant maintained 90 degree hip flexion and 90 degree knee flexion (Akima and

Ando, 2017). The gastrocnemius MVC was assessed by the participant performing plantar flexion against manual resistance (Antwi-Afari et al., 2017). Erector spinae (longissimus) MVC was measured with participants prone on a bench, while feet are restrained, and the lumbar slightly flexed initially before extending against a resistance applied from the researcher (McGill, Juker, and Kropf , 1996). Erector spinae was measured at T9 (Potvin, Norman, and McGill, 1996). The MVC of the multifidous was recorded by lifting the trunk from a prone position with resistance from the researcher as per the SENIAM guidelines. The MVC of the anterior deltoid was measured by asking the participant to perform shoulder flexion to 90 degrees, with a straight elbow, while the researcher asked the participant to resist the applied manual force (Avers and Brown, 2013). MVC of the bicep brachii was measured by the participant sitting in an upright position, with the elbow at 80 degrees (Kant et al, 2021), while resisting force from the researcher. The participant was prone with 45-degree knee flexion, and external leg rotation while the researcher applied force and asked the participant to resist the force to measure the MVC of the bicep femoris (Avers and Brown, 2019).



**Figure 3. 4:** Order of MVC testing with general joint positioning

One MVC was conducted per assessed muscle and held for five seconds (Cardoso, Cardenas, and Albert, 2021), for a total of eight isometric maximal voluntary contractions (Callaghan and McGill, 2001). A two-minute rest period was given if the MVC needed to be repeated (Cardoso, Cardenas, and Albert, 2021). MVCs were repeated if the participant felt as though they did not reach maximum effort during the test.



**Figure 3. 5:** *Bicep Femoris MVC test on participant at Canadian Forces Base Gagetown Fitness Center*

### ***Motion Capture***

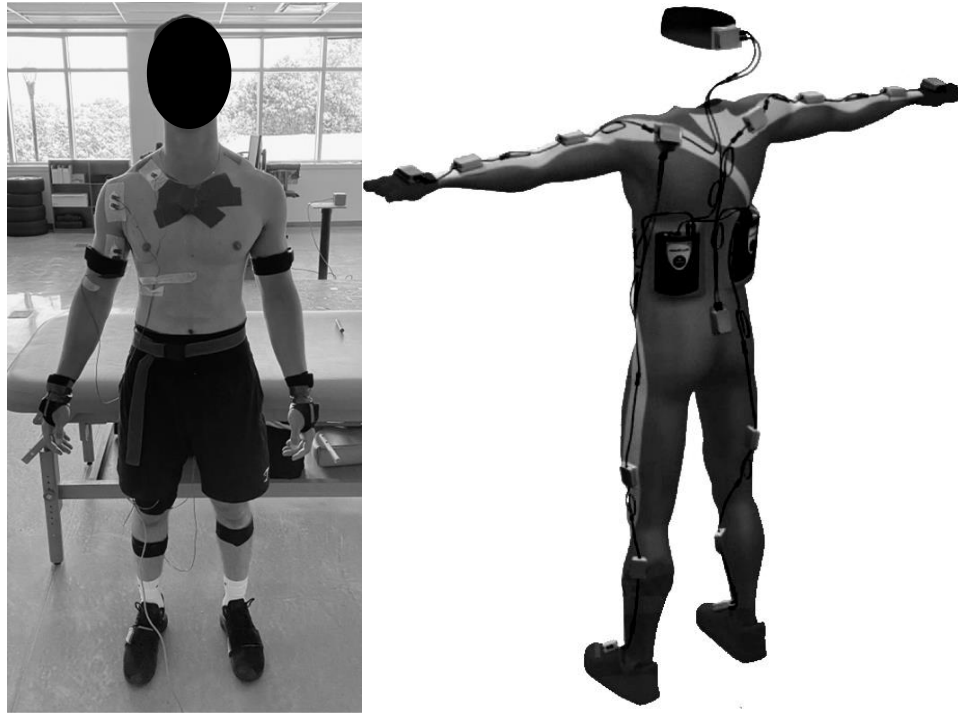
Kinematic data was recorded using the XSENS system and the data collected from the sensors were saved as files by the corresponding software. Anthropometric data was collected and used in the motion analysis. Height, weight, age, foot size, and hand length/breadth were recorded. Segment and joint motions were measured by using IMU motion sensors by XSENS. The XSENS equipment has been shown to have excellent validity for sagittal plane quantification of joint angles in hip, knee, and ankle while participants walk, squat, or jump, and good similarity in joint waveforms (Al-Amri et al. 2018). The XSENS system has shown strong cross correlations of joint and segment kinematics compared to the Vicon system when used to assess movement (Benjaminse et al. 2020). This IMU has been found as an appropriate system for capturing and reconstructing full body motion specifically for military-based movements (Mavor et al.

2020). XSENS Sensors were placed on the feet, lower and upper legs, pelvis, sternum, shoulders, upper and forearms, hands, and head. Straps were wrapped around each sensor to avoid movement during testing.

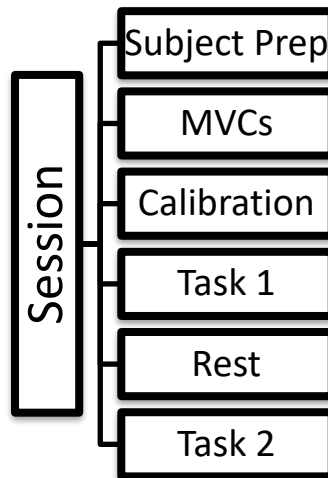
One sensor was placed on a headband and worn on the head. The sternum motion sensor was placed as indicated by the front pouch of the provided shirt. The sensors for the upper arms were placed on the flat surface at the midway point between the elbow and the shoulder. The lower arm motion trackers were placed on top of the wrists. The hand motion trackers were placed in gloves which were worn by the participants. The shoulder motion trackers were placed as indicated by the provided Velcro pads on the back of the shirt. The pelvis tracker was placed on top of the sacrum. The upper leg motion trackers were placed on the flat surface well above the knee. The lower leg motion trackers were placed on top of the flat surface of the shin bone. The foot sensors were placed deep at or under the shoe tongue, and the shoes were tied.

<b>Dimension</b>	<b>Description</b>
Body Height	Ground to top of head when standing upright
Foot or Shoe length	Length of feet or length of shoes if wearing shoes
Shoulder Height	Ground to C7 spinal process
Shoulder Width	Right to left distal tip of acromion (acromial angle)
Elbow Span	Right to left olecranon in T-pose
Wrist Span	Right to left ulnar styloid in T-pose
Arm Span	Tip of right fingers to tip of left fingers in T-pose
Hip Height	Ground to most lateral bony prominence of greater trochanter
Hip Width	Right to left anterior superior iliac spine
Knee Height	Ground to lateral epicondyle on the femoral bone
Ankle Height	Ground to distal tip of lateral malleolus
Extra Shoe Sole Thickness	Additional thickness of soles, different from normal shoe sole height. Use for stilts, platform soles, etc. When this value is set, all other dimensions measured from the ground should NOT include this value.

**Figure 3. 6:** Anthropometrics measured (XSENS Manual)



**Figure 3. 7:** *IMU sensor placement (participant vs. digital model) (Roetenberg, Luinge, and Slycke 2009)*



**Figure 3. 8:** *Timeline of data collection*

***Familiarization***

The participants received a familiarization brief of the task just prior to lifting. All participants completed the lifting task in prior annual FORCE evaluations and were

familiar with the protocol. The participants performed a brief warm up and the details of the warm-up is explained elsewhere (Haddad and Mirka 2013). Participants were required to have already completed the SBL test at least two times prior as performance has been shown to be accurate by the third test (Stockbrugger et al. 2018).

### ***The Lifting Task***

A sandbag lifting task was completed at two different lifting paces: 1) Paced Lifting Task whereby the participant lifted the 20kg sandbag every seven seconds for 3.5 minutes (total of 30 lifts); and 2) Maximal Lifting Task whereby the participant lifted the sandbag 30 times as quickly as possible. Each participant completed lifts under both conditions and the order of the lifting tasks were randomly assigned (Davis et al., 2002). The protocol for each lifting task was the same except for the pace of the task. The participant alternated between left and right sandbags separated by 1.25m. After each lift, the participant laterally shuffled 1.25 m and performed the subsequent lift. Each lift consisted of the sandbag being lifted from the ground, with a grip of the individual's preference, to a height of 1m marked on the wall. The sandbag was pushed against a trigger on the wall to register the bag's contact and the end of the lift. The participant's distance from the wall was determined by personal preference as no standard is given during the SBL test. A reference posture was recorded by the IMU in a relaxed standing posture (Kazemi et al., 2021) to effectively detect kinematic changes.



**Figure 3. 9:** Trigger to send 5V signal through EMG software to indicate placement of the lifting task.

## **Data Analysis**

### ***Outcome Measures***

Two research purposes were explored during this study. The first was to determine differences in lifting technique between a paced and non-paced sandbag lifting protocol. The second was to compare differences between men and women performing these tasks. Lifting technique was assessed by the following sagittal measures: shoulder, elbow, trunk, hip, knee and ankle joint angles at the lift initiation and placement; joint angle changes over the entire lifting envelope (lifting pattern). Changes in muscle activation patterns for each of the eight muscles was assessed by evaluating the mean frequency change between the first five lifts and the last five lifts.

All comparisons included an assessment of sex differences. The data analysis had two factors (sex and lifting style), and four factors total (men, women, paced lifting, max lifting).

### ***EMG Data Analysis***

EMG data was processed using custom computer programs. Mean of %MVC, and max of %MVC values were measured to indicate subsequent fatigue using absolute value averaging. Percent of max values were calculated by using the maximum values

from MVC testing, and continuously comparing values from tests to indicate percent of max values found. Peaks in MVC testing were indicated by measuring absolute highest values, with customized filters to ensure the riddance of false peaks. Average and max values of individual reps were calculated by using windows of time indicated by the triggers. Fatigue levels and compensation during the two lifting tasks were assessed using the indicated statistical analysis (described below). Custom Python coding outputted mean, and max values for individual lifts. An ANOVA was performed to indicate significant differences within tests, and between tests.

### ***Kinematic Data Analysis***

The kinematic data analysis consisted of knee, hip, trunk, elbow, and shoulder joint angle determination.



***Figure 3. 10:*** Picture taken during paced lifting task of a Canadian soldier research participant

Time series kinematic changes were assessed using a cross correlation technique to compare joint angle waveforms at each time point relative to the initial waveforms at time zero. The cross-correlation technique is used as a method to compare the similarity and time lag between lifting patterns. If there is a trending reduction in cross correlation coefficient it will indicate that lifters altered their lifting patterns over time (i.e. less similarity). The cross-correlation coefficient will be a value between zero and one. Values close to one would indicate high correlation of motion curves, while values closer to zero would indicate weak correlation of motion curves. If the trending patterns remained the same, it is an indication that the lifters did not alter their lifting patterns over the lifting period. Lag time can also be calculated using a cross correlation technique and was used here to measure differences in the timing of motion patterns as lifters fatigue. A decreasing lag time is an indicator that the participant's movement happened later, while an increasing lag time is an indicator that the movement happened earlier.

The data were analyzed using custom developed code in VS Code using Python (developed Dr. Noble & Ethan Wilkie). The position for the left shoulder, left hip, left knee, left ankle, and left toe were first determined. These positions were utilized to determine the segment angles of the trunk, thigh, leg, and foot. This was achieved by determining the corresponding vector for each segment via the equation:  $vector = proximal\ position - distal\ position$  (e.g.,  $FootVector = Left\ Ankle\ Position - Left\ Toe\ Position$ ), followed by utilizing the following equation:  $Segment\ Angle = arctan2(vector[:,2], vector[:,0])$ . Following this, the joint angles of the hip, knee, and ankle using the following equations:  $Hip\ Angle = (Thigh\ Angle - Trunk\ Angle) \times R2D +$

$360 \text{ degrees} \text{ *if hip angle is less than } -180 \text{ degrees*}; \text{ Knee Angle} = (\text{Thigh Angle} - \text{Leg Angle}) \times R2D + 360 \text{ degrees} \text{ *if knee angle is less than } -180 \text{ degrees*}; \text{ Ankle Angle} = ((\text{Foot Angle} - \text{Leg Angle}) + \pi/2) \times R2D$ , where R2D represented the conversion factor  $180/\pi$  allowing for the angles to be changed from radians to degrees. The trunk angle was then obtained from the XSENS software directly and multiplied by the conversion factor R2D for the purpose of outputting the measure in degrees. The joint angle data was windowed from the beginning of the lift (lowest left shoulder Z position) to the end of lift (highest left shoulder Z position) and a rubber band function was applied to stretch the frames of the data to 100 frames for ease of making comparisons between participants and tests. This series of calculations was repeated for each participant. The mean joint angles across the repetitions of the given lifting exercise were calculated for each participant. All calculated kinematic data was exported to Microsoft Excel of the hip, knee, ankle, and trunk joint angles during the participants' tests and used for the generation of graphs.

### **Statistical Analysis**

A linear mixed effects model ANOVA was used to statistically analyze the data. Factor one was sex, and the levels were men and women. Factor two was lift style, and the levels were max effort and paced effort. Between subject and within subject analyses were completed to show any significance by factors, or any interaction effects. Post hoc analyses were completed for significant results. The alpha level was set at  $<.05$ , and if any significant interactions were found, they were identified with bold numerical text. Cross correlation analysis on joint angle lifting waveforms provided further insight on kinematic data. A 95% confidence interval was used for relaying all significance

throughout this project, while using the Pearson coefficient with normally distributed data. Effect size was indicated throughout the analyses.

## 4.0 Results

There were several outcomes associated with comparing the paced lifting task to the maximal effort lifting task, men to women, and searching for interaction effects.

Significant findings were bolded in the tables and addressed in text.

### Pre-Collection Measurements

**Table 4. 1:** *Men and Women Anthropometric Measurements  $\pm$  Standard Deviation*

	Men	Women
Hand Breadth (cm)	<b>9.7 <math>\pm</math> 0.5</b>	<b>8.3 <math>\pm</math> 0.5</b>
Hand Length (cm)	<b>19.1 <math>\pm</math> 0.8</b>	<b>17.1 <math>\pm</math> 0.8</b>
Foot Size	<b>10.2 <math>\pm</math> 1.2</b>	<b>6.5 <math>\pm</math> 1.6</b>
Age (yrs)	<b>37.9 <math>\pm</math> 7.5</b>	<b>31.3 <math>\pm</math> 8.3</b>
Weight (kg)	<b>92.2 <math>\pm</math> 14.1</b>	<b>71.2 <math>\pm</math> 11.4</b>
Height (cm)	<b>177 <math>\pm</math> 6.7</b>	<b>162 <math>\pm</math> 9.3</b>

## Main Effect of Lift on Muscle Activity

**Table 4. 2:** Main effect of Lift (Paced vs Max) on Muscle Activity (Mean EMG and Max EMG) at the Anterior Deltoid, Supraspinatus, Bicep Brachii, Erector Spinae (T9), Multifidous (L3), Vastus Lateralis, Bicep Femoris, and Gastrocnemius plus and minus Standard Error. PE: Paced Effort lifting test, ME: Maximal Effort lifting test, Mean: Mean EMG activity, Max: Max EMG activity, ES: Effect Size.

Muscle	PE Mean	ME Mean	PE Max	ME Max	ES	Significance
Anterior Deltoid	7.5 ± 2.5	17.7 ± 2.4	114 ± 8.7	119 ± 8.7	Mean: 0.959 Max: 0.976	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = 0.073
Supraspinatus	7.1 ± 1.1	15.4 ± 1.1	70.3 ± 6.8	88.5 ± 6.8	Mean: 0.999 Max: 0.987	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = <b>0.000</b>
Bicep Brachii	9.6 ± 2.1	22.9 ± 2.1	88.5 ± 7.8	112 ± 8.0	Mean: 0.981 Max: 0.996	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = <b>0.000</b>
Erector Spinae (T9)	17.2 ± 3.3	35.2 ± 3.3	113 ± 7.2	127 ± 7.4	Mean: 0.999 Max: 0.799	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = <b>0.001</b>
Multifidous (L3)	17.8 ± 2.4	35.0 ± 2.4	124 ± 6.8	134 ± 7.1	Mean: 0.979 Max: 0.978	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = 0.069
Vastus Lateralis	20.8 ± 3.6	45.9 ± 3.6	107 ± 10.2	126 ± 10.9	Mean: 0.962 Max: 0.697	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = <b>0.001</b>
Bicep Femoris	14.6 ± 2.8	27.3 ± 2.8	72.9 ± 6.6	93.5 ± 6.7	Mean: 0.997 Max: 0.968	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = <b>0.000</b>
Gastrocnemius	14.5 ± 2.4	32.9 ± 2.4	127 ± 6.9	146 ± 11.8	Mean: 0.971 Max: 0.622	Mean : <i>p</i> = <b>0.000</b> Max: <i>p</i> = 0.128

### ***Main Effect of Lift on Mean EMG***

- Anterior Deltoid Mean EMG Activity was significantly affected by lift style. Max effort lifting involved more muscle activity than paced lifting with an effect size of 0.959.
- Supraspinatus Mean EMG activity was significantly affected by lift style. Max effort lifting required more muscular activity than paced with an effect size of 0.999.
- Bicep Brachii Mean EMG activity was significantly affected by lift style. Max effort lifting required more muscle activity than paced lifting with an effect size of 0.981.
- Erector spinae at T9 Mean EMG activity was significantly affected by lift style. Muscle activity was higher in maximal effort lifting with an effect size of 0.999.
- Multifidous at L3 Mean EMG activity was significantly affected by lift style. Max effort lifting required more muscular activity with an effect size of 0.979.
- Vastus Lateralis Mean EMG activity was significantly affected by lift style. Max effort lifting showed higher mean EMG activity with an effect size of 0.962.
- Bicep Femoris Mean EMG activity was significantly affected by lift style. Max effort lifting required higher mean EMG activity with an effect size of 0.997.
- Gastrocnemius mean EMG activity was significantly affected by lift style. Max effort lifting required higher mean EMG activity with an effect size of 0.971.

### ***Main Effect of Lift on Max EMG***

- Supraspinatus Max EMG Activity was significantly affected by lift style. Maximal lifting required higher max EMG activity with an effect size of 0.987.

- Bicep Brachii Max EMG activity was significantly affected by lift style. Max effort lifting required higher max EMG activity with an effect size of 0.996.
- Erector Spinae at T9 Max EMG activity was significantly affected by lift style. Max effort lifting required higher max values with an effect size of 0.799.
- Vastus Lateralis Max EMG activity was significantly affected by lift style. Max EMG readings were higher in maximal effort lifting tests with an effect size of 0.697.
- Bicep Femoris Max EMG activity was significantly affected by lift style. Higher values were present in the maximal effort tests with an effect size of 0.968.

### Main Effect of Lift on Joint Angles

**Table 4. 3:** Main effect of Lift (Paced vs Max) on Joint Angle (at Lift Initiation and Lift Placement) for the Hip, Knee, Shoulder, Elbow, and L5/S1 plus and minus Standard Error. PE: Paced Effort lifting test, ME: Maximal Effort lifting test, LI: Lift Initiation, LP: Lift Placement, ES: Effect Size.

	PE LI	ME LI	PE LP	ME LP	ES	Significance
Hip	49.4 ± 1.6	48.5 ± 1.7	14.6 ± 1.3	30.1 ± 1.4	LI: 0.484 LP: 0.884	LI: <i>p</i> = 0.324 LP: <i>p</i> = <b>0.000</b>
Knee	53.4 ± 2.1	63.3 ± 2.2	21.5 ± 1.7	34.3 ± 1.8	LI: 0.991 LP: 0.771	LI: <i>p</i> = <b>0.000</b> LP: <i>p</i> = <b>0.000</b>
Shoulder	56.9 ± 1.5	59.2 ± 1.6	7.39 ± 2.1	21.0 ± 2.2	LI: 0.907 LP: 0.979	LI: <i>p</i> = 0.124 LP: <i>p</i> = <b>0.000</b>
Elbow	22.0 ± 1.5	27.5 ± 1.6	14.3 ± 2.0	40.0 ± 2.1	LI: 0.999 LP: 0.932	LI: <i>p</i> = <b>0.001</b> LP: <i>p</i> = <b>0.000</b>
L5/S1	9.63 ± 0.8	11.6 ± 0.8	1.18 ± 0.6	3.78 ± 0.6	LI: 0.778 LP: 0.665	LI: <i>p</i> = <b>0.000</b> LP: <i>p</i> = <b>0.000</b>

### ***Main Effect of Lift on Joint Angles at Lift Initiation***

- Knee angle at lift initiation was significantly affected by lift style. The effect size was 0.991. Max lifting showed greater knee angles than paced lifting.
- Elbow angle was significantly affected by lift style. Participants showed greater elbow angles in Max effort lifting with an effect size of 0.999.
- L5/S1 angle was significantly affected by lift style. Max lifting showed greater L5/S1 angles than paced lifting with an effect size of 0.778.

### ***Main Effect of Lift on Joint Angles at Lift Placement***

- Hip angle at lift placement showed an interaction effect. See “Significant Interaction Effects” for details.
- Knee angle at lift placement showed an interaction effect. See “Significant Interaction Effects” for details.
- Lift style significantly affected shoulder angle at lift placement. Participants had greater shoulder angles during max effort lifting with an effect size of 0.979.
- Elbow angle at lift placement showed an interaction effect. See “Significant Interaction Effects” for details.
- L5/S1 angle at lift placement showed an interaction effect. See “Significant Interaction Effects” for details.

## Main Effect of Sex on Muscle Activity

**Table 4. 4:** Main effect of Sex (Men vs Women) on Muscle Activity (Mean EMG and Max EMG) at the Anterior Deltoid, Supraspinatus, Bicep Brachii, Erector Spinae (T9), Multifidous (L3), Vastus Lateralis, Bicep Femoris, and Gastrocnemius plus and minus Standard Error. W: Women, M: Men, Mean: Mean EMG activity, Max: Max EMG activity, ES: Effect Size.

Muscle	M Mean	W Mean	M Max	W Max	ES	Significance
Anterior Deltoid	13.6 ± 3.2	11.5 ± 3.5	103 ± 12.2	130 ± 12.3	Mean: 0.076 Max: 0.966	Mean : $p = 0.661$ Max: $p = 0.139$
Supraspinatus	8.63 ± 1.4	13.8 ± 1.4	62.8 ± 9.0	95.9 ± 9.6	Mean: 0.999 Max: 0.945	Mean : $p = \mathbf{0.015}$ Max: $p = \mathbf{0.018}$
Bicep Brachii	12.8 ± 2.7	19.7 ± 2.9	93.2 ± 10.3	108 ± 11.2	Mean: 0.694 Max: 0.878	Mean : $p = 0.093$ Max: $p = 0.349$
Thoracic [9]	22.1 ± 4.5	30.2 ± 4.5	105 ± 9.8	135 ± 10.2	Mean: 0.993 Max: 0.594	Mean : $p = 0.215$ Max: $p = \mathbf{0.047}$
Lumbar [3]	21.6 ± 3.02	31.1 ± 3.2	108 ± 8.5	150 ± 9.8	Mean: 0.693 Max: 0.992	Mean : $p = \mathbf{0.040}$ Max: $p = \mathbf{0.004}$
Vastus Lateralis	23.4 ± 4.7	43.4 ± 4.9	97.3 ± 11.5	136 ± 16.3	Mean: 0.692 Max: 0.549	Mean : $p = \mathbf{0.006}$ Max: $p = 0.069$
Bicep Femoris	17.6 ± 3.8	24.3 ± 4.0	76.3 ± 8.6	90.2 ± 9.3	Mean: 0.772 Max: 0.588	Mean : $p = 0.231$ Max: $p = 0.283$
Gastrocnemius	24.5 ± 3.1	22.9 ± 3.1	128 ± 11.2	145 ± 9.0	Mean: 0.042 Max: 0.522	Mean : $p = 0.712$ Max: $p = 0.221$

### ***Main Effect of Sex on Mean EMG***

- Supraspinatus Mean EMG activity was significantly affected by sex. Women had more muscle activity than men with an effect size of 0.999.
- Multifidous at L3 Mean EMG activity was significantly affected by sex. Women had higher mean EMG activity than men with an effect size of 0.693.
- Vastus Lateralis Mean EMG activity was significantly affected by sex. Women showed more VL mean EMG activity than men with an effect size of 0.692.

### ***Main Effect of Sex on Max EMG***

- Supraspinatus Max EMG Activity was significantly affected by sex. Women had greater Max EMG activity with an effect size of 0.945.
- Erector Spinae at T9 Max EMG activity was significantly affected by sex. Women had higher max values with an effect size of 0.595.
- Multifidous at L3 Max EMG activity was significantly affected by sex. Women showed higher max EMG values with an effect size of 0.992.

### **Main Effect of Sex on Joint Angles**

**Table 4. 5:** *Main effect of Sex (Men vs Women) on Joint Angle (at Lift Initiation and Lift Placement) for the Hip, Knee, Shoulder, Elbow, and L5/S1 plus and minus Standard Error. W: Women, M: Men, LI: Lift Initiation, LP: Lift Placement, ES: Effect Size.*

	M LI	W LI	M LP	W LP	ES	Significance
Hip	49.0 ± 2.3	48.9 ± 2.2	21.2 ± 1.7	23.5 ± 1.6	LI: 0.000 LP: 0.057	LI: $p = 0.980$ LP: $p = 0.305$

Knee	58.6 ± 2.8	58.2 ± 2.7	28.2 ± 2.2	27.6 ± 2.1	LI: 0.039 LP: 0.003	LI: <i>p</i> = 0.919 LP: <i>p</i> = 0.832
Shoulder	57.3 ± 2.0	59.7 ± 1.9	10.7 ± 2.6	17.7 ± 2.4	LI: 0.676 LP: 0.841	LI: <i>p</i> = 0.478 LP: <i>p</i> = 0.054
Elbow	29.3 ± 1.8	20.2 ± 1.8	29.2 ± 2.4	25.1 ± 2.5	LI: 0.999 LP: 0.123	LI: <b><i>p</i> = 0.002</b> LP: <i>p</i> = 0.251
L5/S1	10.1 ± 1.2	11.1 ± 1.1	1.19 ± 0.8	3.77 ± 0.7	LI: 0.093 LP: 0.215	LI: <i>p</i> = 0.538 LP: <b><i>p</i> = 0.022</b>

### ***Main Effect of Sex on Joint Angles at Lift Initiation***

- Elbow angle was significantly affected by sex at lift initiation. Men showed greater elbow angles than women with an effect size of 0.999.

### ***Main Effect of Sex on Joint Angles at Lift Placement***

- L5/S1 angle at lift placement showed an interaction effect. See “Significant Interaction Effects” for details.

### **Significant Interaction Effects**

**Table 4. 6:** *Significant Interaction Effects for Main effect of Lift (Paced and Max) and sex (Men and Women) on Joint Angles with indicated Lift Style, Lift Phase, and Post Hoc Significance plus and minus Standard Error.*

	Lift Style	Lift Phase	Men	Women	Post Hoc Significance
Hip	Max	Placement	26.1 ± 2.0	34.0 ± 1.8	<b><i>p</i> = 0.005</b>
Knee	Paced	Placement	25.3 ± 2.4	17.7 ± 2.1	<b><i>p</i> = 0.030</b>
Elbow	Paced	Placement	19.8 ± 2.7	8.8 ± 3.0	<b><i>p</i> = 0.009</b>
L5/S1	Max	Placement	1.57 ± 0.8	5.99 ± 0.8	<b><i>p</i> = 0.001</b>

- During max effort lifts, women showed a greater hip angle than men (34.0 vs 26.1, Post Hoc P value: 0.005).
- Men showed greater knee angle during paced lifting (25.3 vs 17.7, Post hoc P value: 0.030).
- Men showed greater elbow angle during paced lifting (19.78 vs 8.81, post hoc p value: 0.009).
- Women showed greater L5/S1 angle at max effort lifting than men (5.991 vs 1.570, post hoc p value: 0.001).
- There were no significant interaction effects on muscle activity

## Cross Correlation Findings

### *Cross Correlation Findings (Women)*

**Table 4. 7:** Women Cross Correlation findings represented as a coefficient comparing early vs late lifts of Paced tests (PC), and Max tests (MC), as well as across tests (Paced vs Max; PMC). Women Lag frames (% of time) indicated comparing early vs late lifts of Paced test (PL), Max test (ML), as well as across tests (Paced vs Max; PML).

<i>Joint</i>	<i>PC</i> <i>(r<sup>2</sup>)</i>	<i>PL</i> <i>(% time)</i>	<i>MC</i> <i>(r<sup>2</sup>)</i>	<i>ML</i> <i>(% time)</i>	<i>PMC</i> <i>(r<sup>2</sup>)</i>	<i>PML</i> <i>(% time)</i>
<i>Hip</i>	0.87	1.86	0.85	2.50	0.78	-14.17
<i>Knee</i>	0.82	4.29	0.85	2.01	0.78	-11.83
<i>Shoulder</i>	0.87	-0.93	0.89	-2.50	0.80	-0.42
<i>Elbow</i>	0.77	4.07	0.63	-13.25	0.57	-9.25
<i>L5/S1</i>	0.89	-1.93	0.82	-5.83	0.71	-10.58

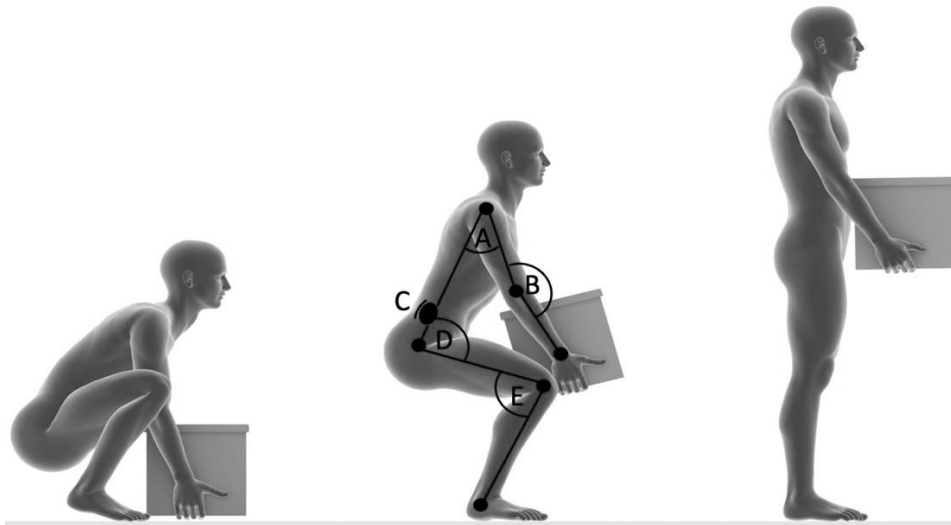
When comparing early vs late timings of paced tests, there was a high positive correlation for the flexion/extension angles at the hip, shoulder, and lumbar/sacral region. When comparing early vs late timings of max effort tests, there was a high positive correlation for the flexion/extension angles at the hip, knee, and shoulder. Lag values were significantly behind later in the max test for the elbow. When comparing paced vs max effort tests, there were lower correlation values and significant negative lag differences found at the hip, knee, and lumbar/sacral region.

### **Cross Correlation Findings (Men)**

**Table 4. 8:** Men Cross Correlation findings represented as a coefficient comparing early vs late lifts of Paced tests (PC), and Max tests (MC), as well as across tests (Paced vs Max; PMC). Men Lag frames (% of time) indicated comparing early vs late lifts of Paced test (PL), Max test (ML), as well as across tests (Paced vs Max; PML).

Joint	PC ( $r^2$ )	PL (% time)	MC ( $r^2$ )	ML (% time)	PMC ( $r^2$ )	PML (% time)
Hip	0.92	0.13	0.91	1.30	0.66	-25.77
Knee	0.86	-0.43	0.90	5.23	0.65	-18.54
Shoulder	0.88	1.43	0.90	-3.31	0.68	-4.23
Elbow	0.90	0.57	0.86	-0.69	0.47	-16.92
L5/S1	0.91	0.36	0.83	-1.08	0.63	-22.54

When comparing early vs late timings of paced tests, there was a high positive correlation for the flexion/extension angles at all joints. When comparing early vs late timings of max effort tests, there was a high positive correlation for all joints other than a lesser correlation value found at the lumbar/sacral region. When comparing paced vs max effort tests, there were low correlation values, and significant negative lag differences found at the hip, knee, elbow and lumbar/sacral region.



**Figure 4. 1:** A: Shoulder Angle, B: Elbow Angle, C: L5/S1 Angle, D: Hip Angle, E: Knee Angle

## Percent Change Findings

### *Percent Change Findings for Lift Style*

**Table 4. 9:** *Percent Change Values (Early 5 reps vs Late 5 reps) of EMG activity (Mean and Max) for Lift style (Paced and Max). PE: Paced Effort lifting test, ME: Maximal Effort lifting test, Mean: Mean EMG Activity, Max: Max EMG activity.*

Muscle	PE   Mean	ME   Mean	PE   Max	ME   Max
Anterior Deltoid	-7%	-11%	6%	11%
Supraspinatus	20%	29%	15%	17%
Bicep Brachii	-1%	4%	-3%	18%
Thoracic [9]	-2%	0%	10%	7%
Lumbar [3]	9%	-6%	14%	-4%
Vastus Lateralis	-16%	3%	-5%	5%
Bicep Femoris	-7%	13%	5%	17%
Gastrocnemius	-14%	-6%	-16%	-4%

- Participants had more supraspinatus activity as the max test went on.
- Participants had more bicep femoris activity as the max test went on.
- Participants had more bicep activity as max testing went on.
- Participants had less lumbar activity as the max test went on and more lumbar activity as the paced test went on.

**Table 4. 10:** *Percent Change Values (Early 5 reps vs Late 5 reps) of Joint Angles for Lift style (Paced and Max). PE: Paced Effort lifting test, ME: Maximal Effort lifting test, LI: Lift Initiation, LP: Lift Placement.*

	PE   LI	ME   LI	PE   LP	ME   LP
Hip	-3%	4%	-13%	-6%
Knee	-7%	2%	12%	-11%
Shoulder	2%	8%	2%	-35%
Elbow	-17%	0%	0%	-6%
L5/S1	7%	21%	-25%	40%

- Participants had more Lumbar flexion as the max test went on at initiation and placement.
- Participants had less hip, more knee, and less lumbar flexion as the paced test went on.
- Participants had more shoulder motion at initiation of max testing and less shoulder at placement of max testing as testing progressed.

***Percent Change Findings for Sex***

***Table 4. 11: Percent Change Values (Early 5 reps vs Late 5 reps) of EMG activity (Mean and Max) for Sex (Women and Men). W: Women, M: Men, Mean: Mean EMG Activity, Max: Max EMG Activity.***

Muscle	W   Mean	M   Mean	W   Max	M   Max
Anterior Deltoid	-11%	-8%	8%	8%
Supraspinatus	27%	23%	20%	12%
Bicep Brachii	-11%	15%	4%	8%
Thoracic [9]	-1%	-1%	4%	12%
Lumbar [3]	12%	-7%	22%	-4%
Vastus Lateralis	-12%	-1%	-12%	4%
Bicep Femoris	5%	2%	15%	7%
Gastrocnemius	-9%	-11%	-10%	-17%

- Women and men had more supraspinatus activity as lifting went on.
- Women had more lumbar flexion as lifting progressed while men had less.
- Men had more bicep activity as lifting went on.
- Women had less vastus lateralis activity as testing went on, and more bicep femoris activity.

- All sexes had less gastrocnemius activity as testing went on.

**Table 4. 12:** *Percent Change Values (Early 5 reps vs Late 5 reps) of Joint Angles for Sex (Men and Women). W: Women, M: Men, LI: Lift Initiation, LP: Lift Placement.*

	W   LI	M   LI	W   LP	M   LP
Hip	0%	0%	-10%	-9%
Knee	-2%	3%	-7%	11%
Shoulder	5%	6%	-19%	-13%
Elbow	0%	-12%	9%	-15%
L5/S1	7%	22%	-19%	38%

- Men had more lumbar flexion as lifting progressed.
- Women had more lumbar flexion at lift initiation as the tests went on, but less at placement of the sandbag.
- Both sexes had less shoulder motion at placement as the test went on and more at initiation.

## **5.0 Discussion**

There were four hypotheses guiding this research. Based on the results, hypothesis one, “The maximal effort lifting task will result in less coordinated movement between lower and upper body”, can be supported. Hypothesis two, “Higher muscle activation will be required during the maximal effort lifting task”, can be supported. Hypothesis three, “Lifting technique will require more lower extremity and trunk motion for women participants to complete the lifting task” can be supported. Hypothesis four, “The muscle activity will be different between men and women performing the lifting tasks”, can be supported.

### **The Main Effect of Lift**

When considering the two lifting styles our results suggest that Maximal Effort Lifting required more mean EMG activity than paced effort lifting for all muscles measured. Five of the eight muscles also showed significantly higher max EMG activity in the maximal effort lifting tasks compared to the paced lifting tasks. Max effort lifting also required greater knee angles, elbow angles, and L5/S1 angles compared to the paced lifting task at lift initiation. At lift placement, maximal effort lifting required greater shoulder angles for all participants.

There is very little research on this topic currently. However, our findings do relate to the literature. A study done by Waters et al. (1993) associates heavier workloads with high %MVC values. This was shown in our research as the vast majority of musculature tested showed higher mean and max EMG values in the maximal effort lifting task. A study done on the effect of lift height showed that more upper body

strength was required for a 1RM lifting height of three to four feet, which is in the range of our lifting placement site (Rice et al. 1996). Our research showed increases in EMG activity of both upper and lower extremity musculature as intensity increased as opposed to relative load.

Dolan and Adams (1998) found that peak bending moment acting on the lumbar spine increased due to increased lumbar flexion throughout 100 lifts of 10kg, paced, from floor to waist. Our research showed that maximal effort lifting increases lumbar flexion angles at lift initiation for all participants and at lift placement for women. Other research had participants lift repetitively in a paced manner to exhaustion, with relative load set at 10% of lifting capacity (Kazemi et al. 2021). In this study, participants adjusted lifting technique as fatigue accumulated, and compressive force ( $F_c$ ) at L5/S1 disk was affected by the repetitive lifting. One new research study questions the current paradigm around 'safe lifting', as they did not find that greater LBP was associated with greater forces (Saraceni et al. 2021), which could provide some context to our findings about maximal effort lifting.

Our research showed exaggerated angles at multiple joints during maximal effort lifting compared to paced effort lifting. This displays that more overall motion was required to complete the maximal effort lifting task. A study by Vijaywargiya, Bhiwapurkar, and Thirugnanam, 2022, suggested to keep maximum accepted lifting weight at 15kg when lifting from floor to ear to avoid MSKI in symmetrical lifting tasks. Our study used lifting loads of 20kg from floor to a trigger, one meter high, on the wall.

## **The Main Effect of Sex**

When considering the sex-related differences our results suggest that women had higher mean EMG activity at the supraspinatus, multifidus (L3), and vastus lateralis. Women also showed greater max EMG activity at the supraspinatus, erector spinae (T9), and multifidus (L3). Women showed lesser elbow angles at lift initiation. Women also showed greater L5/S1 angles at lift placement. During the maximal effort lifting tasks, women showed greater hip angles and L5/S1 angles than men. During the paced effort lifting task, men used greater knee angles and elbow angles than women.

Our findings related to the literature in several ways. Granata and Orishimo (2001) suggest that women may experience greater muscle recruitment when compared to men during similar lifting tasks. We found that women specifically showed significantly higher max and mean EMG values for the indicated musculature above. This shows that the absolute load used in the test required more muscular exertion from the women participants.

We found that women had higher vastus lateralis mean EMG than men. Other research has shown that squat style lifting has higher vastus lateralis activity when compared to a stoop (Hagen, Hallen, and Harms-Ringdahl, 1993). This may infer more reliance on squat lifting approaches for women while lifting in maximal and paced environments. Women have shown to better activate quadriceps and activate less hamstrings with lower body resistance exercises, which supports our findings in a lifting context (Ebben 2009). Women may find themselves more out of breath as lifting in this regard continues, as maximal squat lifting elicits higher  $VO_2$  consumption (Hagen, Hallen, and Harms-Ringdahl 1993).

Women also showed greater L5/S1 and hip angles at maximal effort lifting during placement. They also had greater L5/S1 angles overall. Based on these findings, women also stooped throughout the tests. With consideration of our neuromuscular data, and the literature, we can denote those women adopted a lifting approach with stoop and squat like properties, simultaneously. This was apparent to the researchers as well. In a kinematic motion analysis, Peharec et al. 2007 found that women had high pelvic angle and that contributed to trunk flexion angles overall. One study shows that independent of sex, a semi squat technique was demonstrated under loaded conditions (isometric back strength) (Sadler, Graham, and Stevenson 2013). It is important to consider that lower grip and upper body strength of women could contribute to the adoption of semi squat lifting pattern (Eger and Stevenson, 2004). Other research has studied 100 volunteer on active movements of the lumbar spine and found no significant differences in sex (Vachalathiti, Crosbie, and Smith 1995), however, we did find differences between sex on these lifting tasks. Stooped lifting postures throughout the literature is often viewed as incorrect, but some literature supports the lifting style (Straker 2003).

Women also showed higher supraspinatus activity than men in both mean and max EMG values overall. Since the supraspinatus plays a significant role in stabilization of the glenohumeral joint, there is some interesting research that relates. For example, Martinez et al. (2019) found that as lifting load increases from six kg to 12kg, the glenohumeral joint contributes less to the task for women when compared to men. Since load increases are compensated with changes in function at the glenohumeral joint (GHJ) that favour joint stability (Assila, Duprey, and Begon, 2021), it seems that women required more joint stability at the GHJ as both tests went on instead of experiencing less contribution. Women experienced an exaggerated elbow angle compared to men. This

may infer potential upper extremity fatigue for women, considering that significant differences in strength and power have been noted between men and women, particularly in the upper body (Bartolomei et al., 2021).

A study done by Vaara et al. (2022) showed that improvement in maximal lifting capacity in military context can be achieved by strength training or combined strength and aerobic training. To be better prepared for either style of lifting test, an emphasis on lower volume but higher intensity training should be applied (Vaara et al. 2022), and adopted by our Canadian Armed Force members.

## **Cross Correlation**

Women showed high positive correlation for the flexion/extension angles at the hip, shoulder, and lumbar/sacral region, when comparing early vs late timings of paced tests. When comparing early vs late timings of max effort tests, there was a high positive correlation for the flexion/extension angles at the hip, knee, and shoulder for women. Women showed low correlation at the elbow during the maximal effort test from beginning to end of the test. They also showed lower correlation values and significant lag differences found at the hip, knee, and lumbar/sacral region, when comparing paced vs max effort tests. Lag values were also significantly behind later in the max test for the elbow, which was the only significant within test difference in lag for all participants. Elbow technique was not well correlated for women towards the end of the maximal effort test. Other work has shown that women are more synchronized at hip and knee when performing stoops and squats with a box than men (Lindbeck and Kjellberg 2001). Women lifting absolute load when compared to men displayed a less synchronized motion (Plamondon et al. 2014), and similarly with relative load Plamondon et al. (2017). We did not have the significant findings to suggest either conclusion other than the synchronization in the upper limbs as mentioned.

Men showed high positive correlation for the flexion/extension angles at all joints, when comparing early vs late timings of paced tests. When comparing early vs late timings of max effort tests, there was a high positive correlation for all joints other than a lesser correlation value found at the lumbar/sacral region for the men. They also showed low correlation values, and significant lag differences found at the hip, knee, elbow and lumbar/sacral region, when comparing paced vs max effort tests. Men overall

showed more consistency in lifting technique overall towards the end of the maximal effort lifting task when compared to women. However, due to the absolute load of 20kg for continuous repetitions used in our study, it seems reasonable that we would note the difference indicated. Ultimately, the maximal style lifting task did result in less coordinated movement overall with higher lag values.

### **Percent Change (Early vs Late)**

The maximal effort test required more supraspinatus activity, bicep femoris activity, bicep brachii activity, and less lumbar activity as the test progressed. More lumbar activity was shown as the paced test progressed. Since lower frequency values indicate muscular fatigue (Kazemi et al. 2022 ; Boocock, Mawston, and Taylor, 2015), it appears that the lumbar musculature fatigued during the maximal effort test and did not during the paced test. Newer studies like the one done by Kazemi et al. (2022), also confirm that repetitive lifting tasks demonstrate trunk fatigue.

The maximal effort test required more lumbar flexion as the test went on. The paced showed less hip, more knee, and less lumbar flexion as the test progressed. Both sexes showed more supraspinatus activity as testing progressed. Fischer et al. (2015) found that lifting technique of men and women altered equivalently as fatigue accumulated during exposure to a prolonged lifting task that is defined in relative terms, however we have found differences between sexes in joint angles throughout the lifting tasks. Women had more lumbar EMG activity as lifting progressed and more lumbar flexion at lift initiation. It has been shown that women may have more endurance specifically in the erector spinae muscles (Mannion et al. 1997). Research has shown that women have a larger percentage of type one muscle fibers which may attribute to

increased endurance and less fatigue compared to men (Wüst et al., 2008; Côté, 2012). It appears, any enhanced endurance for women did not combat increased lumbar flexion angles throughout the absolute loaded test. Timing indications would be a good additive for future work to give clear insight of performance throughout the lifting tasks.

Men had less lumbar EMG activity, and more lumbar flexion as lifting progressed. We know that injury risk is increased while EMG activity of erector spinae is non-existent (Burgess-Limerick 2003). However, higher threshold motor units may not initially be active, so an increase in median frequency as fatigue accumulates and the size principle transpires is possible (Potvin and Fuglevand 2017). Due to the intensity of the lifting tests, higher threshold motor units may not have been initially active which could be why we noted significant reductions in frequency for men.

## **Limitations**

1. All participants were active Canadian Forces members. However, some were encouraged to participate by their chain of command. This could have affected levels of motivation to perform the maximal effort test for some participants at maximum intensity.
2. All participants were experienced with the bona-fide occupational standard of the Canadian military and would have previously participated in a SBL test. This was required to ensure familiarization with the test. However, our lifting station had some unique properties that would have been different from the regular FORCE evaluation such as: triggers that needed to be pressed with the sandbag, and support legs on both sides of the station that did not inhibit movement of the participant but that could have been distracting. The participant did not have a practice test on the lifting station.
3. The triggers installed on the lifting station were designed to send a 5-voltage signal through the EMG software at lift placement. The triggers worked effectively; however, some signal was leaked to other channels. False peaks on other channels were rided of during data processing with custom python coding but more ideal circumstances would have been no leakage from other channels.
4. Maximal effort and paced tests were completed on the same day. Participants were given 20 minutes for rest in between tests to ensure adequate recovery and tests were randomized. However, fatigue from the prior test could have been a factor in determining some outcomes of neuromuscular and kinematic data.

5. There was drift present while using the XSENS motion capture system for longer tests. Consideration of using a different motion capture system may have resulted in less drift.
6. Physical Activity levels of participants were not recorded during this research project. Considering this information could have provided the researcher and the reader with more insight into training status and fitness level and its effect on lifting.
7. Electromyography was measured by placing electrodes on the left side of the body. Depending on the handedness of the participant, this could have affected the neuromuscular activity recorded during tests.
8. Missing data was generally under 10% of data collected. This was present more on gastrocnemius EMG recordings for neuromuscular activity more than others due to reliability of electrodes to stay in firm contact with the musculature considering the quick lateral movements. A linear mixed effects model ANOVA was used on all data.
9. Peaks of MVC data was used by measuring absolute values and not an average of a particular window of time. EMG filters were applied to rid of false peaks, but an average of a 0.5 second window may have given more accurate results.

## Significance of Results

The XSENS IMU system is appropriate for capturing military-based movements (Mavor et al. 2020). Flexion and extension angles were measured throughout this study. One study showed that when attempting to validate the XSENS IMU system against a camera-based motion capture system, the XSENS most accurately measures flexion/extension joint angles with a coefficient of multiple correlation (CMC) of:  $CMC < 0.96$  for all joints (Zhang et al. 2013). Another study which aimed to measure the accuracy of the single pose calibration of the XSENS IMU system, found an average intraclass coefficient for all axes and joints between 0.90 and 0.94 with a standard error of measurement between 1.5 degrees and 2.1 degrees (Robert-Lachaine et al. 2017). Al-Amri et al. (2018) examined the validity and reliability of the XSENS IMU system by having a clinician with no prior experience with IMU systems measure movements and compare it to the measurements of an experienced clinical movement scientist. Validity was excellent in the hip, knee, and ankle for sagittal plane movement however, jumping resulted in the lowest reliability rating of “low to high” (Blair et al. 2018). A study that analyzed the validity of the XSENS IMU system when compared to the Vicon motion analysis system in a sport specific setting showed trivial to small differences at the sagittal joints of knee and hip. Trivial to small measurement errors were defined at 0.1 to 5.8%. Considering the small yet reasonable confirmation of technical error within the motion capture system used in this study, some of our significant findings may not be valid. There were some differences found in the kinematic data that, with appreciation of the above notes on validity of the XSENS IMU system, could have been due to measurement error of the equipment.

Some results had trivial to small effect size. Effect size was generally medium to high throughout the significant findings. High effect size was shown in particular for max effort vs paced effort significant comparisons. However, trivial to small effect size was calculated for various joint angle comparisons. Significant findings were still indicated and discussed; however the reader should be aware of the small strength of the relationship between the variables. A sample size calculation indicated that ideal sample size is 33. Ideally, we would have had more total participants. The researcher's goal was 50 total (25 men/25 women) for ideal statistical power, however due to time, resources, facilities, and volunteer availability – a lesser number of participants (31) were studied.

## **Future Directions**

Future studies should consider exploring kinetic changes during an acute paced and maximal effort lifting task. Evaluating compressive and shear load on L4/L5 and L5/S1 would provide further insight into injury risk by using inverse dynamics. These findings would pair well with the evaluation of neuromuscular and kinematic differences of pacing and sex. Additionally, we recommend a complete biomechanical assessment of the CAF FORCE evaluation which encourages maximal effort on each of the four components. Further research is needed to support the novel findings of this study as they relate to sex differences in short duration lifting tasks and the differences between performing the task paced and with maximum effort with absolute load. Strength capacity could also be tested in future research as strength capacity, not sex, has been shown to influence peak low-back extensor moment during lifting in new research (Clusiault et al. 2022).

Since higher strength capacity individuals experience lower normalized peak low-back extensor moment when lifting (Clusiault et al., 2022), it may be important to consider strength differences while evaluating for differences in sex while lifting. Furthermore, a study done by (Kranz et al., 2021) showed that grip strength is a significant indication of perceived workload in a lift. In this study they recommend that grip strength be considered for a more appropriate screening tool more so than sex in heavy manual tasks, so considering grip strength in future sex comparison lifting studies may be useful.

## 6.0 Conclusion

### Significance & Implications

Our study provides insight to a wider scope of research. We can apply our knowledge gained from this study to other incentive level occupational testing, including the other tests of the CAF Force evaluation. This research provides a framework when further assessing sex differences during short duration maximal effort lifting and paced lifting with absolute load of 20kg.

This study had four hypotheses that are supported by our research:

**The maximal effort lifting task will result in less coordinated movement between lower and upper body.**

- The maximal effort lifting task overall resulted in lesser values of cross correlation, and increased lag times. Elbow kinematics also lagged in later lifts for women participants during the maximal test when compared to earlier lifts.
- Max effort lifting required greater knee angles, elbow angles, and L5/S1 angles compared to the paced lifting task at lift initiation.
- At lift placement, maximal lifting required greater shoulder angles.

**Higher muscle activation will be required during the maximal effort lifting task.**

- Maximal Effort Lifting required more mean EMG activity than paced lifting for all muscles measured.
- Five of the Eight muscles showed significantly higher max EMG activity in the maximal effort lifting tasks compared to the paced lifting task.

**Lifting technique will require more lower extremity and trunk motion for women participants to complete the lifting task.**

- During max effort lifts women showed greater hip angles and L5/S1 angles than men.

**The muscle activity will be different between men and women performing the lifting tasks.**

- Women had higher mean EMG activity at the supraspinatus, multifidous (L3), and vastus lateralis. Women also showed greater max EMG activity at the supraspinatus, erector spinae (T9), and multifidus (L3).

Four out of four of our hypotheses were fully supported by our findings. There were lots of insightful additional findings as well. The maximal effort lifting task overall resulted in slightly lesser values of cross correlation, and increased lag times. The maximal effort lifting task showed higher muscle activation in measurements of mean and max EMG overall when compared to the paced lifting task. Muscle activity differed between men and women performing the lifting. During the maximal effort lifting task, women showed more lower extremity and trunk motion. However, men used more knee motion during the paced effort task which gives some interesting insight into differences in sex while considering intensity of lifting. Due to the small effect sizes found throughout the study, a more comprehensive biomechanical analysis should be completed for further insight on sex differences of paced and maximal effort lifting. It is important to consider bodyweight in future studies as incremental lifting machine scores have been correlated to bodyweight for women when compared to men (Stevenson et al. 1996). The novel findings above provide information on neuromuscular and kinematic tendencies of men and women as it relates to varying intensities of lifting with absolute loads. When maximal effort lifting is encouraged, we recommend an accessible training

regimen that would elicit appropriate adaption of lifting performance prior to participation, specific to sex.

## 7.0 Appendices

### *Appendix 7. 1: Participant Consent Form*



### CONSENT

*The purpose of this study has been explained to me by \_\_\_\_\_.*

*I have understood the information, including the risks of participation, and agree to participate in the study. I have been given a copy of the Study Information sheet and the Consent form, which I have read and understood. I have been given an opportunity to ask questions about the study and my participation, and I understand that I may withdraw at any time. **This project has been reviewed by the Research Ethics Board of the University of New Brunswick.***

*By signing this form, I agree to participate in the study with the understanding that my participation is voluntary and that I may withdraw from it at any time, without giving a reason or cost.*

Click or tap to enter a date.

\_\_\_\_\_  
Name of Participant (Print)

\_\_\_\_\_  
Participant- Tick the box  
(I agree to participate)

\_\_\_\_\_  
Date (Select a date)

.....  
:

If you wish to be informed of the research results, please provide contact information.

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**BIOMECHANICAL ASSESSMENT OF PACED AND MAXIMAL  
EFFORT ACUTE SYMMETRICAL LIFTING IN CANADIAN  
SOLDIERS – A SEX COMPARISON**

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**PURPOSE OF THE STUDY**

The aim of this study is determine changes in lifting technique, muscle exertion and stress to the back while performing the standardized Canadian Armed Forces sand bag test when it is performed in a paced manner and as fast at possible. The study will also determine whether the lifting technique changes differ between men and women.

**BACKGROUND**

The Canadain FORCE evaluation is used as a measure of overall fitness and combat readiness. The sand bag test requires the lifting of a 20-kg sand bag from the floor to a 1-m height a total of 30 times in under 3.5 minutes to achieve a passing grade. A reduction in time to complete the test is associated with a higher scoring, which encourages the test to be completed as fast as possible. It is not well understood how

this increase in lifting pace changes the body postures used to lift, the muscle effort required and the stress on the back. Therefore, asking the question, “does increasing the pace of lifting lead to a risk of injury?”. The difference in lifting technique between men and women when lifting pace is increased is not well understood and could provide valuable information regarding sex differences.

It is the intent of this research to better understand these changes and inform the Canadian Armed Forces on whether there is an increased risk of injury associated with a maximal effort sand bag test.

## **WHAT WE ARE ASKING OF YOU.**

If you agree to be part of this study you will be asked to:

- come to the facility at Base Gagetown
- perform the lifting task (sandbag test) twice; once where the lifting pace will be set and once where the lifting will be done as quickly as possible;
- have motion analysis sensors placed on your arms, back and legs to track the motion of your body. These sensors are smaller than an iWatch and are attached with Velcro straps;
- have surface electromyography (EMG) electrodes placed over arm, shoulder, leg and back muscles to monitor the activity of the muscles while lifting. The electrodes are the size of quarter and are heled on the skin with an adhesive similar to a bandaid.

## **POTENTIAL RISKS**

In this study, risks associated with partaking in physical activity are outlined in the Get Active questionnaire forms. You may feel muscle soreness for two days after the test, similar to that felt after a hard workout in the gym. If you are ill or injured, you will not be permitted to participate in this research study.

## **POTENTIAL BENEFITS TO PARTICIPANTS AND/OR SOCIETY**

The research will provide a better understanding of the muscle activity required to do this test and how the different lifting pace effects how the sand bag is lifting and the stress to the muscles and lower back. It will also inform the Canadian Armed Forces on the difference in lifting technique and muscle stress between men and women, which may guide exercise interventions or practical guidance in preparing for the SBL test. This study will also serve as the first biomechanical assessment of the Canadian FORCE evaluation.

## **CONFIDENTIALITY**

No personal information collected during this project will be shared. All results will be of group data only. You will provided a participant code and this will be used

throughout the assessment of your information. Only the researchers will have access to your information. All data will be stored in a locked environment within the Occupational Performance Laboratory in the Faculty of Kinesiology at the University of New Brunswick and will remain there for a period of five years; at that point, it will be destroyed. The results of the study will not include your individual data unless you have given prior consent.

## **PARTICIPATION AND WITHDRAWAL**

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without explanation of why you are withdrawing and without consequences.

**This project has been reviewed by the Research Ethics Board of the University of New Brunswick.**

## Appendix 7. 3: Get Active Questionnaire



# Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –  
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see [csep.ca/certifications](http://csep.ca/certifications)) or health care provider is advisable. This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.

- I am completing this questionnaire for myself.
- I am completing this questionnaire for my child/dependent as parent/guardian.

<input checked="" type="checkbox"/> YES	<input checked="" type="checkbox"/> NO	<h3>PREPARE TO BECOME MORE ACTIVE</h3> <p>The following questions will help to ensure that you have a safe physical activity experience. Please answer <b>YES</b> or <b>NO</b> to each question <u>before</u> you become more physically active. If you are unsure about any question, answer <b>YES</b>.</p>
<input type="radio"/>	<input type="radio"/>	<b>1</b> Have you experienced <b>ANY</b> of the following (A to F) <b>within the past six months</b> ? <ul style="list-style-type: none"> <li><b>A</b> A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?</li> <li><b>B</b> A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?</li> <li><b>C</b> Dizziness or lightheadedness during physical activity?</li> <li><b>D</b> Shortness of breath at rest?</li> <li><b>E</b> Loss of consciousness/fainting for any reason?</li> <li><b>F</b> Concussion?</li> </ul>
<input type="radio"/>	<input type="radio"/>	<b>2</b> Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
<input type="radio"/>	<input type="radio"/>	<b>3</b> Has a health care provider told you that you should avoid or modify certain types of physical activity?
<input type="radio"/>	<input type="radio"/>	<b>4</b> Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?
... > <b>NO</b> to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY ... >		
<b>YES</b> to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE ... >>		

## ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

- 1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)?  DAYS/WEEK
- 2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity?  MINUTES/DAY
- For adults, please multiply your average number of days/week by the average number of minutes/day:  MINUTES/WEEK

Canadian 24-Hour Movement Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see [csep.ca/guidelines](http://csep.ca/guidelines)).



## GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.



## DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct. If my health changes, I will complete this questionnaire again.

I answered **NO** to all questions on Page 1

I answered **YES** to any question on Page 1

Sign and date the Declaration below

Check the box below that applies to you:

- I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.
- I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

<input type="text"/>	<input type="text"/>	<input type="text"/>
Name (+ Name of Parent/Guardian if applicable) [Please print]	Signature (or Signature of Parent/Guardian if applicable)	Date of Birth
<input type="text"/>	<input type="text"/>	<input type="text"/>
Date	Email (optional)	Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

- Check this box if you would like to consult a QEP about becoming more physically active. (This completed questionnaire will help the QEP get to know you and understand your needs.)

Use this reference document if you answered **YES** to any question and you have not consulted a health care provider or Qualified Exercise Professional (QEP) about becoming more physically active.

1 Have you experienced ANY of the following (A to F) within the past six months?	
<p><b>A</b> A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>Physical activity is likely to be beneficial. If you have been treated for heart disease but have not completed a cardiac rehabilitation program within the past 6 months, consult a doctor – a supervised cardiac rehabilitation program is strongly recommended. If you are resuming physical activity after more than 6 months of inactivity, begin slowly with light- to moderate-intensity physical activity. If you have pain/discomfort/pressure in your chest and it is new for you, talk to a doctor. Describe the symptom and what activities bring it on.</p>
<p><b>B</b> A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>Physical activity is likely to be beneficial if you have been diagnosed and treated for high blood pressure (BP). If you are unsure of your resting BP, consult a health care provider or a Qualified Exercise Professional (QEP) to have it measured. If you are taking BP medication and your BP is under good control, regular physical activity is recommended as it may help to lower your BP. Your doctor should be aware of your physical activity level so your medication needs can be monitored. If your BP is 160/90 or higher, you should receive medical clearance and consult a QEP about safe and appropriate physical activity.</p>
<p><b>C</b> Dizziness or lightheadedness during physical activity</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>There are several possible reasons for feeling this way and many are not worrisome. Before becoming more active, consult a health care provider to identify reasons and minimize risk. Until then, refrain from increasing the intensity of your physical activity.</p>
<p><b>D</b> Shortness of breath at rest</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>If you have asthma and this is relieved with medication, light to moderate physical activity is safe. If your shortness of breath is not relieved with medication, consult a doctor.</p>
<p><b>E</b> Loss of consciousness/fainting for any reason</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>Before becoming more active, consult a doctor to identify reasons and minimize risk. Once you are medically cleared, consult a Qualified Exercise Professional (QEP) about types of physical activity suitable for your condition.</p>
<p><b>F</b> Concussion</p> <p><input type="checkbox"/> <b>YES</b></p>	<p>A concussion is an injury to the brain that requires time to recover. Increasing physical activity while still experiencing symptoms may worsen your symptoms, lengthen your recovery, and increase your risk for another concussion. A health care provider will let you know when you can start becoming more physically active, and a Qualified Exercise Professional (QEP) can help get you started.</p>
<p>After reading the <b>ADVICE</b> for your <b>YES</b> response, go to Page 2 of the <i>Get Active Questionnaire – ASSESS YOUR CURRENT PHYSICAL ACTIVITY</i></p>	

Use this reference document if you answered **YES** to any question and you have not consulted a health care provider or Qualified Exercise Professional (QEP) about becoming more physically active.

<p><b>2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?</b></p>	<input type="checkbox"/> <b>YES</b>
<p>If this swelling or pain is new, consult a health care provider. Otherwise, keep joints healthy and reduce pain by moving your joints slowly and gently through the entire pain-free range of motion. If you have hip, knee or ankle pain, choose low-impact activities such as swimming or cycling. As the pain subsides, gradually resume your normal physical activities starting at a level lower than before the flare-up. Consult a Qualified Exercise Professional (QEP) in follow-up to help you become more active and prevent or minimize future pain.</p>	
<p><b>3 Has a health care provider told you that you should avoid or modify certain types of physical activity?</b></p>	<input type="checkbox"/> <b>YES</b>
<p>Listen to the advice of your health care provider. A Qualified Exercise Professional (QEP) will ask you about any considerations and provide specific advice for physical activity that is safe and that takes your lifestyle and health care provider's advice into account.</p>	
<p><b>4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?</b></p>	<input type="checkbox"/> <b>YES</b>
<p>Some people may worry if they have a medical or physical condition that physical activity might be unsafe. In fact, regular physical activity can help to manage and improve many conditions. Physical activity can also reduce the risk of complications. A Qualified Exercise Professional (QEP) can help with specific advice for physical activity that is safe and that takes your medical history and lifestyle into account.</p>	
<p><b>After reading the ADVICE for your YES response, go to Page 2 of the Get Active Questionnaire – ASSESS YOUR CURRENT PHYSICAL ACTIVITY</b></p>	

**WANT ADDITIONAL INFORMATION ON BECOMING MORE PHYSICALLY ACTIVE?**

► [csep.ca/certifications](http://csep.ca/certifications)

CSEP Certified members can help you with your physical activity goals.

► [csep.ca/guidelines](http://csep.ca/guidelines)

Canadian 24-Hour Movement Guidelines for all ages.

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