Measurement of Isometric Hip Strength in Male Ice Hockey Players: Investigation of the Within-Day, Between-Day, and Intertester Reliability of the Activ5© Handheld Dynamometer

by

Abigail Proteau

Thesis Supervisor: Dr. Derek Kivi

Committee Members: Dr. Paolo Sanzo and Dr. Nicholas Ravanelli

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HHD	Handheld dynamometer	7
ICC	Intraclass correlation coefficient	7
ROM	Range of motion	12
EMG	Electromyography	17
N	Newtons	18
NHL	National Hockey League	20
BD	Biodex© Dynamometer	35
LOA	Limits of agreement	36
DAS©	Dynamometer anchoring station©	36
PAR-Q	Physical activity readiness questionnaire	43
SD	Standard deviation	48
SEM	Standard error of measurement	48

Abstract

Background. Isometric strength testing involves assessing the maximum amount of force a muscle group can produce when there is no change in its length and is typically measured using a handheld dynamometer (HHD). Reliability is a measure of the consistency or repeatability of a measure and is important when conducting isometric strength testing using HHDs. The Activ5© is a small and inexpensive HHD which uploads the data immediately via Bluetooth to a smartphone app. The reliability of the Activ5© as a clinical or research tool has not been investigated. ***Purpose****:* To investigate the within-day and the between-day reliability of the Activ5©, and to investigate the intertester reliability of the Activ5© in measuring isometric hip strength in competitive male ice hockey players. ***Methods****:* Part One investigated the reliability of the Activ5© in measuring mass both within-day and between-day. Testing took place on two consecutive days with the same procedures being followed during each session. Standardized weights ranging from 0.5 kg to 22.8 kg were placed on top of the Activ5© at 45-step increments and in random order, with three measurements taken at each increment. Within-day reliability was established using the Intraclass Correlation Coefficient (ICC) by comparing the force data at each increment between trials one and two from session one. Between-day reliability was established using the ICC by comparing the mean force among the three trials at each increment between sessions one and two. Part Two investigated the intertester reliability of the Activ5©. Twenty competitive male ice hockey players (age = 24.4 $\pm$ 2.9 years, mass = 89.3 $\pm$ 7.8 (kg), and height = 181.6 $\pm$ 6.1 cm) performed three maximal isometric contractions in hip extension, hip internal rotation, and hip abduction on their dominant leg. Two experienced female testers performed the isometric testing with the isometric force being measured by the Activ5© against the tester's resistance. Intertester reliability was assessed using the ICC by comparing the mean

isometric force of the three trials for each hip joint motion across participants between testers one and two. ***Results.*** An excellent ICC (1.00) was found for both between-day and within-day reliability. High intertester reliability was found for hip internal rotation (ICC=.664) and abduction (ICC=.622), and very high reliability for hip extension (ICC=.786). ***Conclusion****:* The results from this study suggested that the Activ5© had excellent within-day and between-day reliability, and high intertester reliability. Future research assessing the reliability of the Activ5© using different muscle groups would be of value to investigate if these results can be replicated across other joints.

Measurement of Isometric Hip Strength in Male Ice Hockey Players: Investigation of the Within-Day, Between-Day, and Intertester Reliability of the Activ5© Handheld Dynamometer

Ice hockey is a popular, fast-paced sport played world-wide with the main objective of scoring more goals than the other opponent. The average athlete plays 15-20 minutes of the 60-minute game and during this time requires rapid changes in velocity and experiences frequent body contact (Montgomery, 1988). The sport of ice hockey is extremely physically demanding. Burr et al. (2008) suggested that a well-rounded ice hockey player requires both physical and physiological capabilities; these include anaerobic fitness, aerobic fitness, muscular strength, and power. Terry and Goodman (2019) stated that skating alone is extremely technical and requires coordination, speed, power, agility, and physical conditioning, in addition to technical skill. These athletes must possess both skill and high-level physical conditioning, often achieved through mental preparation, training, and proper nutrition (Potteiger et al., 2010). Orvanova (1987) suggested that ice hockey players are reliant on lean body mass and muscular strength and the skills of ice hockey require total body fitness and strength to be successful and avoid injury (Orvanova, 1987).

Skating Stride

The action of skating is a unique series of repetitive movements requiring the synergy of various joint actions and muscle groups to perform the movement (Upjohn et al., 2008). The ice hockey skating stride requires unique hip involvement with increased motion and activity of the hip abductor, external rotator, flexor, and extensor muscles (Buckeridge et al., 2015). These muscles work to produce the on-ice acceleration and sprinting ability (Bracko, 2004). Force is required for optimal push-off especially in the first 3-4 strides in a player's acceleration as the

athlete propels forward by pushing off the ice with force applied perpendicular to the skate blade (Robbins et al., 2018). During forward skating, the inside blade edge creates friction on the ice and provides a surface for push-off (Robbins et al., 2018). A male ice hockey player can move his feet at approximately 7 m/s and the greatest forward push force will be when beginning to skate from rest (Ice Hockey Biomechanics: How to Skate Faster and Avoid Injury, 2019). The maximum speed an ice hockey player can reach is directly influenced by how quickly he can move his feet on the ice (Ice Hockey Biomechanics: How to Skate Faster and Avoid Injury, 2019). Furthermore, Marino and Weese (2008) determined when skating velocity increases, the mean stride rate also increases. Therefore, fast skating speed is related to the number of times that force is applied to the ice over a specific period.

Forward skating occurs with movements occurring in both the sagittal and frontal planes (Upjohn et al., 2008). During the forward skating stride, one skate is used to push off the ice while the other skate is raised or glides on the ice (Hockey Canada, 2017). This sequence of movements is then repeated with the alternate leg being the push-off foot. The skating stride is illustrated in Figure 1 and can be divided into the following phases: the initial contact, single support gliding, single support propulsive, terminal stride, and recovery phases (Upjohn et al., 2008). Due to the importance of the hip during skating, a discussion of the relevant hip anatomy is required.

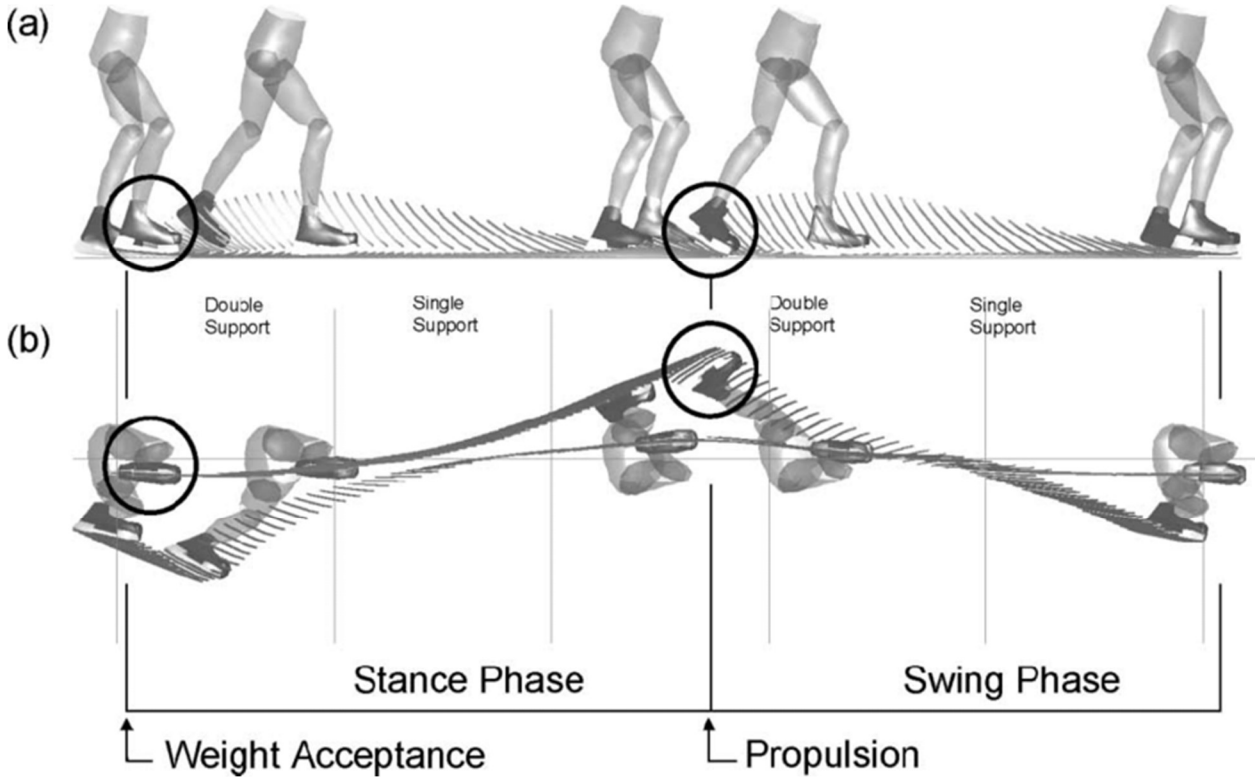

Figure 1. *Forward Skating.* The phases of the skating stride (Upjohn et al., 2008).

Anatomy of the Hip

The hip is a complex joint with multiple unique structures which are required for it to function effectively and without pain (see Figure 2). In high-performance athletes, it is vital to have healthy hips that function properly to avoid injury and be successful in the given sport.

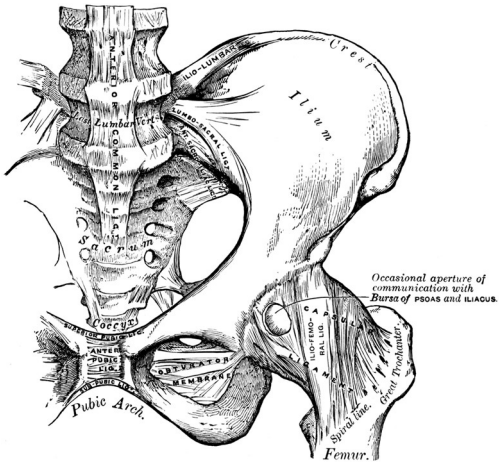

Figure 2. *The Hip Joint*. The bones and ligaments are associated with the ball-and-socket hip joint. (“Pelvis”, n.d.).

The Hip Joint

The hip joint is a ball-and-socket joint consisting of the head of the femur and the acetabulum of the hip which is a part of the innominate bones (Miller, 2006). It contains a strong and dense articular capsule that extends from the acetabulum to the head of the femur. There are three accessory ligaments associated with the hip joint including the iliofemoral, pubofemoral, and ischiofemoral ligaments (see Figure 3). All three of these ligaments make up thickened portions of the articular capsule that limit the range of motion (ROM) to prevent injury (Miller, 2006). The pubofemoral ligament extends from the pubis to the neck of the femur and prevents excessive abduction of the hip joint and stabilizes the articular capsule. The ischiofemoral

ligament extends from the ischium to the neck of the femur and is designed to resist hip abduction (Tortora & Derrickson, 2006). The iliofemoral ligament, which extends from the ilium to the femur anterior to the joint, is the strongest ligament of the body and prevents hyperextension (Tortora & Derrickson, 2006). The hip joint also contains fibrous cartilage referred to as the acetabular labrum which deepens the hip socket (Tortora & Derrickson, 2006).

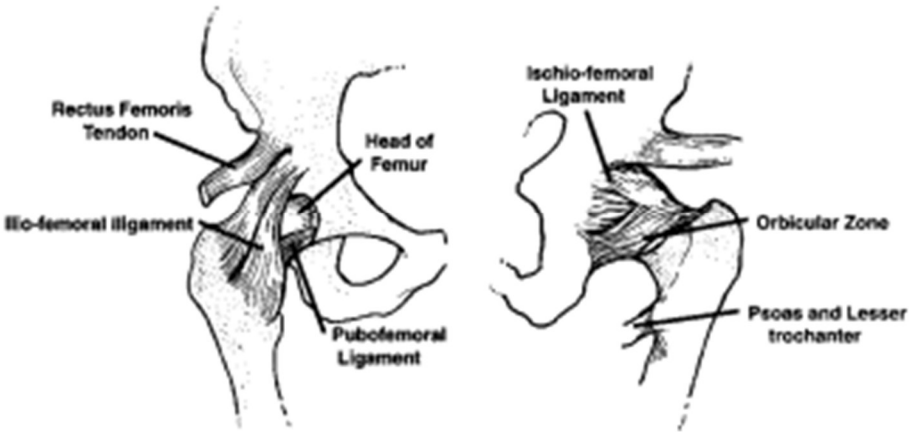

Figure 3. *The Major Ligaments of the Hip.* Anterior and posterior view of the major ligaments of the hip (Anderson et al., 2001)

The Muscles of the Hip

The hip performs a variety of movements and is composed of numerous skeletal muscles that support the joint. Many muscles that move the femur originate in the pelvic girdle (see Figure 4) and insert into the femur (Tortora & Derrickson, 2006). The hip flexors are vital for skating with the most powerful hip flexor being the iliopsoas muscle (Tortora & Derrickson, 2006). The pectineus muscle is another hip flexor that originates on the pubis and inserts onto the pectineal line of the femur (Anderson et al., 2001). The rectus femoris muscle flexes the hip joint and originates on the anterior inferior iliac spine and acetabular rim and inserts on the tibial tuberosity via the patellar ligament (Anderson et al., 2001). The sartorius muscle originates on

the anterior aspect of the iliac spine and inserts onto the pes anserinus and flexes the hip (Anderson et al., 2001).

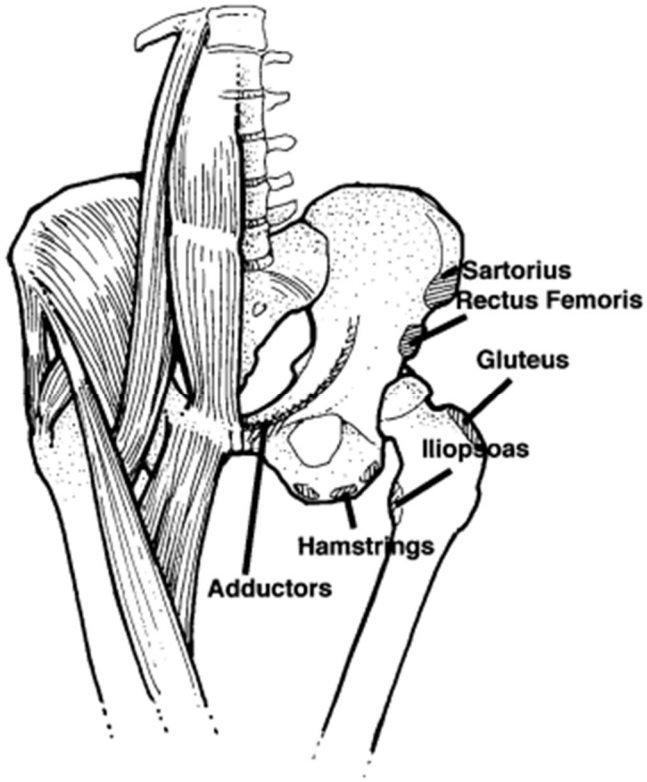

Figure 4. *Anterior View of the Musculature of the Hip.* This figure provides a visual representation of the hip flexors and their origin and insertion points (Anderson et al., 2001).

The gluteal muscles (see Figure 5) are responsible for both movement and stability at the hip and include the gluteus maximus, gluteus medius, and gluteus minimus (Tortora & Derrickson, 2006). The gluteus maximus is a strong extensor of the lumbar spine and hip joint (Tortora & Derrickson, 2006). The muscle originates in the tract of the iliotibial band and inserts onto the iliac crest, sacrum, coccyx, and aponeurosis of the sacrospinalis (Tortora & Derrickson, 2006). This muscle extends the hip, which is essential for forceful push-off in the single-leg

propulsive phase of skating. The gluteus medius is a strong abductor of the hip and lies deep in the gluteus maximus muscle (Tortora & Derrickson, 2006). It originates in the ilium and its insertion is on the greater trochanter of the femur (Tortora & Derrickson, 2006). The gluteus medius and minimus muscles both abduct the hip, which is vital in forward skating due to the lateral pushing movement to elicit the forward motion (Pearsall & Turcotte, 2000). The gluteus minimus originates on the gluteal surface of the ilium and inserts on the anterior aspect of the greater trochanter (Tortora & Derrickson, 2006).

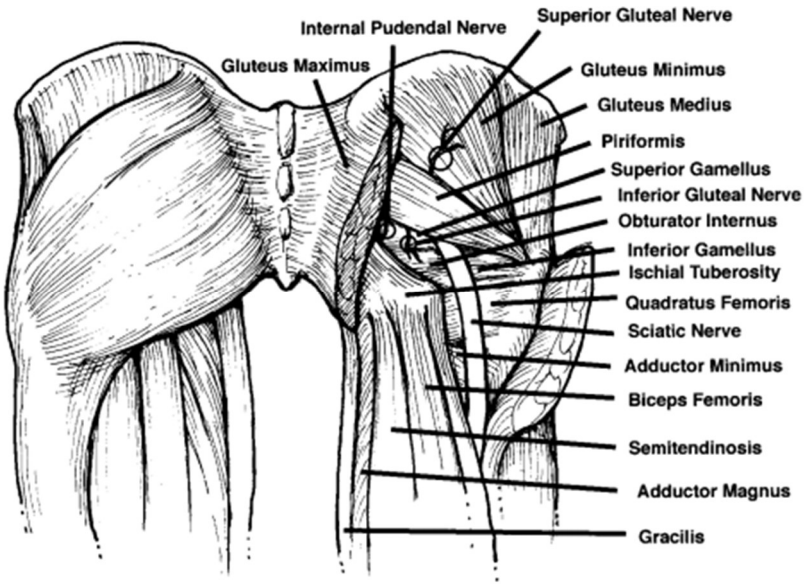

Figure 5. *The Posterior Musculature of the Hip.* Muscles in the hip (Anderson et al., 2001).

There are several small muscles deep to the gluteus maximus that externally rotate the hip and play an important role in single-support propulsion during skating. These muscles include the piriformis, obturator internus and externus, superior and inferior gemellus, and quadratus femoris muscles (Tortora & Derrickson, 2006). During the initial contact phase of skating, internal rotation of the hip produces a force to propel the body forward.

The tensor fascia lata is another abductor of the hip joint and originates on the iliac crest and inserts onto the tibia via the iliotibial band (Tortora & Derrickson, 2006). This muscle, along

with the gluteus medius and minimus muscles, function as abductors of the hip joint (Anderson et al., 2001).

The adductor brevis and longus muscles both originate on the pubic ramus and insert onto the linea aspera of the femur and adducts the hip joint (Anderson et al., 2001). The adductor magnus originates on the pubic ramus and ischial tuberosity and inserts onto the linea aspera and adductor tubercle of the femur and adducts the hip joint (Anderson et al., 2001). Terry and Goodman (2017) stated that the force generated to move the skater across the ice is due to a series of muscle contractions. The ability for the athlete to recover during the skating stride is primarily achieved by the adductor muscles; therefore, stronger adductors enable the athlete to return to the recovery leg to prepare to repeat the skating stride (Terry & Goodman, 2017). By doing so quickly and with force, the athlete can push and propel into the next skating stride (Terry & Goodman, 2017).

Hip Strength

There has been minimal research on the importance of hip strength within the ice hockey population even though the motion of the skating stride requires forceful contractions of the hip musculature (Kea et al., 2001). All ice hockey players need to be strong to resist actions from their opponents (Terry & Goodman, 2019). Hip strength is also important for noncontact aspects of the sport such as skating (Terry & Goodman, 2019).

As the skating stride is largely based on the hip, it is vital to assess the importance of hip strength to be able to assess various measures associated with performance in hockey players such as speed and agility. Ice hockey players rely heavily on the adductor muscles while they balance above their blades' edges during forward skating (Terry & Goodman, 2017). The

stronger the muscles associated with skating, the more force the skater can generate and the faster they will skate (Terry & Goodman, 2017).

Chang et al. (2010) investigated hip adductor muscle function in forward skating in collegiate ice hockey players. Muscle activation patterns were quantified using surface electromyography (EMG) and lower extremity kinematics were analyzed (Chang et al., 2010). A flexible strain gauge electrogoniometer was attached to the lateral aspect of the hip and knee and the posterior aspect of the ankle (Chang et al., 2010). The measurements collected at the hip were for hip flexion, extension, abduction, and adduction while participants skated at a maximum speed on the skating treadmill. The adductor magnus muscle exhibited the greatest overall changes in activation magnitude and time (Chang et al., 2010). When considering the area of the base of support in an ice hockey skate blade, there is a reduced surface when compared to the foot (Chang et al., 2010). Therefore, having lateral instability can cause balance challenges that require the involvement of the piriformis, superior and inferior gemellus, obturator internus and externus, and quadratus femoris muscles to maintain balance (Chang et al., 2010).

Isometric Strength

According to Newton and Dugan (2002), maximum strength is the greatest amount of force a muscle group can produce, and isometric strength testing is one method by which it can be measured. With an isometric contraction, the length of the muscle does not change, meaning the muscles exert force with no change in joint angle (Bellar et al., 2015). Isometric assessment of muscle function has been used for over 65 years in the field of exercise science assessing both maximal force and the rate of force development (Wilson & Murphy, 1996). These tests have

demonstrated high reliability when investigating single and multi-joint isometric assessment protocols (Wilson & Murphy, 1996).

Isometric strength testing is typically measured using a handheld dynamometer (HHD) (see Figure 6) which is a relatively small, portable device with a display to provide the force measurement in Newtons (N) or pounds/kilograms. These devices vary in cost; for example, the Lafayette© HHD costs CAD $1295.00 (Lafayette Instrument®, n.d) and the Activ5© HHD costs CAD $149.90 (Activbody, n.d).

Isometric strength tests pose a minimal injury risk, have high test-retest reliability, and can detect subtle changes in strength (Lum et al., 2020). In a systematic review, isometric strength testing demonstrated a strong potential to predict dynamic capabilities in activities involving strength and explosive power (Lum et al., 2020). For example, a study of collegiate football players examined the relationship between isometric strength testing and dynamic performance (Nelson et al., 2008). The one-repetition maximum for the squat, bench press, and power clean exercises were used to determine dynamic strength. The researchers used the isometric mid-thigh pull exercise to test the participant's isometric strength. This study suggested that isometric testing provided a good indication of an athlete's dynamic performance (Nelson et al., 2008).

Haff et al. (2005) determined that there was great utility in specific isometric testing and that isometric force was strongly related to dynamic strength. Six elite women weightlifters were tested to evaluate the force-time curve intercorrelation of isometric and dynamic muscle strength. The participants conducted isometric and dynamic mid-thigh clean pulls and weight was calculated at 30% of maximal isometric peak force and 100 kg from a standardized position.

Isometric peak force was strongly correlated to the participants' competitive snatch clean and jerk, and combined total (Haff et al., 2005).

Wang et al. (2002) investigated the reliability of HHD when measuring isometric hip flexor, extensor, and abductor muscle strength in older adults. The location of the dynamometer for testing hip flexion was at the front thigh, proximal to the knee. When testing hip extension, the participant was standing and leaning forward with support at chest height, the hip was in slight flexion, and the knee was straight. The HHD was placed on the posterior aspect of the thigh proximal to the knee joint. Lastly, when testing the hip abductors, the participant was positioned in supine with the hip in a neutral rotation and slightly abducted. The HHD was placed on the lateral aspect of the thigh, proximal to the knee joint. The test-retest reliability coefficient ranged from .95-.99, suggesting that the device demonstrated excellent reliability for isometric testing (Wang et al., 2002).

Lastly, Keep et al. (2016) investigated the validity of using a HHD for measuring isometric hip extension strength with comparisons to an isokinetic dynamometer in healthy adults (9 males and 11 females). Hip extension was assessed in a prone position, and the participant leaned forward on the testing table to support the trunk. The test leg was placed at 45º of hip flexion with the knee fully extended. The tester exerted a static force equal to the participant when holding the HHD. When the tester applied a force equal to that of the participant's, it was termed an isometric 'make' test. Participants were instructed to maintain the position through the entire isometric contraction which was a total of 5 s (Keep et al., 2016). The researchers concluded that the HHD demonstrated high intrasession reliability.

Measuring Hip Strength in Hockey Players

Because the muscles of the hip are essential movers in skating, it is vital to assess the strength of the hip musculature to predict performance measures such as speed and agility in forward skating (Upjohn et al., 2008). Tyler et al. (2001) investigated the relationship between hip strength and flexibility in National Hockey League (NHL) ice hockey players and the frequency of adductor and hip flexor muscle strains. The authors concluded that ice hockey players with hip adductor muscle strength, which was less than 80% of the contralateral hip adductor strength, were 17 times more likely to develop an adductor muscle strain (Tyler et al., 2001). Furthermore, the athletes who sustained hip injuries presented with a decrease in pre-injury adductor strength in comparison to the athletes that did not sustain injuries (Tyler et al., 2001). The researchers used manual muscle testing with a Lafayette© HHD to test strength. This device can assess peak force, time to reach peak force, total test time, the time within selectable ranges, and average force (Tyler et al., 2001). This study measured hip flexion, abduction, and adduction strength with this instrument. The researchers assessed hip flexion strength by having the participant in a seated position, and then asking the participant to raise their knee 8 inches from the surface and to maintain that position. A manual force was applied to the segment with the manual muscle testing device in hand to break the muscle contraction. Tyler et al. (2001) used a previously studied method of measuring isometric strength where the researchers "broke" the muscle contraction resistance that was applied at the end of the ROM (Conable & Rosner, 2011). The goal was to investigate how much force (measured in N) was required to break the muscle hold. This test was repeated for both legs and the average of two maximal effort tests for each action was taken. Abductor muscle strength was tested with the participants positioned in side-lying and each player was asked to abduct the leg above the horizontal position, and the

breaking force was applied distally, 1 inch above the lateral malleolus. When testing adduction strength, the participants were asked to straighten the lower leg and then lift the straight leg 12 inches off the table and a breaking force was applied 1 inch above the medial malleolus (Tyler et al., 2001). Based on the biomechanics of skating and the rate of injury due to muscular imbalances at the hip, it can be suggested that hip strength is crucial to an ice hockey player's success. The key findings of the study are in line with the components of ice hockey as the sport requires directional changes at fast speeds. Hip strength can be measured using a variety of medical devices and equipment that will be explored further.

Activ5©

The Activ5© (see Figure 6) is a HHD which can measure isometric strength (N or kg) and uploads the data immediately to a smartphone app (Activbody, n.d). The maximal force load that can be measured with the Activ5© is 1112.06 N, with an accuracy within ± 6.22 N of applied force (Activbody, n.d). The test time can range between a 0-60 s contraction and can be used to assess isometric strength for all major muscle groups including the hip (Activbody, n.d).

Figure 6. *Activ5©.*

The device is marketed to be used by professionals such as athletic trainers, physiotherapists, and researchers to measure isometric muscle force and to assess muscular symmetries and imbalances (Activbody, n.d). HHDs are commonly used in scientific research and clinical practice to measure strength as they provide a more objective measure than manual muscle testing and are more portable and affordable than an isokinetic dynamometer (Keep et al., 2016). There is minimal published information on the use of the Activ5© as a research tool, however, a recent study by Merry et al. (2021) suggested that the device was valid and reliable but did not assess the device in typical use cases.

Merry et al. (2021) investigated the Activ5©'s validity and reliability by comparing the device to a gold-standard test instrument. Data collection was conducted over a single testing session using an Instron ElectroPuls E10000© universal testing machine with an Instron Dynacell© 2527-202 load cell (10 kN capacity). The Instron ElectroPuls E10000© was considered as the gold-standard measure for this protocol (Merry et al., 2021). To accommodate the Activ5©'s roughly tear dropped shape, the researchers created a plastic shell to avoid point loading or potentially cracking the device. The researchers applied forces to the Activ5© ranging from 10 N to 883 N, however, they did not assess up to the maximal design load of 1079 N (110 kg) to not risk damaging the device. Merry et al. (2021) determined that the Activ5© had excellent reliability (ICC (3,1) = .999-1.000) and found that the standard deviation from the applied force increased at higher loads. This was similar to the stated error of the device as noted by the manufacturer and suggested that at higher loads the device was less consistent.

Validity and Reliability

Validity and reliability are essential to research, especially regarding a measurement tool as they will help ensure that the data collected is reproducible and credible from a research

perspective. Ensuring the measurement tools are valid and reliable is also vital for both clinical and real-world settings to ensure that the device measures what it is intended and can be repeated. To assess strength, a researcher, clinician, or physiotherapist, for example, must be certain that the testing device measures the intended variable of interest (Thomas et al., 2005). This is important as the validity of a device reassures that it is credible in measuring what is intended to measure. When a device is poorly designed and also has low validity and reliability it will lead to inaccurate and/or inconsistent data which then limits the ability to make conclusions based on the research (Korb, 2012). Validity is a term used to reflect the degree to which researchers can have confidence in their conclusions and are based on the research conducted (Kowalski et al., 2018).

There are four basic types of validity including logical, content, construct, and criterion (Thomas et al., 2005). Logical validity is sometimes referred to as face validity and is the degree to which a test appears to measure what it claims to (Thomas et al., 2005). Further, face validity assures that the process of defining variables into measurable factors seems like a good translation of the construct (Trochim & Kane, 2005). Constructs are internal attributes or characteristics that cannot be directly observed but are useful for describing and explaining behaviour (Gravetter & Wallnau, 2017). Construct validity is the degree to which a test measures a hypothetical construct; usually established by relating the test results to some behaviour (Thomas et al., 2005). The Activ5© measures the construct of a participant's isometric strength.

Content validity is largely associated with an educational setting, meaning a test with content validity adequality samples what was covered in the course (Thomas et al., 2005). This approach requires a detailed description of the entire content domain of a construct which can be challenging for complex constructs (Bhattacherjee, 2012). A second form of content validity

occurs with attitude instruments (Thomas et al., 2005). When using this technique, researchers assign each statement to one of the instrument categories. These categorizations are then tallied across all experts and the percent who agreed with the original categorization are reported. Agreements ranging between 80-85% indicate that the statements represent the content category (Thomas et al., 2005).

Criterion validity is the degree to which scores on a test are related to some recognized standard or criterion (Thomas et al., 2005). There are two main types of criterion validity including concurrent and predictive validity. Predictive validity is the degree to which scores of predictor variables can accurately predict criterion scores. Concurrent validity examines the degree a measurement tool correlates with a "gold standard" test with proven validity and reliability. When comparing a tool to a "gold standard" the tests are completed at approximately the same time (Thomas et al., 2005).

An integral part of validity is reliability, which involves consistency or repeatability of a measure (Thomas et al., 2005). A test cannot be considered valid if it is not reliable, yet scores from a test can be reliable but not valid. Therefore, a HHD can measure isometric hip strength very consistently, but it could be consistently measuring strength incorrectly. For example, the data for hip flexion collected on a HHD could have an output of 400 N across three trials but the participant could be producing an output of 390 N. In this case the device is not valid but is it reliable. An example of how a test cannot be valid if it is not reliable, is if a HHD measured trials for isometric hip strength and demonstrated an output of were 400 N, 360 N, and 410 N, then this device is not valid or reliable. As this example demonstrated, if there are inconsistent results, the researchers cannot make definitive conclusions on the isometric hip strength data as there is no confidence in the tool when a lack of reliability is present.

This concept is illustrated in Figure 7 which demonstrates an example of a device that is valid but not reliable producing data centered around the area of the target but not in the narrow or consistent range (Bhattacherjee, 2012). Whereas, if the measure is reliable but not valid, then the data would present within a narrow or consistent range but off from the centre of the target. When a device is both valid and reliable the data points will be both centred on the target and in consistent range, hence demonstrating the need for both to assure adequate measurement of the construct of interest (Bhattacherjee, 2012).

Figure 7. *Validity and Reliability Visual.* This image highlights the importance of ensuring a device is reliable and valid (Bhattacherjee, 2012).

Measurement error is a key component in the reliability of a tool. As discussed by Thomas et al. (2005), measurement error causes the observed value to differ from the true score, and can come from four sources including the participant, the test, the scoring method, and the instrumentation used. Measurement error attributed to the participant includes factors such as mood, motivation, fatigue, health, fluctuation in memory, previous practice, specific knowledge, and familiarity with the test items. Motivation could impact the results of isometric hip strength; for example, if the participant lacks motivation to provide maximal contractions, then the data will not represent an accurate sample of the individual's maximal isometric hip strength. This

may cause the results to be inconsistent and impact the overall findings of the study and conclusions made. Fatigue can impact the results of the study similarly as the participant's maximal effort will be impacted by fatigue and potentially present as decreased isometric force across trials. Errors in testing are due to a lack of clarity in the directions, how rigidly the instructions are followed, or whether supplementary directions or motivation is given to the participant. Therefore, this type of error may occur when assessing isometric hip strength if the researcher does not clearly state that the participant should take 1-2 s to 'ramp up' to a maximal contraction and then hold the maximal contraction for 5 s. This would be especially prevalent if these instructions were clear for one participant and not another. Scoring errors derive from competence and experience. If the examiner lacks experience in using HHDs and does not hold the device securely, scoring errors would likely result. Additionally, the extent that the examiner is familiar with the behaviour being tested can affect scoring accuracy. Therefore, if the examiner is unfamiliar with the testing, they may produce more errors than someone familiar with the testing. Instrument error can occur due to a lack of calibration of the electronic equipment (Thomas et al., 2005). Ensuring a device is calibrated correctly allows for confidence in the accuracy and precision of the device. Each device is calibrated to a standard to ensure accurate measurements.

Measurement error causes the observed score to differ from the true score (Thomas et al., 2005). The theory of measurement assumes that some amount of error will be present regardless of the type of measurement (Šerbetar, 2015). Random error is the difference between the observed score and true values (Thomas et al., 2005). This error can occur by the researchers when measuring isometric strength by not using the same location to place the HHD during each trial (Bhandari, 2022). This type of error is unpredictable in nature, but the potential of the errors

can be reduced by conducting multiple trials and following a standardized order. Whereas systematic error is a consistent difference between the observed and true values. For instance, when measuring isometric hip strength with an HHD that is calibrated incorrectly may consistently measure the force as higher than the participant is producing (Bhandari, 2022). There are two different types of systematic error which are offset error and scale factor error. The offset error occurs when a score is not calibrated to a correct zero point. When a measure is consistently different from the true score, it is referred to as the scale factor or correlational systematic error (Bhandari, 2022).

The Classical Test Theory deals with the obtained and the true score (Šerbetar, 2015). This theory states that each measurement is the sum of the true score of the participant and random error (Thomas et al., 2005). True score is the part of the observed score that represents the individual's real score and does not contain measurement error. This can be represented by Equation 1:

$$X=T+e \quad (1)$$

where:

X=observed score

T=true score

e=random error (Thomas et al., 2005)

Therefore, a measure that has zero random error and is all true score has perfect reliability. When a measure has a lot or all random error, and minimal to zero true score, there is no reliability in this measure. Therefore, the smaller amount of random error, the better the measure. The goal of the tester is to minimize error to yield the true score (Thomas et al., 2005). The classical true score theory can also be revised to account for systematic error as well.

This can be represented by Equation 2:

$$X=T+e_r+ e_s \quad (2)$$

Where:

X=observed score

T=true score

e_r=random error

e_s=systematic error (Thomas et al., 2005)

The degree of reliability is expressed by a correlation coefficient ranging from .00 to 1.00 (Thomas et al., 2005). Less error variance is present when the coefficient is closer to 1.00 and reflects the truer score assessed. To determine the reliability coefficient an intraclass correlation (ICC) is the most appropriate statistical analysis. The ICC estimates the systematic and error variance, meaning that systematic differences between trials can be examined. The ICC is a measure of how similar the outcomes of individuals within a cluster are likely to be, relative to those of other clusters. In statistics, ICC is an inferential statistic that can be used when quantitative units are organized into groups. It describes how strongly units in the group resemble each other. Unlike other correlations, it operates with data structures as groups rather than paired observations (Thomas et al., 2005).

Intertester reliability is the degree to which different testers can obtain the same scores when following the same procedures on the same construct (Thomas et al., 2005). This method is used to assess the consistency between two or more independent raters of the same construct (Bhattacherjee, 2012). This is important when assessing isometric strength using a HHD to ensure that any tester using the device and who follows the same protocol will be able to assess isometric strength reliably. Understanding the differences in the scores between testers is

accomplished by assessing the absolute difference. The absolute difference is the difference in the mean score between tester one and tester two, and is taken without regard to a sign between the values of the two variables (Marriott et al., 1990). For example, when measuring isometric force using an HHD, if tester one found hip extension to be 20 kg and tester two found 23 kg the absolute difference between the testers is 3 kg. When assessing intertester reliability, absolute differences between the testers' mean values are important if each participant is assessed by different testers (Asmundson, 2022). The absolute difference allows the researchers to identify the difference between the means of the two testers, along with other statistical analyses such as ICC which provide further insights into intertester reliability.

ICC assesses the agreement; therefore, it is typically used to determine reliability (Koo & Li, 2016). An advantage of the ICC is that it can be used to assess agreement between more than two sets of data; ICC estimates closer to 1 represent greater reliability (Koo & Li, 2016). The absolute difference is the distance between two numeric value means but does not provide information of the relative magnitude (Marriott et al., 1990). However, ICC is calculated by mean squares obtained through analysis of variance (Koo & Li, 2016). Absolute agreement concerns if different raters assign the same score to the same subject (Koo & Li, 2016). The absolute agreement definition should always be chosen for test-retest reliability studies because measurements would be meaningless if there is no agreement between repeated measurements (Koo & Li, 2016). The absolute difference highlights the distance of between the mean scores, meaning the value of how different the data were between the testers. The absolute difference alone does not provide enough insights into the data to provide a confident conclusion, but when paired with ICC researchers can have confidence in the interpretation of results. ICC is fundamental to clinical assessment because, without it, researchers cannot have confidence in

measurements, nor can they draw any rational conclusions from these measurements (Koo & Li, 2016). Therefore, using both ICC and absolute differences when assessing intertester reliability allows for well-rounded insights into the testers' results to highlight both the mean differences and reliability.

Test-retest reliability is a measure of consistency between two measurements of the same construct taken at two different testing sessions (Bhattacherjee, 2012). When the researcher uses a test-retest design, the test is administered during one session and then is repeated after time, often can be with 3-7 days in between sessions (Thomas et al., 2005). The intervals between testing sessions may vary based on the extent of how strenuous the testing is on the participant, although the testing cannot be too far apart from the first session as effects such as changes in ability, maturation, and the learning effect can impact the results (Thomas et al., 2005). If the results do not change substantially between the two tests, then the measure is considered reliable (Bhattacherjee, 2012). Assessing same-day test-retest reliability is used for establishing reliability in which a test is given at least twice to the same participant on the same day (Thomas et al., 2005). Same-day test-retest method is typically used with physical performance tests to eliminate the practice effect (Thomas et al., 2005). The test-retest on the same day typically results in a higher reliability coefficient than when retesting on separate days (Thomas et al., 2005).

Validity and Reliability in Handheld Dynamometry

There is great value of HHD in research and clinical settings as isometric assessments are a safe form of measuring strength (Lum et al., 2020). Various studies have investigated the validity and reliability of this type of device when assessing isometric hip strength. Previous

research has also examined the intertester, intratester, same-day, and test-rest reliability of HHDs at the hip along with machine testing of HHDs.

Shechtman et al. (2005) conducted a study to examine the reliability and validity of the digital DynEx© dynamometer. The researchers used 20 lbs weight increments ranging from 20 lbs to 100 lbs (Shechteman et al., 2005). The weights were added by suspending the mass from the center of the dynamometer's handle for three trials and in random order. The researchers also assessed accuracy, measurement error, test–retest reliability, interrater reliability, and concurrent validity of the device (Shechteman et al., 2005). Shechteman et al. (2005) determined there to be an average measurement error of the DynEx© dynamometer of 1.63%. Additionally, the researchers found that the interrater reliability of the DynEx© dynamometer was perfect (r=1.0) and attributed this to the digital readout (Shechteman et al., 2005). The researchers also determined there to be a high test-retest reliability (r=.99) (Shechteman et al., 2005). From these results, Shechteman et al. (2005) concluded that the device presented with a high test-retest reliability.

Denton et al. (2014) conducted a study investigating the test-retest reliability of a testing procedure for assessing isometric hip strength using the Lafayette Instrument© HHD. Strength was assessed using the 'make' test where isometric muscle action matched that of the examiner (Denton et al., 2014). The examiner's arms were positioned with the elbows locked in extension to ensure the HHD was maintained in a perpendicular position relative to the test limb (Denton et al., 2014). They were asked to give one submaximal contraction of 50% effort, followed by three tests of maximal effort with a 5 s rest between trials. Hip flexion was measured in sitting with the hip and knee flexed to 90° (Denton et al., 2014). The HHD was positioned on the surface of the skin immediately proximal to the superior pole of the patella. Hip extension was measured in

prone with the hips in neutral and legs supported by a foam wedge. The dynamometer was placed on the surface of the skin of the posterior thigh 2 cm proximal to the femoral epicondyles. Hip abduction and adduction were measured with the participant positioned in side lying. The dynamometer was placed immediately superior to the lateral femoral epicondyle for abduction and medial femoral epicondyle for adduction. Internal rotation and external rotation were assessed with the participant positioned in side lying with the dynamometer placed 2 cm proximal to the lateral malleolus (internal rotation) and medial malleolus (external rotation; Denton et al., 2014). A paired t-test showed no difference between repeated measures for each of the muscle groups and the ICC values ranged from .86-.97 which demonstrated excellent reliability (Denton et al., 2014). More specifically, the ICC values for the six isometric hip strength measures were: flexion=.86, extension=.97, abduction=.97, adduction=.94, internal rotation=.94, and external rotation=.94. This study established a reliable strength testing protocol for the assessment of isometric strength of all six muscle groups associated with hip movement (Denton et al., 2014).

In the study by Kollock et al. (2010), intertester, intratester, same-day, and test-retest reliability of portable fixed dynamometry during hip and knee strength assessment was evaluated. The Evaluator^{TM} HHD was used for this study and the methods consisted of two phases with a test-retest design. Phase one involved three test sessions separated by one day, and phase two involved two session separated by 7 days. Same-day and test-retest reliability of the Evaluator^{TM} was assessed in phase one. In phase one, two examiners tested 11 healthy college graduate students, and in phase two, two new examiners tested 26 healthy college students. Each participant was asked to identify the dominant limb, which was used for all tests (Kollock et al., 2010). Testing procedures consisted of seated and standing positions for all isometric strength

measures. Each isometric contraction was 5 s in duration followed by a 10 s rest period between trials. All seated measures were assessed using the Evaluator™ dynamometer along with a load cell (see Figure 8) designed to measure both compression and tensile forces. The participants were asked to push or pull in the opposite direction of the attached load cell. Internal and external rotation of the hip was assessed in seated, along with knee flexion and extension (Kollock et al., 2010).

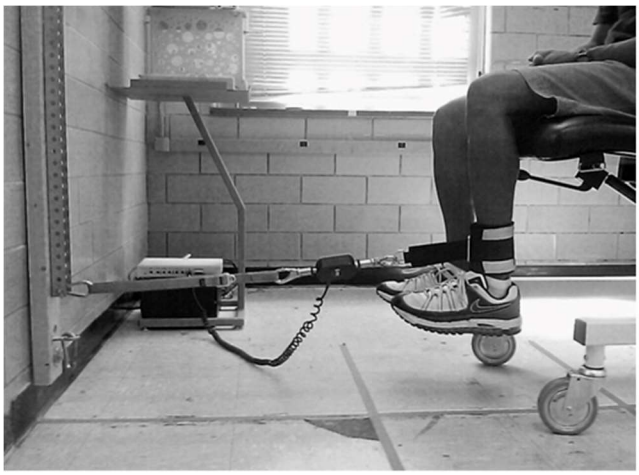

Figure 8. *Seated Testing Procedure.* This figure demonstrates the seated position of testing the Evaluator™ (Kollock et al., 2010).

The standing measures were assessed on a portable platform system using the Evaluator Software System™ (see Figure 9). The platform system had an integrated load cell which was interfaced through a data acquisition box. Hip adduction, abduction, flexion, and extension were assessed in standing with the feet positioned shoulder-width apart (Kollock et al., 2010).

Figure 9. *Standing Testing Procedure.* The Evaluator™ HHD used in standing testing (Kollock et al., 2010).

During phase two, the intrarater and interrater reliability was evaluated. Therefore, there were different testers for each phase and the results from each tester were recorded for analysis. The ICC ranges for same-day reliability across three days of testing for each isometric measure were .88-.99 (day 1), .85-.99 (day 2), and .92-.96 (day 3). The ICC for test-retest for between-day ranged from .70-.94 for isometric hip testing. The interrater ICC between examiners ranged from .69-.91 (Kollock et al., 2010). The researchers concluded that the peak outcomes recorded were reliable across multiple trials. Additionally, hip flexion and extension demonstrated the lowest ICC for intrarater reliability (Kollock et al., 2010). The researchers did not suggest why this was the case. The remainder of the isometric measures for the hip and knee within this study ranged from ICC .86-.94, with external rotation demonstrating the highest ICC of .94 (Kollock et al., 2010). The researchers concluded that the Evaluator™ dynamometer allowed for adequate assessment of isometric hip strength. This suggested that the device's reliability, portability, and rapid testing protocol makes the device ideal for lower extremity isometric strength assessments (Kollock et al., 2010).

Mentiplay et al., (2015) assessed the lower limb muscle strength and rate of force development using the Lafayette© Instrument and Hoggan Scientific© HHD and fixed dynamometer to test the concurrent validity of the two HHDs and reliability of fixed dynamometry. This study used a concurrent validity and test-retest reliability design whereby participants attended two identical testing sessions (Mentiplay et al., 2015). The Lafayette© Instrument Manual Muscle Tester and the Hoggan Scientific microFET2© HHDs were compared to the fixed laboratory based KinCom© dynamometer. Concurrent validity was assessed by comparing the results from the two HHDs to the gold standard laboratory based KinCom© using ICC. The researchers assessed concurrent validity for peak force and rate of force development and the results stated were good to excellent (ICC>.75). The inter-device reliability indicated that peak force results were interchangeable between the two different HHDs (Mentiplay et al., 2015). Comparison of the Hoggan Scientific© and Lafayette© Instrument HHDs used in this study revealed no apparent differences between the devices in their reliability or validity for either measure of peak force or rate of force development (Mentiplay et al., 2015).

Ogborn et al. (2021) investigated the concurrent validity and test-retest reliability of isometric knee flexion strength measured by a fixed HHD compared to a Biodex© Dynamometer (BD). This study investigated 44 healthy participants and the testing was completed over 2 sessions with 3-7 days between sessions (Ogborn et al., 2021). The order of the HHD and BD were randomized in the first session and the order was maintained on the second testing day. The HHD was externally fixed to the wall by a glass suction cup via two S-biers. The HHD was outfitted with a hook-shaped clip insert for the inelastic Velcro® strap that looped around the participant's lower limb (Ogborn et al., 2021). The HHD data was collected by three investigators to assess interrater reliability. Three attempts were provided on each device and

position with a 5 s hold for isometric actions, a 10 s break between maximal contractions, a 30 s break between different feet positions, and a 5 min break between devices (Ogborn et al., 2021). Peak force (N) and torque (Nm) were recorded for each device. Bland-Altman limits of agreements (LOA) analysis were calculated from the difference between test and retest values plotted against the average of the trials. Interrater reliability of the fixed HHD was high as all but one exceeded 0.9. Additionally, Bland-Altman LOA analysis in isometric knee torque between the HHD and BD found low bias with wide LOA. The validity of fixed-HHD had a moderate to high degree of correlation with the BD (Ogborn et al., 2021).

Trajković et al. (2022) investigated the interrater and intrarater reliability of the EasyForce© dynamometer when assessing shoulder, knee, and hip muscle strength in young adults. The researchers included 23 participants to investigate the hypothesis. Three repetitions were completed for all joint motions and the testing was completed by three raters on the same day. The three testers undertook a period of training with the EasyForce© HHD and the measurement with the dynamometer were performed according to the manufacturer's recommendations. The next trial was started only after resetting the device but no exact time was noted for this (Trajković et al., 2022). The results of this study demonstrated good to high interrater and intrarater reliability (ICC=.63-.91). The researchers noted that the differences between trials for the testers may have been due to the possible alteration in the techniques also noting that three trials were sufficient to account for trial-to-trial variability (Trajković et al., 2022).

Scott et al. (2004) compared the interrater and intrarater reliability of a portable dynamometer anchoring station© (DAS©) to an HHD. The researchers included 15 participants who were tested over two sessions (Scott et al., 2004). Three consecutive measures of bilateral

isometric strength were obtained for hip abduction, extension, and flexion by two testers (Scott et al., 2004). On test day one, Tester A performed the first session with the DAS© and the third session with the HHD, and Tester B performed the second session with the DAS© (Scott et al., 2004). On day two, Tester A performed the second session with the DAS© and the third session with the HHD, and tester B performed the first session with the DAS© (Scott et al., 2004). To test reliability, ICCs were calculated by using both the average and the maximal value for each movement (Scott et al., 2004). Interrater ICCs for hip flexion ranged from .84-.92, hip abduction ICC values ranged from .69-.88, and hip extension ICC values ranged from .56-.80 (Scott et al., 2004). Therefore, the DAS© showed good intrarater reliability for hip flexion and abduction whereas the HHD demonstrated higher reliability for hip extension.

Bohannon and Andrews (1987) investigated interrater reliability of isometric strength testing using an HHD and used absolute differences between the testers to explain their results. In this study, two researchers performed HHD testing on six muscle groups using the digital Chatillon© force gauge (Bohannon & Andrews, 1987). The researchers assessed the right side of some participants and the left side of others, each tester conducted one trial per muscle group assessed (Bohannon & Andrews, 1987). Each tester performed the tests independently and was blind to the results of the other. The researchers found a range of good to high correlations between testers; for example, when assessing hip flexion the results of the Pearson Product Moment Correlation was .84 which is considered good (Bohannon & Andrews, 1987). The largest absolute difference between the testers was 1.2 kg, and the researchers noted this to be encouraging for this type of research due to the small value, which also is reflected in the reliability value being high in the results (Bohannon & Andrews, 1987). The small value reflects

minimal differences between the testers' means, suggesting that the data obtained by each tester was relatively similar when assessing the participants.

There are various studies which have also investigated isometric hip strength, and more specifically, the validity and reliability of the HHDs and the procedures used for the assessment of isometric strength. Within this body of research, the testing position for each hip motion used is relatively similar. Hip extension is frequently tested in prone lying (Denton et al., 2014; Mentiplay et al., 2015; Tyler et al., 2001) and hip abduction is typically tested in side lying (Denton et al., 2014; Mentiplay et al., 2015; Tyler et al., 2001). Because these hip joint motions and muscular actions are important during the skating stride (Buckeridge et al., 2015) they are important to include when using an HHD to measure isometric hip strength in hockey players.

Research Problem

Skating is a unique form of locomotion involving distinct movement characteristics and phases, with forward skating occurring in both the sagittal and frontal planes (Upjohn et al., 2008). Accordingly, forward skating requires unique hip movement and activity of all the hip musculature (Buckeridge et al., 2015). Isometric assessment of muscle function has been used extensively to assess both maximal force and the rate of force development (Wilson & Murphy, 1996). Isometric strength testing requires the athlete to exert force while the joint does not move and the muscle length remains the same and can be measured with a dynamometer (Lum et al., 2020). Isometric strength tests pose a minimal injury risk, have high test-retest reliability, and can detect subtle changes in strength (Lum et al., 2020). Intertester reliability is the degree to which different testers can obtain the same scores when following the same procedures on the same construct and this method is used to assess consistency (Bhattacherjee, 2012). This is

important when assessing isometric strength using an HHD to ensure that any tester using the device will be able to assess isometric strength in a reliable manner.

The Activ5© is an HHD which has been used in one recent study involving isometric strength testing and has been found to be valid and reliable (Merry et al., 2021). There are, however, various limitations to this study. Merry et al. (2021) aimed to assess validity and reliability of the device itself with the researchers not taking into account user-related error. The researchers used a gold-standard device for comparison rather than assessing the device using human testers. In addition, a wide range of forces (10-833 N) were used, which are considerably larger than the forces that the hip musculature can produce. Previous research has reported that males between the ages of 20-59 years produced 170.7 N of force for hip abduction and 217.7 N of force for hip internal rotation (McKay et al., 2017). Finally, this study only collected data for one day and the test-retest reliability of this device still needs to be assessed. As isometric testing is a safe form of isometric strength measurement, there is great potential value in the Activ5©. When compared to other HHDs, the Activ5© allows the tester to immediately have the results available on their mobile device. The Activ5© also permits data storage on the mobile device and can create graphs over time as an individual's strength changes, allowing continued monitoring of the patient or athlete to evaluate progress over time in a rehabilitation or training program. This portable HHD may potentially be the way of the future for efficient isometric strength data collection. Therefore, ensuring that the Activ5© is reliable is essential for the use of this novel HHD as a clinical and research tool.

Purpose

1) To investigate the test-retest reliability of the Activ5© when measuring force on different days.

2) To investigate the test-retest reliability of the Activ5© when measuring force within-day.
3) To investigate the intertester reliability of the Activ5© in measuring isometric hip strength in competitive male ice hockey players.

Hypothesis

1) The Activ5© will demonstrate a high degree of test-retest reliability when measuring force on different days.
2) The Activ5© will demonstrate a high degree of test-retest reliability when measuring force within-day.
3) The Activ5© will demonstrate a high degree of intertester reliability when measuring isometric hip strength in competitive male hockey players.

Methodology

Study Design

This study was divided into two parts. Part One included both within-day and between-day test-retest methods when measuring force using the Activ5©, with the same testing procedures being repeated over two test sessions. Part Two involved assessing the intertester reliability using the Activ5© and involved two testers assessing isometric hip strength for the same three joint movements and following the same data collection procedures.

Part One

To assess the reliability of the Activ5© in measuring force both within-day and on different days, standardized weights were placed on top of the Activ5© model A5PR1 (Activbody Inc., San Diego, CA, USA) at 45 step increments ranging from 0.5 kg to 22.8 kg. Previous research has reported a normative peak isometric force for hip internal rotation in males aged 20-59 years of age of 217.7 N, or 22.2 kg (McKay et al., 2017). Because this was the

highest force value reported in this study, it was essential to ensure that the Activ5© can reliably assess isometric force up to this magnitude.

To apply the weights to the Activ5©, a metal bar (length = 37 cm, mass = 0.5 kg) was used. The bar had a c-shaped curve at the top end and threaded at the bottom end with a washer and nut attached. The standardized weights, each with a hole in the middle, were slid down the bar and rested on the washer at the bottom (see Figure 10). This supported the weights and allowed them to be placed on the Activ5© in a consistent manner. The force (kg) at each weight increment was measured by the Activ5© and recorded as it appeared on the Activbody app.

Figure 10. *Metal bar which will be used for Part One of testing, including weight plates.*

Each measurement was completed by carefully placing the weighted bar in a vertical position on the Activ5© for 3 s, after which the weight was removed. Applying the weight for 3 s was consistent with the reported amount of time that isometric contractions are held during testing with HHDs (Katoh & Yamasaki, 2009). The weighted bar was supported during each trial using a carabiner which was positioned around the bar so that it applied no vertical force. In addition, a small dot was placed in the centre of the Activ5© with a marker. The weighted bar

was placed on this dot during each measurement to ensure consistency in the placement. The weights were added to the Activ5© in random order (Shechtman et al., 2005), with the measurements at each weight increment being repeated three times per testing session (Shechtman et al., 2005). The weight of each individual plate used was determined using an Adam Equipment GFK 330aH© digital scale. To account for any minor difference in mass among the weight plates, the same individual weight plates were used at each increment to ensure the same amount of weight was applied during each of the three trials. A total of two sessions on different days were completed following the same procedures on both days.

Part Two

Participants

The participants included 20 competitive male ice hockey players (age = 24.4 $\pm$ 2.9 years, mass = 89.3 $\pm$ 7.8 kg, and height = 181.6 $\pm$ 6.1 cm). This number of participants was selected based on previous reliability research involving HHDs (David et al., 2004; Kellen et al., 2008; Trajkovi´et al., 2022). The years of ice hockey experience ranged from 15-25 years. There were 16 participants who were right leg dominant and 4 participants that were left leg dominant.

Recruitment Criteria

Convenience and purposive sampling were used to recruit participants who met the criteria for inclusion in the study and were known by the student researcher. The student researcher contacted the potential participants from contacts developed from previous employment as the student athletic trainer with the Lakehead Thunderwolves. The potential participants were recruited with a letter sent via email by the student researcher inviting them to participate. The potential participants were made aware of the testing procedures and potential risks and benefits if they chose to participate.

The inclusion criteria of this study were healthy males who played competitive hockey and included both current and recently retired players (+/- 4 years). The participants were excluded from this study if they sustained a hip injury or any injury to the lower extremity within the last 6 months that would have prevented them from skating or participating in other forms of physical activity. Some injuries that would prevent an ice hockey player from skating include strains, sprains, contusions, or fractures. Participants were also be excluded from participation in this study if they indicated "yes" on any item on the Physical Activity Readiness Questionnaire (Par-Q). None of the participants indicated "yes" on the Par-Q form.

Testing Procedures

Prior to data collection, ethical approval from the Lakehead University Research Ethics Board was obtained. Data collection was completed in the Exercise Physiology Laboratory (SB-1025) at Lakehead University in the Sanders Building. The testing took approximately 30-40 minutes for each participant and was completed in one session. The participant was asked to wear athletic clothing appropriate for exercise, as well as athletic footwear.

Once the participant arrived for the testing session, the information letter was reviewed, and the consent form was signed. Following consent, participants filled out the PAR-Q to confirm their ability to participate in physical activity. Years of playing ice hockey experience, age (years), body mass (kg), height (cm), and the dominant leg were identified and recorded on a participant information form. A stadiometer was used to measure the participant's height, and body mass was measured using a scale. The dominant leg was identified previously as the leg to lead with when starting a movement, specifically kicking a soccer ball (Peters, 1998). As the participants in this study played competitive hockey, they were asked to identify which was their dominant limb based on the limb they would use to initiate the skating stride from a stationary

position. The tested leg was the one identified verbally by each participant as the one they would initiate the skating stride.

Prior to testing, the participant completed a 5 min warm-up on a cycle ergometer at a self-selected pace and resistance, followed by lower body stretching which was supervised by the student researcher (Ogborn et al., 2021). Static stretching included a 15 s hold of the hurdler stretch per side, and the butterfly stretch held for 15 s for 3 repetitions. The participants were also instructed to find a spot on the wall, and complete 10 kickbacks per leg, 10 abduction leg lifts per leg, and 10 hip-openers per leg (see Appendix A).

Testing was completed with the participant positioned on a therapy table. Maximal isometric strength for hip internal rotation, extension, and abduction was assessed in this study as these muscles are important during the skating stride to produce the on-ice acceleration and skating speed (Bracko, 2004; Buckeridge et al., 2015). Hip internal rotation was assessed with the participant positioned in supine lying with 90º of knee flexion and 90º of hip flexion (see Figure 11). The Activ5© was positioned 2 cm proximal to the lateral malleolus (Denton et al., 2014) and the participant was asked to maximally internally rotate into the Activ5© against the examiner's resistance (Activbody, n.d).

Figure 11. *Hip Internal Rotation Testing Procedure.* The testing procedure for the Activ5© for hip internal rotation (Activbody, n.d).

To test hip extension, the participant was positioned in prone lying with the knee flexed to 90º. The Activ5© was placed on the posterior thigh 2 cm proximal to the femoral epicondyles (see Figure 12; Denton et al., 2014). The participant's arms were positioned overhead or abducted to the sides of the table for participant comfort and stability. The participants were asked to push maximally into the Activ5© against the examiner's resistance while keeping the pelvis on the table.

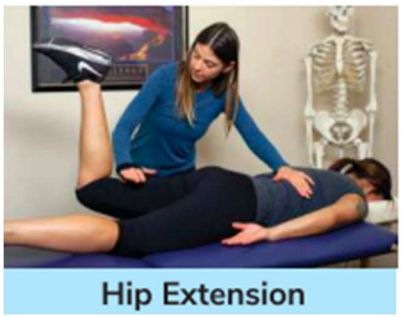

Figure 12. *Hip Extension Testing Procedure.* The testing procedure for the Activ5© in hip extension (Activbody, n.d).

When testing hip abduction, the participant was positioned in side lying with the testing hip placed in 10º of abduction (Jeon, 2019). This angle was measured using a goniometer to ensure consistency across trials. The non-testing hip was placed in neutral at 0° resting on the testing table, and the knee was held in slight flexion for the participant's comfort (Jeon, 2019). The knee joint on the tested side was fully extended (Jeon, 2019) and the Activ5© was located 2 cm proximal to the lateral femoral epicondyle (see Figure 13; Denton et al., 2014). The participants were asked to maximally abduct into the Activ5© against the resistance of the examiner.

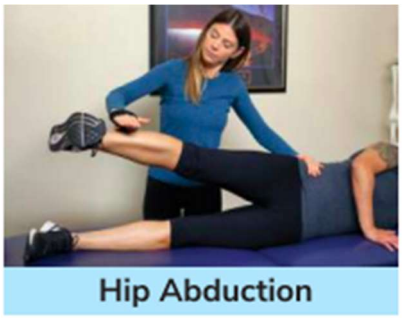

Figure 13. *Hip Abduction Testing Procedure.* The testing procedure for the Activ5© in hip abduction (Activbody, n.d).

Two testers assessed each joint motion. Both had a background in Kinesiology and undertook a training period to familiarize themselves in the use of the Activ5© to ensure efficacy and competency (Trajkovi´et al., 2022).

Table 1.

Descriptive Information for Testers

	Age (yrs)	Height (cm)	Body Mass (kg)
Tester 1	25	163	77.1
Tester 2	24	157	54.4

The order in which the two testers completed their testing on each participant was randomized (Trajkovi´et al., 2022). The order in which each hip joint motion was tested was also randomized across participants (Trajkovi´et al., 2022). Three trials were completed per joint motion direction per tester on the dominant leg; therefore, a total of six isometric contractions were completed per hip joint motion with 18 isometric contractions completed in total.

Each test trial started with a 2 s ramp up to a maximal contraction which was held for 3 s, after which the participant relaxed (Katoh & Yamasaki, 2009). There was a 30 s rest provided between trials (Trajkovi´et al., 2022). After the first tester completed their set of three trials for one joint motion, a 2 min rest was provided after which the second tester completed their set of

three isometric contractions. A 2 min rest was also provided before the first tester completed their next set of three trials. Each tester ensured the Activ5© HHD was consistently positioned in the proper location and on the specific anatomical landmark by checking its position between trials. In addition, both testers said “push push push” for the last 3 seconds of each trial and then “relax” after the trial was completed. These instructions were consistent for all participants, across all trials, and for each joint motion.

The session was completed by a supervised standardized cool-down consisting of static stretching specific for the hip (Appendix E). The participants completed a 15 s hold of the hurdler stretch per side, and the butterfly stretch held for 15 s for 3 repetitions. If a participant felt they needed more time to stretch, it was performed at their discretion. The participants were thanked for their time and for participating in the study and were advised they would be receiving the results if it was indicated on the consent form.

Data Analysis

Dependent Variable

For Part One, the dependent variable was mass measured in kg. For Part Two, the dependent variable was isometric hip strength measured in kg.

Independent Variables

The three independent variables for this study included testing day, the tester, and hip joint motion. Testing day involved both within-day and between-day comparisons of the force measurements and were based on Part One of the data collection. The tester was assessed in Part Two by having two individuals perform the testing. The hip joint motions that were assessed in Part Two included hip internal rotation, extension, and abduction.

Statistical Analysis

Descriptive statistics were calculated for the data collected from the independent and dependent variables. For Part One, the mean and standard deviation (SD) for the three trials at each weight increment were calculated, as well as standard error of measurement (SEM). For Part Two, the mean and SD for the three trials for each joint motion were calculated for each tester, as well as SEM.

1. Test-retest reliability of the Activ5© was established using ICC by comparing the mean (k=3) at each weight increment between session one and session two using a 2-way mixed-effects model. The magnitude of the correlation was evaluated using a modified scale developed by Hopkins (2000); trivial: r<.1; low: .1 to .29; moderate: .3 to .49: high: .5 to .69; very high: .7 to .89; nearly perfect >.9; and perfect=1.0. The level of significance that was used was alpha level $p \leq .05$.
2. Within-day reliability of the Activ5© was established using ICC by comparing the data (k=1) at each weight increment between trial one and trial two from the first testing session using a 2-way mixed-effects model. The magnitude of the correlation was evaluated using a modified scale developed by Hopkins (2000). The significance level was set at the alpha $p \leq .05$ level.
3. Intertester reliability of the Activ5© was determined using ICC by comparing the mean force (k=3) for each hip joint motion across participants between tester one and tester two using a 2-way mixed-effects model. The magnitude of each correlation was evaluated using the modified scale developed by Hopkins (2000) described previously. The level of significance used was alpha level $p \leq .05$.

Results

Part One

Part One addressed purposes 1 and 2 of this study which was to investigate the test-retest reliability of the Activ5© when measuring force on different days (purpose 1) and when measuring force within-day (purpose 2). The individual measurements from each trial at each weight increment, including mean, SD, and SEM are provided for session 1 and session 2 in Appendix G.

Assessment of Reliability

An excellent ICC of 1.00 was found for both between-day and within-day reliability of the Activ5©. The data is presented in Figure 14 (Between-Day Reliability of the Activ5©) and Figure 15 (Within-Day Reliability of the Activ5©).

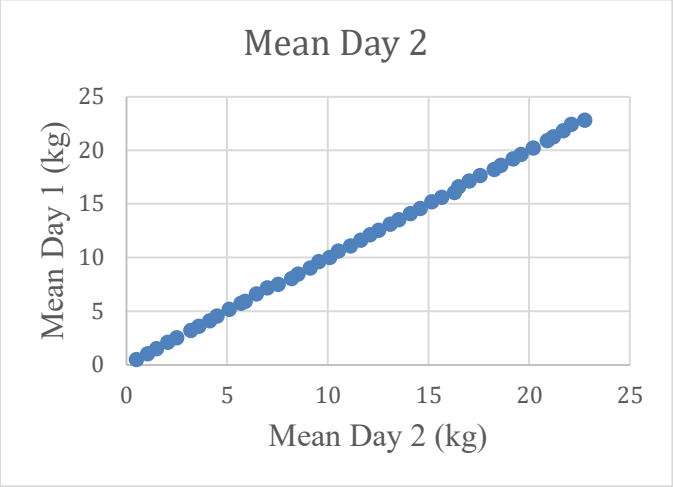

Figure 14. *Between-Day Reliability of the Activ5©.* The means of the three trials were compared per weight increment between-day one and two.

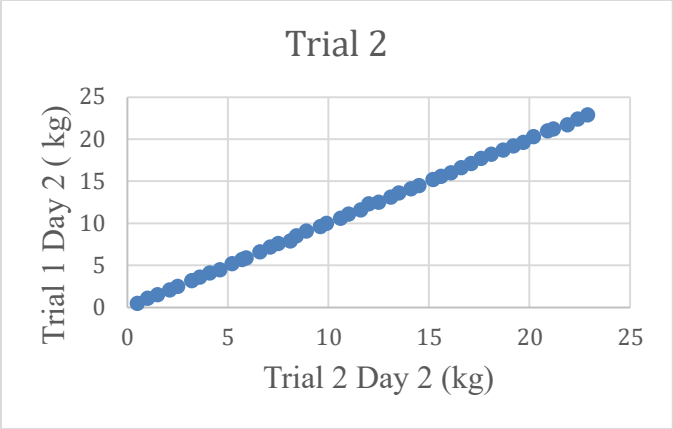

Figure 15. *Within-Day Reliability of the Activ5©.* Trial 1 and 2 from day 2 were compared to assess within-day reliability of the Activ5©.

Part Two

Part Two addressed purpose 3 of the study, which was to investigate the intertester reliability of the Activ5© in measuring isometric hip strength in competitive male ice hockey players. Figure 16 presents the mean (± SD) isometric strength for all participants as measured by tester 1 and tester 2 across the three hip motions. The values in the graph are as follows: internal rotation tester 1 (14.6 ± 3.7 kg) and tester 2 (15.9 ± 3.4 kg); hip abduction tester 1 (22.4 ± 2.9 kg) and tester 2 (20.5 ± 3.5 kg); hip extension tester 1 (16.7 ± 5.9 kg) and tester 2 (17.1 ± 3.6 kg). The absolute difference in the mean score between tester 1 and tester 2 across all participants for internal rotation was 1.3 kg, abduction was 1.9 kg, and extension was 0.4 kg.

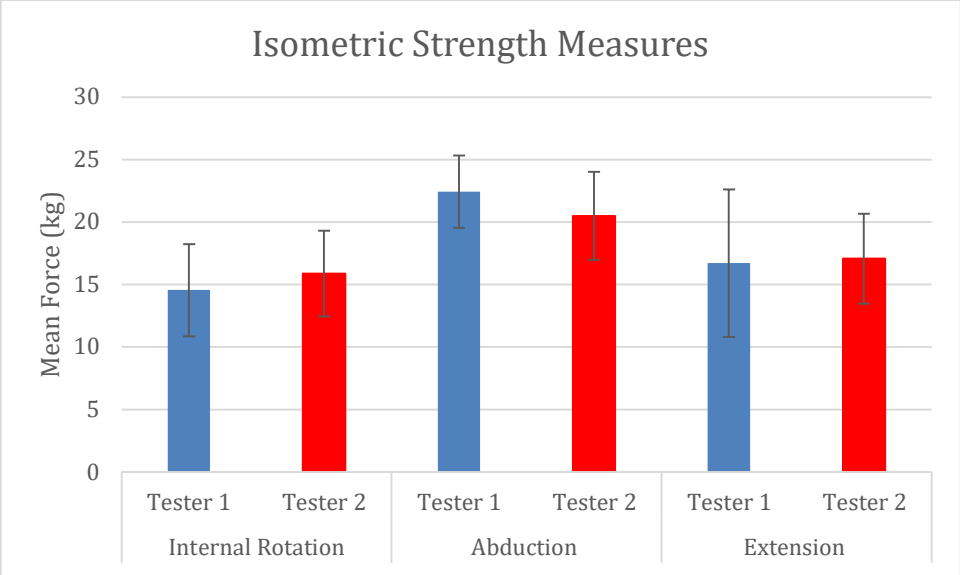

Figure 16. *Mean (± SD) isometric strength (kg) as measured by tester 1 and tester 2 across all three hip motions.*

Assessment of Reliability

Two-way mixed effect, absolute agreement, multiple measurement ICC (3,*k*) were run in SPSS to assess the reliability of the Activ5©. Figures 17, 18, and 19 provide a graphical display of the mean isometric strength (kg) measured by tester 1 and tester 2 for each participant in hip internal rotation, hip abduction, and hip extension, respectively. Intertester reliability for hip internal rotation (.664) and abduction (.622) demonstrated high intertester reliability using the Activ5© based on the Hopkins (2000) scale. Intertester reliability of hip extension (.786) with the Activ5© HHD presented with very high reliability.

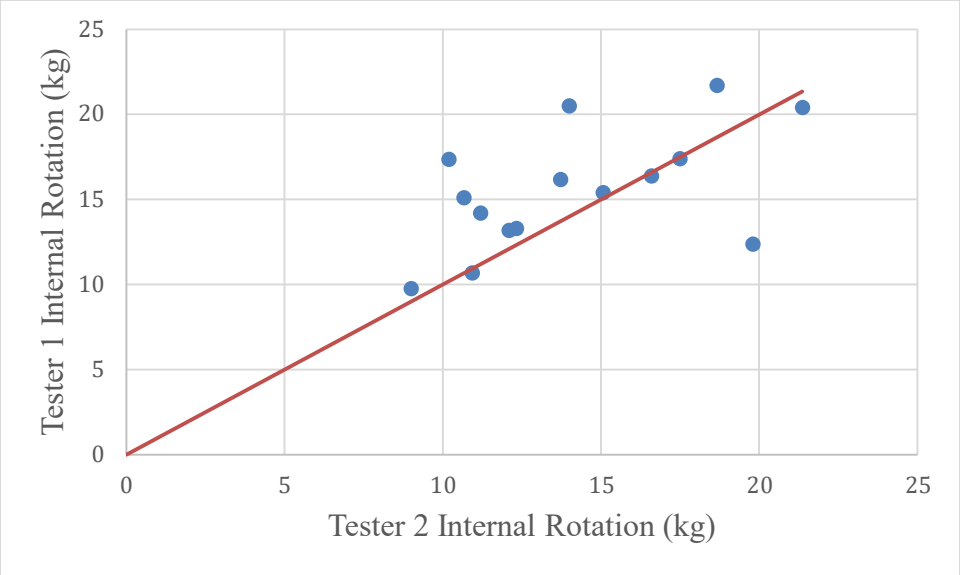

Figure 17. *Hip Internal Rotation Results.* The graph illustrates tester 1 compared to tester 2 when assessing hip internal rotation.

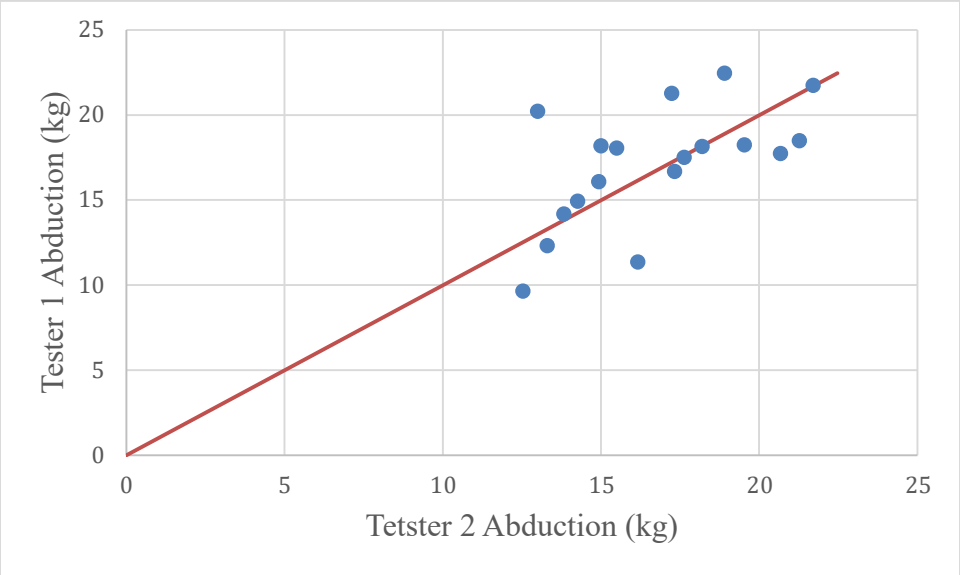

Figure 18. *Hip Abduction Results.* The graph illustrates tester 1 compared to tester 2 when assessing hip abduction.

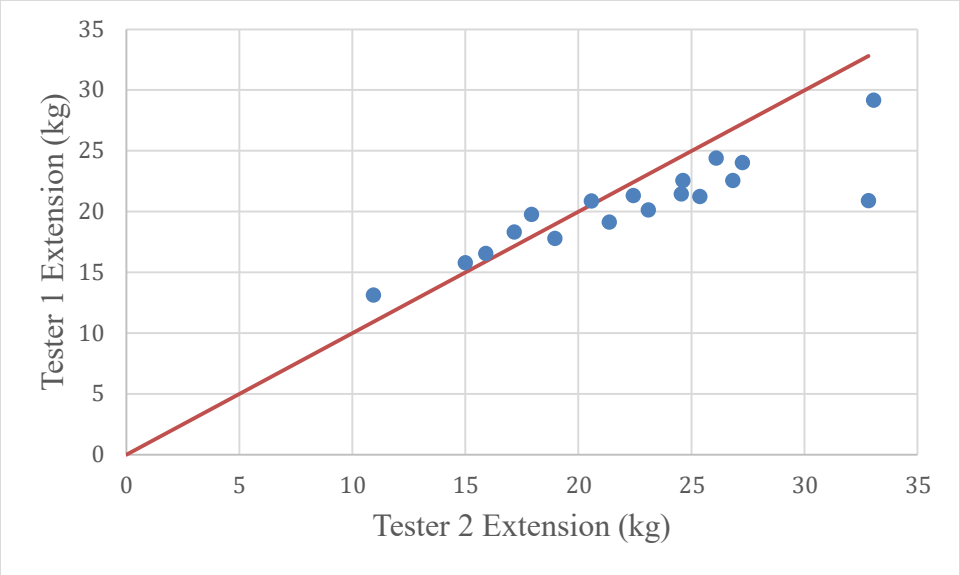

Figure 19. *Hip Extension Results.* The graph illustrates tester 1 compared to tester 2 when assessing hip extension.

Discussion

Numerous studies have examined the validity and reliability of HHDs in various populations (Denton et al., 2014; Kollock et al., 2010; Mentiplay et al., 2015; Ogborn et al., 2021; Scott et al., 2004; Shechteman et al., 2005; Trajković et al., 2022), however, the Activ5© has only been explored previously in one study which did not use participants (Merry et al., 2021). Merry et al., (2021) investigated the Activ5© validity and reliability by comparing it to the Instron ElectroPuls E10000© universal testing machine (UTM)©, with data collection being conducted in a single testing session (Merry et al., 2021). This differed from Part One of the current study as the data was collected over two sessions to assess both within-day and between-day reliability. Merry et al. (2021) found that the Activ5© had excellent reliability (ICC = .999-1.000), which was consistent with the findings in this research. Merry et al. (2021) also reported that the measured force deviated from the applied force at higher loads (up to 883 N) and suggested that at higher loads the device was less consistent. This differed from the results of this thesis research as the SD and the SEM remained consistently small during both of the testing sessions and across the various weight increments. This is likely because the highest mass applied in the current study (22.8 kg or 223.7 N) fell within the lower end of the range of the forces applied by Merry et al. (2021). Overall, when considering the results of this study with those of Merry et al. (2021), it can be stated that the Activ5© demonstrates excellent between-day and within-day reliability, particularly when masses of smaller magnitude are measured. Additionally, Merry et al. (2021) solely conducted machine testing on the Activ5© and did not test the device on human participants. Assessing the reliability of an HHD using human participants may introduce measurement errors due to landmark placement, tester strength, participant fatigue, and participant motivation (Thomas et al., 2005), therefore, assessing the

Activ5© using machine-driven methodologies and without using human participants allows for greater control in the testing procedures, which would result in greater confidence in the reliability of the device.

Intertester reliability of the Activ5© was assessed in Part Two of this study using current or previously competitive ice male hockey players as the participants. This population was selected as the hip is a vital component of the skating stride, therefore, the musculature of these athletes is more developed and less likely to fatigue over multiple trials, ensuring consistency throughout the testing (Terry & Goodman, 2017). In addition, male hockey players were recruited as they have been found to produce forces more consistently across trials than females (Grunte et al., 2010). The researchers reported that women demonstrate greater torque fluctuations when producing maximal voluntary contractions in comparison to men (Grunte et al., 2010). Therefore, having a population that can produce maximal isometric force more consistently allows for a more direct comparison between the two testers when using the Activ5©. If the study used participants with less developed hip strength, there would have been a higher potential for inconsistency in the data at the participant level, which would have resulted in higher random error in the data. The population was selected to ensure that the current study investigated the intertester reliability of the Activ5© rather than participant consistency.

When assessing intertester reliability, the participants were assessed using a same-day test-retest method which is typically used with physical performance tests such as isometric strength assessments, as this testing method helps to minimize the practice effect (Thomas et al., 2005). By minimizing the practice effect there is increased confidence in the results of the Activ5© and allowed for the isolation of the differences between testers one and two. As measurement theory suggests that some amount of error is present regardless of the type of

measurement (Thomas et al., 2005), in this study as both testers attempted to minimize error as they undertook a training period prior to testing to familiarize themselves with the use of the Activ5©. Random error was also minimized by using a marker to identify the specific anatomical landmark used for the placement of the Activ5© for each joint movement. Additionally, the testing protocol was followed precisely by each tester for each participant to ensure consistency in the measurement across all trials.

Although the Activ5© was found to be reliable when measuring isometric hip strength between the two testers for each hip joint movement, the ICC was highest for hip extension and lowest for hip abduction. The joint movement that was considered very high (extension) also showed the smallest absolute difference between testers (0.4 kg). The other two joint movements which demonstrated high ICC values (hip internal rotation and abduction) showed larger absolute difference values (1.3 kg and 1.9 kg, respectively). The results for both the ICC and absolute difference across joint movements can be explained through the body positions used by the testers during testing and the gender of the testers. Hip extension was the only movement where the tester's shoulders were positioned over the participant's leg during testing, which may have aided in the ability to withstand force more consistently for both testers. The testers were able to use more of their body weight when testing hip extension to withstand force when compared to the hip internal rotation and abduction where the resistance was primarily from the upper body. Thorborg et al. (2019) found that the stronger the participants, the larger the between-tester differences in measured hip muscle strength. In addition, the two testers in this study were both the same sex and used the same testing technique, therefore it would be expected that similar ICC values would be present for all hip movements tested. In an earlier study conducted by Thorborg et al. (2011), a female tester was found to systematically measure

lower strength values in isometric hip strength when compared to a male tester. Thorborg et al. (2011) stated that this is likely due to the differences in upper-extremity strength, although the tester sample size (both male and female) was too small to generalize the results. In the current study, there were differences in the body mass between the two testers (77.1 kg versus 54.4 kg) and there could also have been differences in the strength, but this was not assessed. Despite the difference in mass, the results still indicated high to very high reliability of the Activ5© suggesting that the device can produce reliable results during isometric strength assessment as long as the same testing techniques are used by different testers. It would be advantageous to independently assess the strength of each tester to be able to discuss if the strength differences between the testers could have impacted the results. Additionally, there is merit in assessing between-sex intertester reliability of the Activ5© to highlight any systematic differences that may occur.

A small number of studies have investigated isometric strength testing for all six hip muscle groups (Denton et al., 2014; Kollock et al., 2010; Mentiplay et al., 2015). These studies included strength-testing positions where the tester was required to stabilize the subject or hold the non-test limb during testing, leaving only one arm available to counteract the force produced by the hip muscles (Denton et al., 2014). When assessing the muscles of the hip, it is important to utilize a testing procedure that ensures the testers can apply sufficient force (Denton et al., 2014). There is no single, universally accepted testing protocol for the muscles of the hip (Denton et al., 2014). Ensuring the testers are in a stable testing position is required to account for the magnitude of force produced by the hip musculature (Denton et al., 2014). Within the Denton et al. (2014) study testers varied their leg stance and body position to be able to withstand the force of the participant. This was not noted in the methodology as it was not the

focus of the study. Future research using HHDs, specifically the Activ5©, should consider investigating the degree to which the stance and posture of the tester(s) impacts the results, as a key component of isometric testing is the ability to withstand the participant's force. Being able to identify the best stance for testers can help minimize systematic error and aid the weaker tester by providing the best stance per joint motion that allows the tester to withstand the force of a participant.

During the isometric hip strength testing in Part Two of this study, the anatomical location where the Activ5© was positioned was specific to each joint motion. When testing hip extension, the Activ5© was positioned on a larger surface area as compared to the other two joint movements. The Activ5© is approximately the size of a hockey puck and fits in the palm of the tester's hand with dimensions of 12.45 x 10.92 x 4.95 cm and a mass of .28 kg. The Activ5© has minimal padding in comparison to other devices such as the Lafayette© HHD which has different padded attachments for various isometric tests, and which provides comfort for the participants. It was noted that some participants felt discomfort after performing multiple maximal effort trials in hip internal rotation and abduction but not in extension. The Activ5© is more convex in shape as compared to other devices with concave design characteristics such as the Lafayette© HHD. As such, the Activ5© may be better designed to ergonomically fit the tester's hand rather than providing comfort for the participant during maximal effort trials. It is believed this did not have a significant impact on the results as high (hip abduction and hip internal rotation) and very high (hip extension) ICC values were reported, however, it is recommended that if the device is positioned on a bony landmark when conducting research or performing testing that the number of trials should be limited or use a device that has adequate padding.

When comparing the intertester reliability of the Activ5© to other HHDs, the Activ5© achieved similar findings. Scott et al. (2004) investigated intra- and interrater reliability of bilateral hip muscle strength using the Chatillon CSD 300 a©. The researchers included similar procedures to those of the current study by conducting three repetitions for all hip joint movements. Interrater ICCs of average peak strength ranged from .69 – .88 for hip abduction and .56 – .80 for hip extension (Scott et al., 2004). An ICC range was presented for this study because these researchers assessed both hips. Similar to Scott et al. (2021), this thesis research study found the highest ICC value in hip extension. The lower ICC values presented in the Scott et al. (2004) study was suggested to be attributed to testing multiple muscles on numerous occasions with subject fatigue and motivation to exert maximal contractions having an effect. This was controlled for in the current study as the student researcher selected a population for whom fatigue would be minimized, yet motivation may still impact the results when using human participants regardless of skill level (Thomas et al., 2005). The motivation effect was minimized in the current study as testing took place in one session. In this study, each participant was instructed to push as hard as possible into the Activ5© with a 2-second ramp-up.

Practical Applications

The results from the current study suggest that the Activ5© demonstrates excellent within-day and between-day reliability and is a very reliable HHD when different individuals assessed isometric hip strength. As such, the Activ5© has applications in various settings including fitness testing, isometric strength assessments for clients and athletes, and ongoing isometric strength monitoring over time. Isometric strength assessment for clients and athletes would allow the practitioners to assess isometric strength at any training location due to Activ5©'s portability. Ongoing strength monitoring would allow practitioners to adjust the client

or athlete's training program as needed. It is worth noting that the position of the Activ5© may influence the comfort level of the participant being tested and depends on how close the device is to a bony landmark. Discomfort with bony landmarks may impact the results over multiple trials, as participants may be hesitant to provide a maximal contraction. In addition to its ability to produce reliable results, the Activ5© also provides benefit due to its affordability, portability, and data analyzing software in assessing isometric strength.

Conclusion

The objectives of this thesis research were to examine the within-day and between-day test-retest reliability of the Activ5©, and to investigate the intertester reliability of the Activ5© in measuring isometric hip strength. The results of this study showed that the Active5© demonstrates excellent within-day and between-day reliability, and the intertester reliability was found to be very high when measuring isometric force in hip extension and high when measuring in hip internal rotation and abduction.

Limitations

As the hip was the only joint assessed in Part Two, this is a limitation of the current study and the results cannot be generalized to other joint movements or muscle groups. Additionally, a limitation of this study was that both testers were the same sex and had similar levels of experience in isometric testing. It would be of value to have additional testers of both sexes and with different levels of experience to assess the reliability of the Activ5©. As human participants were used, there was the possibility of fatigue in both the tester and participant from the multiple trials of maximal effort isometric contractions, though, all attempts to mitigate this were taken.

Delimitations

This study was delimited to include only male ice hockey players. Using competitive hockey players ensured that the participants were consistent in their ability to produce isometric force at the hip across multiple testing trials. In addition, the intertester reliability of the Activ5© was only assessed at the hip and in only three joint motions (hip abduction, internal rotation, and extension).

Assumptions

It was assumed that the Activ5© was positioned on the same anatomical landmarks and placed in the same direction for each participant. It was also assumed that all participants were competitive hockey players who demonstrated consistent hip strength across trials. Lastly, it was assumed that each participant truly provided a maximal effort isometric contraction, however, there was no method of testing or controlling this beyond the act of ensuring the participants understood that they were required to provide a maximal effort isometric contraction for each trial.

Future Research

It would be of value to investigate the Activ5© over multiple testing days during a training or rehabilitation program to assess if the device can successfully assess muscular strength changes over time in a reliable manner. Moreover, assessing the reliability of the Activ5© using different muscle groups would be of value to investigate if these results can be replicated across other joints. Another potential research opportunity would be to investigate the reliability of the Activ5© on different segments of the population, including between sexes and among individuals of different abilities or fitness levels. Lastly, assessing the reliability between testers from both sexes and with different backgrounds or years of experience would be of value.

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Appendix A
Draft Email to Participants

Dear Potential Participant,

My name is Abigail Proteau, I am a graduate student in the Master of Science in Kinesiology program at Lakehead University. I am looking to recruit current or recently retired competitive hockey players to serve as participants for my thesis research project titled "Measurement of Isometric Hip Strength in Male Ice Hockey Players: Investigation of the Activ5© Intertester Reliability."

You are receiving this email as you play / played on a university level varsity hockey team. My research which will investigate the reliability of testing isometric hip strength between two experienced testers. In this study, participants will be asked to come to the Lakehead University Fieldhouse for one testing session where hip extension, abduction and internal rotation will be assessed in the dominant leg using the Activ5© which is a new device used for testing isometric strength. The testing session will take approximately 30-40 minutes of your time.

For further information on this study, please refer to the information letter which I have attached to this email. If after receiving this email and reviewing the information letter you are interested in participating in this study, please contact me to schedule a testing session.

Thank you for your consideration and please reach out if there are any further questions.

This research study has been reviewed and approved by the Lakehead University Research Ethics Board file #1469261. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 807-343-8283 or research@lakeheadu.ca.

Best regards,

Abby

Appendix B
Information Letter

School of Kinesiology
t: (807) 343-8645
derek.kivi@lakeheadu.ca

Dear Potential Participant:

Thank you for your interest in the study "Measurement of Isometric Hip Strength in Male Ice Hockey Players: Investigation of the Activ5© Intertester Reliability." This research is being conducted by Abigail Proteau, a second year student in the Master of Science in Kinesiology program at Lakehead University. This research will be supervised by Dr. Derek Kivi, Associate Professor in the School of Kinesiology. Taking part in this study is voluntary. Before you decide whether you would like to take part in this study, please read this letter carefully to understand what is involved. After you have read the letter, please ask any questions you may have.

Purpose

To investigate the intertester reliability of the Activ5© in measuring isometric hip strength in competitive male ice hockey players.

What Information Will be Collected

You are being asked to participate in this study because you are a retired or current competitive level hockey player. The information that will be collected is isometric hip strength in abduction, extension, and internal rotation of the dominant hip. Prior to starting the testing, all health concerns or injuries that may influence your participation with this study must be disclosed. You will be required to fill out a consent form and a Physical Activity Readiness Questionnaire (PAR-Q). In addition, you will also be asked to provide your age, height, weight, years of hockey playing experience, and identify which leg is your dominant leg.

What is Requested of me as a Participant?

The testing will require one session and will take approximately 30-40 minutes. Prior to testing, you will complete a five-minute warm up on a cycle ergometer at a self-selected pace and resistance, followed by lower body stretching as required supervised by the student researcher. Static stretching will include a 15 s hold of the hurdler stretch per side, and the butterfly stretch held for 15 s for 3 repetitions. You will be instructed to find a spot on the wall, and complete 10 kickbacks per leg, 10 abduction leg lifts per leg, and 10 hip-openers per leg.

There will be two testers involved in this study; the student researcher (Abigail Proteau), and Celia Berry. Both testers have a background in Kinesiology and are familiar with using Activ5© for isometric strength testing. Hip extension, abduction and internal rotation will be assessed by both testers. You will complete three trials completed per joint motion per tester on the dominant leg; therefore, a total of six isometric contractions will be completed per hip joint motion and 18 isometric contractions in total. Each individual test trial will start with a 2 s ramp up to a maximal contraction which will then be held for 3 s, after which you will relax. There will be a 30-second rest provided between trials. After the first tester completes their set of three trials for one joint motion, a 2-minute rest will be provided after which the second tester will complete

their set of three isometric contractions. A 2-minute rest will also be provided prior to the first tester completing their next set of three trials.

The testing will be completed with you positioned on a therapy table. Hip internal rotation will be assessed with you laying on your back with 90º of knee flexion and 90º of hip flexion. To test hip extension, you will be on your stomach with your knee at 90º of flexion. When testing hip abduction, you will be positioned in side lying with the testing hip is in 10º of abduction measured by a goniometer. The session will be completed by a standardized cool down consisting of static stretching specific for the hip.

What are the Risk and Benefits?

As with any form of physical activity and maximal effort muscle contractions, there is a potential risk of physical injury, such as delay-onset muscle soreness, mild muscle strains, and mild ligament sprains. This risk is minimized in this study as you are a competitive ice hockey athlete who is experienced in performing physical activity assessments and are familiar with the movements being performed in this study. You will also be screened for any contraindications to physical exercise utilizing the PAR-Q form. To reduce risk of acute musculoskeletal injury, a thorough warm-up will be performed including moderate aerobic activity. If an injury does occur during participation of this study, you will no longer be permitted to continue with the testing. The student researcher is trained in first aid and will provide any necessary immediate treatment.

You may directly benefit from participating in this study by understanding if the Activ5© is reliable to assess strength by different individuals which can be used to monitor strength progression during the season. When compared to other isometric strength measuring devices, the Activ5© allows you or the strength and conditioning coach to immediately have the results available on their mobile device. The Activ5© also permits data storage on the mobile device and can create graphs over time as an individual's strength changes, allowing continued monitoring to evaluate progression over time in a rehabilitation or training program. With the safety of isometric strength testing, this tool has the potential to safely monitor strength over time specifically as the hip is a vital component to ice hockey performance.

What are my Rights as a Participant?

As a potential participant, you maintain the following rights throughout this study:

A. You are under no obligation to participate, are free to withdraw at any time without prejudice to pre-existing entitlements
B. Your decision to participate will not affect your academic status/employment
C. You will be given, in a timely manner throughout the course of the research project, information that is relevant to your decision to continue or withdraw from participation
D. You will be given information on the participant right to request withdrawal of data or human biological materials, include any limitation on the feasibility of that withdrawal

COVID-19 Safety Measures

By participating in this study, there is an increased risk of exposure to COVID-19. Upon arrival you will be asked to wear a mask, however, you will be allowed to remove your mask when physical activity begins. Whenever possible during testing, physical distancing (2m) will be maintained between the researchers and participants. Hand sanitizer will be available for the researchers and participants to use and will be required at the beginning and the end of data collection sessions. Between participants and between testers, the Activ5© will be disinfected using a disinfecting spray.

How Will My Confidentiality be Maintained?

As a participant in this study, your information will remain confidential throughout the study. Upon arrival to the first testing session, you will be assigned a unique identification number to which only the student researcher will have access. The data that is gathered during the testing will be safely stored on a password-protected computer. Only the student researcher (Abigail Proteau) will know the passwords and only the student researcher, the second tester (Celia Berry), and the research supervisor will see the data. Your name will not be attached to any of the data (a numerical identification will be used instead) and your name will not be published with any of the results.

What Will My Data be Used for?

The results for the testing procedures will be used solely for statistical analysis in this study. The data for the hip will remain confidential due to the number association rather than your name. The data will be used to determine the intertester reliability of the Activ5©.

Where Will My Data be Stored?

The researcher and the faculty advisor will only have access to any personal information. The data will be stored in Dr. Kivi's office for a period of 5 years

How Can I Receive a Copy of the Research Results?

If you wish to receive a copy of your results as well as a summary of the overall results of this study, please check "yes" in the appropriate box on the consent form and provide an email where these results can be emailed to. You will also be provided with an opportunity meet with the researcher over Zoom to discuss the results if you choose.

What if I Want to Withdraw from the Study?

Please be advised that, as a volunteer participant, you can withdraw from the study at any time or refuse to complete any part of the study if you are not comfortable with what is being asked of you. There will be no penalty for withdrawing. You are also encouraged to ask the student researcher any questions regarding the nature of the study.

Researcher Contact Information

If you wish to participate in this study, please sign and return the attached consent form as soon as possible. If you would like additional information, please contact Abigail Proteau at (807) 472-8310 or acprotea@lakeheadu.ca.

Research Ethics Board Review and Approval

This research study has been reviewed and approved by the Lakehead University Research Ethics Board, file #1469261. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 807-343-8283 or research@lakeheadu.ca.

Your participation would be greatly appreciated!

Sincerely,

Abigail Proteau
Research Investigator
(807) 472-8310
acprotea@lakeheadu.ca

Derek Kivi, Ph.D.
Faculty Advisor
(807) 343-8645
dkivi@lakeheadu.ca

Appendix C
Consent Form

Lakehead UNIVERSITY

School of Kinesiology
t: (807) 343-8645
derek.kivi@lakeheadu.ca

Consent Form

I _____, agree to participate in the study titled "Measurement of Isometric Hip Strength in Male Ice Hockey Players: Investigation of the Activ5© Intertester Reliability" which will analyze the reliability of the Activ5©. This study will be conducted by Abigail Proteau, a second-year Master of Science in Kinesiology student at Lakehead University, with the Faculty Advisor, Dr. Derek Kivi.

- ✓ I have read and understand the information contained in the Information Letter
- ✓ I agree to participate
- ✓ I understand the risks and benefits to the study as there is physical activity involved. I also understand the benefits of participating in this study as it will provide awareness in novel tools that can be used in University level hockey players to assess isometric hip strength as it is a vital component of the skating stride.
- ✓ I understand that I am a volunteer and can withdraw from the study at any time and may decline to answer any questions
- ✓ I understand that the data will be securely stored in Dr. Derek Kivi's office for a minimum period of 5 years following completion of the research project
- ✓ I understand that the research findings will be made available to me upon request
- ✓ I understand that I will remain confidential in the written report and in the presentation of the results; each participant will be assigned a number to code for the data
- ✓ I understand that due to the COVID-19 pandemic there is higher risk with in-person testing, but I understand the safety measures in place
- ✓ All of my questions have been answered

□ Please check this box and provide your email address if you would like to receive a summary of the results from the study.

Email address: _____

_____

Signature of Participant Date

_____

Signature of Student Researcher Date

_____

Signature of Supervisor

Appendix D
ParQ Form

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→ **DELAY BECOMING MUCH MORE ACTIVE:**

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

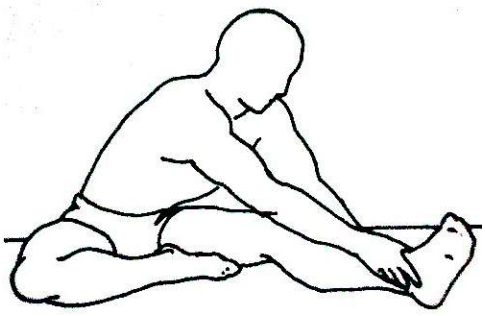
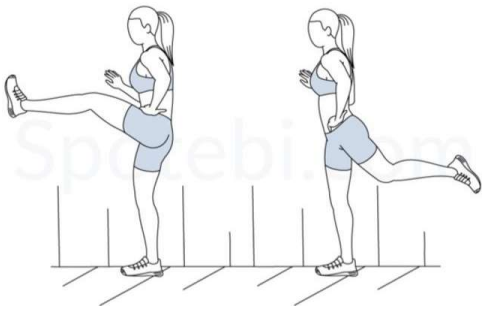
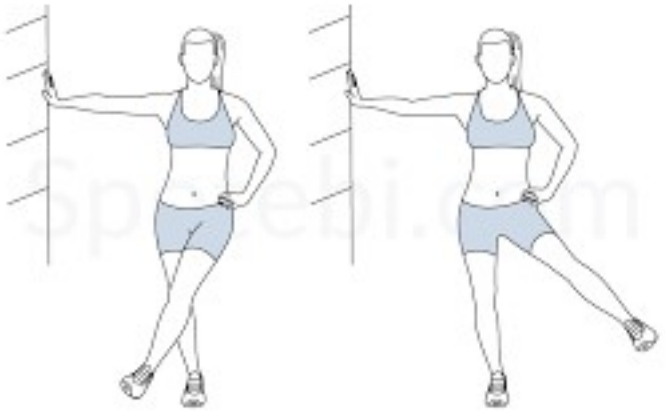
SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

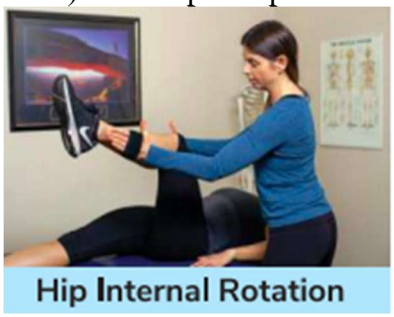
Appendix E
Stretching Protocol

	
Hurdler stretch 15 second hold for 3 repetitions	Butterfly stretch 15 second hold for 3 repetitions
	
10 kick backs per leg	10 abduction swings per leg
	
	10 hip opener per side

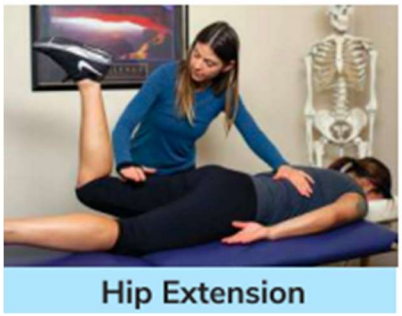
Appendix F
Isometric Hip Strength Testing Protocol

Activ5. (Activbody, n.d).

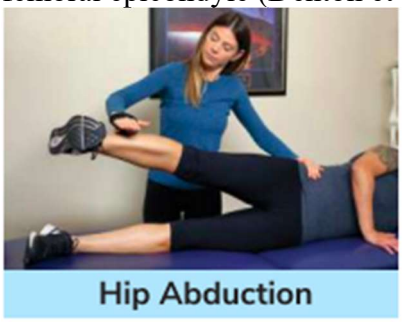
Hip internal rotation will be assessed with the participant supine with 90º of knee flexion and 90º of hip flexion. The Activ5© will be located 2 cm proximal to the lateral malleolus (Denton et al., 2014) and the participant will be asked to internally rotate into the Activ5© (Activbody, n.d).



To test hip extension, the participant will be positioned in prone lying with the knee at 90º of flexion. The Activ5 will be placed on the posterior thigh 2 cm proximal to the femoral epicondyles (Denton et al., 2014). The participant's arms may be positioned overhead or abducted to the sides of the table for participant comfort and stability.



When testing hip abduction, the participant will be positioned in side lying with the testing hip is in 10º of abduction (Kor, 2019). This angle will be measured using a goniometer to ensure consistency across trials. The non-testing hip will be at 0° on the testing table, and the knee at held in slight flexion for the participant's comfort (Kor, 2019). The knee joint on the tested side will be fully extended (Kor, 2019). The Activ5 will be located 2 cm superior to the lateral femoral epicondyle (Denton et al., 2014).



Appendix G
Data Collected in Part Two by Testers 1 and 2

Table 4

Descriptive Statistics for the Means of the Activ5© for Test Day 1

Weight (kg)	Trial 1 (kg)	Trial 2 (kg)	Trial 3 (kg)	Mean (kg)	SD	SEM
0.5	0.5	0.6	0.5	0.5	.05	.01
1.0	1.1	1.0	1.1	1.1	.05	.01
1.5	1.5	1.5	1.5	1.5	.00	.00
2.0	2.1	2.0	2.1	2.1	.05	.01
2.5	2.5	2.5	2.5	2.5	.00	.00
3.1	3.2	3.2	3.2	3.2	.00	.00
3.6	3.6	3.6	3.6	3.6	.00	.00
4.1	4.1	4.2	4.1	4.1	.05	.01
4.6	4.6	4.5	4.6	4.6	.05	.01
5.1	5.1	5.1	5.1	5.1	.00	.00
5.7	5.7	5.7	5.7	5.7	.00	.00
5.9	5.9	5.9	5.9	5.9	.00	.00
6.5	6.5	6.5	6.4	6.5	.05	.01
7.0	7.0	7.0	7.0	7.0	.00	.00
7.5	7.5	7.5	7.6	7.5	.05	.01
8.0	8.2	8.2	8.2	8.2	.00	.00
8.5	8.6	8.5	8.5	8.5	.05	.01
9.0	9.1	9.1	9.2	9.1	.05	.01
9.5	9.6	9.6	9.5	9.6	.05	.01
10.0	10.1	10.1	10.1	10.1	.00	.00
10.5	10.5	10.5	10.6	10.5	.05	.01
11.0	11.1	11.1	11.2	11.1	.05	.01
11.5	11.7	11.6	11.6	11.6	.05	.01
12.1	12.1	12.2	12.2	12.2	.05	.01
12.6	12.5	12.6	12.5	12.5	.05	.01
13.1	13.2	13.1	13.1	13.1	.05	.01
13.5	13.5	13.5	13.6	13.5	.05	.01
14.1	14.1	14.2	14.1	14.1	.05	.01
14.6	14.6	14.6	14.8	14.7	.11	.01
15.1	15.1	15.3	15.1	15.2	.11	.01
15.6	15.6	15.7	15.7	15.7	.05	.01
16.1	16.3	16.3	16.3	16.3	.00	.00
16.6	16.5	16.5	16.6	16.5	.05	.01
17.1	17.0	17.0	17.1	17.0	.05	.01

17.6	17.6	17.6	17.5	17.6	.05	.01
18.2	18.2	18.3	18.3	18.3	.05	.01
18.6	18.6	18.7	18.6	18.6	.05	.01
19.2	19.0	19.3	19.3	19.2	.17	.02
19.7	19.6	19.6	19.6	19.6	.00	.00
20.2	20.3	20.2	20.3	20.3	.05	.01
20.8	20.5	20.7	20.7	20.6	.11	.01
21.2	21.2	21.2	21.2	21.2	.00	.00
21.7	21.7	21.7	21.7	21.7	.00	.00
22.2	22.2	22.1	22.2	22.2	.05	.01
22.8	22.7	22.8	22.8	22.8	.05	.01

Table 5

Descriptive Statistics for the Means of the Activ5© for Test Day 2

Weight (kg)	Trial 1 (kg)	Trial 2 (kg)	Trial 3 (kg)	Mean (kg)	SD	SEM
0.5	0.5	0.5	0.5	0.5	.00	.00
1.0	1.0	1.1	1.0	1.0	.06	.01
1.5	1.5	1.5	1.5	1.5	.00	.00
2.0	2.1	2.1	2.1	2.1	.00	.00
2.5	2.5	2.5	2.5	2.5	.00	.00
3.1	3.2	3.2	3.2	3.2	.00	.00
3.6	3.6	3.6	3.6	3.6	.00	.00
4.1	4.1	4.1	4.1	4.1	.00	.00
4.6	4.6	4.5	4.5	4.5	.06	.01
5.1	5.2	5.2	5.1	5.2	.06	.01
5.7	5.7	5.7	5.8	5.7	.06	.01
5.9	5.9	5.9	5.9	5.9	.00	.00
6.5	6.6	6.6	6.6	6.6	.00	.00
7.0	7.1	7.2	7.2	7.2	.06	.01
7.5	7.5	7.6	7.6	7.6	.06	.01
8.0	8.1	7.9	8.1	8.0	.12	.02
8.5	8.4	8.5	8.5	8.5	.06	.01
9.0	8.9	9.1	9.1	9.0	.12	.02
9.5	9.6	9.6	9.6	9.6	.00	.00
10.0	9.9	10.0	10.1	10.0	.01	.01
10.5	10.6	10.6	10.6	10.6	.00	.00
11.0	11.0	11.1	11.1	11.1	.06	.01

11.5	11.6	11.6	11.6	11.6	.00	.00
12.1	12.0	12.3	12.1	12.1	.12	.02
12.6	12.5	12.5	12.6	12.5	.06	.01
13.1	13.1	13.1	13.1	13.1	.00	.00
13.5	13.5	13.6	13.5	13.5	.06	.01
14.1	14.1	14.1	14.1	14.1	.00	.00
14.6	14.5	14.5	14.7	14.6	.12	.02
15.1	15.2	15.2	15.2	15.2	.00	.00
15.6	15.6	15.6	15.6	15.6	.00	.00
16.1	16.1	16.0	16.1	16.1	.06	.01
16.6	16.6	16.6	16.6	16.6	.00	.00
17.1	17.1	17.1	17.2	17.1	.06	.01
17.6	17.6	17.7	17.6	17.6	.06	.01
18.2	18.1	18.2	18.3	18.2	.01	.01
18.6	18.7	18.7	18.6	18.7	.06	.01
19.2	19.2	19.2	19.2	19.2	.00	.00
19.7	19.7	19.6	19.7	19.7	.06	.01
20.2	20.2	20.3	20.2	20.2	.06	.01
20.8	20.9	21.0	20.8	20.9	.01	.01
21.2	21.2	21.2	21.3	21.2	.06	.01
21.7	21.9	21.7	21.8	21.8	.01	.01
22.2	22.4	22.4	22.4	22.4	.00	.00
22.8	22.9	22.9	22.8	22.9	.06	.01

Table 6

Internal Rotation Descriptive Statistics

	Tester 1			Tester 2		
Participant	Mean (kg)	SD	SEM	Mean (kg)	*SD*	SEM
1	21.3	1.85	.41	20.4	2.62	.59
2	15.1	4.03	.90	15.4	.85	.19
3	19.8	2.18	.49	12.4	.55	.12
4	10.6	1.44	.32	15.1	3.65	.82
5	18.7	3.66	.82	21.7	4.53	1.01
6	13.8	1.15	.26	16.2	1.46	.33
7	12.4	1.62	.36	13.3	.26	.06
8	16.6	1.71	.38	16.4	4.04	.90
9	11.2	1.18	.26	14.2	5.98	1.34
10	10.2	1.28	.29	17.4	.89	.20
11	9.0	.79	.18	9.8	.32	.07
12	17.5	3.28	.73	17.4	3.48	.78

13	12.1	.95	.21	13.3	2.18	.49
14	10.9	2.63	.59	10.7	.90	.20
15	14.0	3.36	.75	20.5	2.12	.47
16	14.9	3.15	.70	14.0	2.46	.55
17	19.6	1.42	.32	19.5	2.03	.45
18	14.6	2.15	.48	18.7	1.46	.33
19	23.4	1.85	.41	23.0	2.23	.50
20	18.1	3.81	.85	17.4	2.35	.52

Table 7

Hip Abduction Descriptive Statistics.

		Tester 1			Tester 2	
Participant	Mean (kg)	SD	SEM	Mean (kg)	*SD*	SEM
1	21.3	.25	.05	18.5	.83	.19
2	15.5	1.75	.39	18.1	1.04	.23
3	17.2	5.45	1.21	21.3	1.34	.30
4	16.2	1.33	.30	11.4	2.54	.57
5	18.2	2.59	.58	18.2	.64	.14
6	13.8	.67	.15	14.2	1.57	.35
7	21.7	.90	.20	21.8	1.46	.33
8	17.6	1.78	.40	17.6	.40	.09
9	17.3	1.23	.26	16.7	.56	.12
10	13.0	1.32	.30	20.2	.84	.19
11	14.9	.06	.01	16.1	.52	.12
12	18.9	.70	.16	22.5	1.10	.24
13	13.3	2.10	.47	12.3	.60	.14
14	12.5	1.81	.41	9.6	1.30	.30
15	20.7	.31	.07	17.8	1.96	.44
16	14.3	.35	.08	15.0	.06	.01
17	15.0	.69	.15	18.2	.90	.20
18	19.5	.67	.15	18.3	.40	.08
19	24.9	.83	.19	21.3	.21	.05
20	18.1	1.30	.30	17.4	.61	.14

Table 8

Hip Extension Descriptive Statistics.

		Tester 1			Tester 2	
Participant	Mean (kg)	SD	SEM	Mean (kg)	*SD*	SEM
1	26.1	5.90	1.32	24.4	1.05	.24
2	20.6	0.64	.14	20.9	1.84	.41
3	10.9	1.68	.38	13.1	.12	.03
4	21.4	1.93	.43	19.1	3.02	.68

5	22.4	2.05	.46	21.3	1.56	.35
6	19.0	0.91	.20	17.8	1.56	.35
7	23.1	1.08	.24	20.1	.91	.20
8	26.8	1.15	.26	22.6	1.50	.34
9	25.4	0.55	.12	21.2	2.72	.61
10	24.6	2.66	.59	22.6	.12	.03
11	15.9	0.87	.19	16.6	.40	.09
12	33.1	2.35	.52	29.2	2.55	.57
13	17.2	1.98	.44	18.3	1.01	.23
14	15.0	2.96	.66	15.8	3.32	.74
15	17.8	1.96	.44	21.4	1.50	.34
16	17.9	1.27	.28	19.7	.47	.11
17	27.3	4.12	.92	24.0	1.07	.24
18	32.8	2.64	.59	20.9	.26	.06
19	26.9	2.35	.53	24.5	.28	.06
20	22.4	1.72	.38	19.4	.76	.17

Table 9

Tester 1 Internal Rotation (kg)

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
20.3	20.3	23.5	21.3	1.85	.41
19.7	12.3	13.2	15.1	4.03	.90
21.3	17.3	20.8	19.8	2.18	.49
9.6	10.1	12.3	10.6	1.44	.32
14.6	19.7	21.7	18.7	3.66	.82
14.4	12.4	14.4	13.77	1.15	.26
12.6	13.8	10.6	12.37	1.62	.36
18.4	16.4	15.0	16.6	1.71	.38
9.9	11.5	12.2	11.2	1.18	.26
9.1	11.6	9.9	10.2	1.28	.29
9.3	9.6	8.1	9.0	.79	.18
14.5	21.0	17.0	17.5	3.28	.73
11.6	11.5	13.2	12.1	0.95	.21
8.9	13.9	10.0	10.9	2.63	.59
10.2	15.2	16.6	14.0	3.36	.75
13.1	18.5	13.0	14.9	3.15	.70
20.6	20.3	18.0	19.6	1.42	.32
12.4	16.7	14.6	14.6	2.15	.48
23.3	21.6	25.3	23.4	1.85	.41
21.3	19.2	13.9	18.1	3.81	.85

Table 10

Tester 2 Internal Rotation (kg)

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
22.8	17.6	20.8	20.4	2.62	.59
16.2	14.5	15.5	15.4	.85	.19
12.1	12.0	13.0	12.4	.55	.12
18.0	11.0	16.3	15.1	3.65	.82
17.5	26.5	21.1	21.7	4.53	1.01
16.8	14.5	17.2	16.2	1.46	.33
13.2	13.1	13.6	13.3	.26	.06
20.7	12.7	15.7	16.4	4.04	.90
21.1	10.8	10.7	14.2	5.98	1.34
16.9	18.4	16.8	17.4	.89	.20
9.9	9.4	10.0	9.8	.32	.07
14.6	16.3	21.3	17.4	3.48	.78
13.6	15.1	10.8	13.3	2.18	.49
10.6	11.6	9.8	10.7	.90	.20
21.3	22.1	18.1	20.5	2.12	.47
13.2	12.1	16.8	14.0	2.46	.55
17.3	21.3	19.9	19.5	2.03	.45
19.2	17.1	19.9	18.7	1.46	.33
23.9	24.7	20.5	23.0	2.23	.50
15.0	19.7	17.4	17.4	2.35	.52

Table 11

Tester 1 Hip Abduction (kg)

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
21.0	21.5	21.3	21.3	.25	.05
14.0	15	17.4	15.5	1.75	.39
11.0	19.6	21.1	17.2	5.45	1.21
17.3	16.5	14.7	16.2	1.33	.30
15.4	18.7	20.5	18.2	2.59	.58
14.4	14.0	13.1	13.8	.67	.15
20.7	22.2	22.3	21.7	.90	.20
15.6	18.9	18.4	17.6	1.78	.40
16.3	18.7	17.0	17.3	1.23	.26
14.0	13.5	11.5	13.0	1.32	.30

14.9	15.0	14.9	14.9	.06	.01
18.6	18.4	19.7	18.9	.7	.16
15.6	11.5	12.8	13.3	2.10	.47
12.8	10.6	14.2	12.5	1.81	.41
21.0	20.6	20.4	20.7	.31	.07
14.6	13.9	14.3	14.3	.35	.08
14.6	14.6	15.8	15.0	.69	.15
19.2	19.1	20.3	19.5	.67	.15
25.6	25.2	24.0	24.9	.83	.19
19.4	16.8	18.0	18.1	1.30	.30

Table 12

Tester 2 Hip Abduction (kg

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
17.8	18.2	19.4	18.5	.83	.19
16.9	18.4	18.9	18.1	1.04	.23
20.9	22.8	20.2	21.3	1.34	.30
14.3	9.8	10.0	11.4	2.54	.57
17.7	18.9	17.9	18.2	.64	.14
12.5	14.5	15.6	14.2	1.57	.35
23.4	21.3	20.6	21.8	1.46	.33
17.3	17.3	18.0	17.6	.40	.09
16.2	16.6	17.3	16.7	.56	.12
21.2	19.7	19.8	20.2	.84	.19
16.7	15.8	15.8	16.1	.52	.12
21.9	23.7	21.8	22.5	1.10	.24
11.7	12.4	12.9	12.3	.60	.14
8.4	9.6	11.0	9.6	1.30	.30
15.5	18.9	18.9	17.8	1.96	.44
15.0	15.0	14.9	15.0	.06	.01
18.9	17.2	18.5	18.2	.90	.20
18.0	18.7	18.1	18.3	.40	.08
21.2	21.5	21.1	21.3	.21	.05
18.1	17.1	17.0	17.4	.61	.14

Table 13

Tester 1 Hip Extension (kg)

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
22.9	32.9	22.5	26.1	5.90	1.32
20.2	21.3	20.2	20.6	.64	.14
12.4	11.3	9.1	10.9	1.68	.38
22.9	19.2	22.0	21.4	1.93	.43
24.8	21.2	21.3	22.4	2.05	.46
18.0	19.1	19.8	19.0	.91	.20
22.8	22.2	24.3	23.1	1.08	.24
26.8	28.0	25.7	26.8	1.15	.26
25.1	25.0	26.0	25.4	.55	.12
23.0	23.2	27.7	24.6	2.66	.59
15.5	15.3	16.9	15.9	.87	.19
35.7	32.3	31.2	33.1	2.35	.52
15.4	19.3	16.8	17.2	1.98	.44
14.7	18.1	12.2	15.0	2.96	.66
15.5	18.9	18.9	17.8	1.96	.44
17.2	19.4	17.2	17.9	1.27	.28
23.8	26.2	31.8	27.3	4.12	.92
29.9	35.0	33.6	32.8	2.64	.59
24.6	29.3	26.8	26.9	2.35	.53
24.3	21.8	21.0	22.4	1.72	.38

Table 14

Tester 2 Hip Extension (kg)

Trial 1	Trial 2	Trial 3	Mean	SD	SEM
25.5	23.4	24.3	24.4	1.05	.24
20.4	22.9	19.3	20.9	1.84	.41
13.2	13.0	13.2	13.1	.12	.026
15.8	19.9	21.7	19.1	3.02	.68
21.1	19.9	23.0	21.3	1.56	.35
16.9	16.9	19.6	17.8	1.56	.35
21.1	20.0	19.3	20.1	.91	.20
22.7	24.0	21.0	22.6	1.50	.34
18.1	22.6	23.0	21.2	2.72	.61
22.5	22.7	22.5	22.6	.12	.03

16.8	16.1	16.8	16.6	.40	.09
26.7	31.8	29.0	29.2	2.55	.57
19.4	18.2	17.4	18.3	1.01	.23
19.5	14.8	13.1	15.8	3.32	.74
23.2	20.5	20.7	21.4	1.50	.34
19.6	20.3	19.4	19.7	.47	.11
24.6	22.8	24.7	24.0	1.07	.24
21.1	20.6	21.0	20.9	.26	.06
24.8	24.3	24.3	24.5	.28	.06
20.1	19.6	18.6	19.4	.76	.17