A Feasibility Study to Test the Potential Efficacy of a Rowing-Related Yoga Program on Male Varsity Competitive Rowers

by

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BSc., University of Guelph, 2015

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In the School of Exercise Science, Physical & Health Education

Supervisory Committee

Effects of a Yoga Programme on Hip Muscle Strength and Hip Flexion Range of Motion in Male Varsity Rowers

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Abstract

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The purpose of this present study was to assess the feasibility and determine the potential short-term efficacy of implementing a specific 9-week "Yoga for Rowers" (ROWGA) program on male varsity rowers during a competitive training season. Sixteen competitive male varsity rowers (20.6 ± 2.1 years) were recruited to participate, using a single group, pre-test-post-test, quasi-experimental research design. All participants performed two 60 min ROWGA sessions per week for 9 weeks during their fall competitive season. The primary objectives were to test the efficacy of a ROWGA program in a real-world context by evaluating: 1) the feasibility of implementing the program during the training and competitive season as measured by program adherence; 2) its potential effect on strength by evaluating hip muscle strength acting in the sagittal, frontal, and transverse planes as well as on hip muscle strength ratios between the agonist versus antagonist muscle groups; and 3) its potential effect on hip flexion range of motion (ROM). Two pre-test baseline measurements were performed on all participants over 1-week prior to initiating the ROWGA sessions while a single post-test was conducted following the ROWGA intervention. Intraclass correlation coefficients for ROM and strength were used to determine reliability of measurements by taking the two pre-intervention test scores. Outcome measures included hip flexion range of motion, peak isometric hip muscle forces normalized to body weight, including hip flexors, extensors, abductors, adductors, both internal and external rotators as well as peak isometric agonist-antagonist hip muscle strength ratios. Pre and post peak isometric hip strength measurements were calculated for agonist-antagonist muscle groups within each plane by dividing flexors by extensors, adductors by abductors, and internal by external rotators. Feasibility of the ROWGA program was determined from program attendance and adherence rates.

The adherence rate was considered high with 89% attending all sessions, after adjusting for compulsory competitions. Significant improvements in peak isometric strength were demonstrated for hip flexors, extensors, abductors, and adductors, and external rotators, while a significant reduction for hip flexion ROM was observed. No significant changes in isometric hip muscle strength agonist-antagonist ratios were demonstrated. The results from this research support the feasibility of the ROWGA program in terms of rower's acceptance, adherence, and the ability to accommodate the time requirements within their schedule as well as potential strength benefits gained. This research could help provide a platform for future large-scale research related to injury prevention in rowing.

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Acknowledgements

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1. Introduction

Rowing is regarded as one of the most physically and biomechanically strenuous endurance sports (Hosea & Hannafin, 2012; Thornton et al., 2016). It is a repetitive and technical sport, which delivers high amounts of force to the hip, pelvis, and lower back regions during the power stroke (Hosea & Hannafin, 2012; Rumball, Lebrun, Di Ciacca, & Orlando, 2005). Injury is one of the most common contributors to changing a rower's technique (O'Sullivan et al., 2003). The most common areas of injuries in rowing include the lower back and pelvic region accounting for 15-25% of reported injuries (Hosea & Hannafin, 2012; Rumball et al., 2005).

Due to the high volume, high-intensity, repetitive sagittal plane training sessions typical of this sport, it is not surprising that an estimated 73.8% of rowing-related injuries are due to muscular overuse, according to an epidemiological study that examined injuries in elite-level junior rowers (Smoljanovic et al., 2009). Although the exact underlying cause of hip and lower back injuries remain unknown, research has demonstrated that rowers who experience injury exhibit muscular imbalances (e.g. external/internal hip rotators, gluteus maximus/medius) (Riganas, Vrabas, Papaevangelou, & Mandroukas, 2010; Rumball et al., 2005), hip muscle weakness (e.g hip abductors,) (Nadler, Malanga, Stitik, Feinburg,/ & Deprince, 2000), tightness of pelvic muscles including hamstring muscles (Nadler et al., 2002; Riganas et al., 2010), a reduction in passive hip flexion range of motion (ROM) (Gajdosik, Albert, & Mitman, 1994), and altered pelvic tilt (McGregor, Anderton, & Gedroyc, 2002) compared to asymptomatic rowers. Rumball et al. (2005) reviewed and summarized how rowing related injuries to the hips and lower back are predominantly related to muscle overuse, alterations in rowing technique, muscular compensations, or the volume of training. They suggested that these factors create issues such as low hamstring to quadriceps strength ratios at the knee, left and right limb strength asymmetries, and hip muscular strength imbalances (Rumball et al., 2005), all of which predispose rowers to injury. Factors such as muscular strength imbalances and altered ROM can, in turn, contribute to a host of musculoskeletal overuse injuries including femoral-acetabular impingement (FAI) (Boykin et al., 2013), patellofemoral pain syndrome (Perrin, 2010), iliotibial (IT) band friction syndrome (Hosea & Hannafin, 2012), lower back muscle strain and disc herniation (Thornton et al., 2016). For example, tight hamstring muscles could prevent the appropriate hip flexion needed to achieve proper pelvic position during the catch position, which could result in inappropriate movement compensations that lead to injury (Thornton et al., 2016).

Isometric hip strength ratios between agonist and antagonist muscle groups within a movement plane have been used to evaluate muscular strength imbalances and weaknesses (Diamond et al., 2016). While sculling or sweeping, the rower moves from lumbar spine and hip flexion into extension (i.e. catch to power phase) to propel the boat through the water. During this, the strength of agonist and antagonist muscle groups acting within the same plane may become imbalanced, leading to restrictions in particular ranges of joint motion (Holt, Bull, & Cashman, 2003; Rumball et al., 2005). During the highly compressive catch position, leading into the drive phase, there is a large amount of potential energy stored in the legs, back, pelvis, and arms (Hosea & Hannafin, 2012). This may consequently lead to an increased risk of injury in the lumbo-pelvic region due the very repetitive movement, especially during training. Alvarenga, Kiyomoto, Martinez, Polesello, & Alves (2019) reported isometric hip muscle force ratios for non-rower females between the ages of 20-29 years old. All participants performed bilateral contractions about the hip. Peak isokinetic hip muscle strength values were measured with an isometric dynamometer expressed in kilograms, which were then converted to normalized values proportional to individual body weight expressed in percentages. The hip flexor muscles demonstrated an isometric muscle force of 38.54% of body weight versus a muscle force of 27.04% for the extensors, 16.89% for the adductors versus 16.85% for abductors, and 17.09% for the external rotators versus 23.82% for internal rotators. However, there is limited literature documenting agonist-antagonist isometric strength ratios specifically for the rowing athletic population.

During the repetitive transferring of power from the catch position (hip and lumbar spine flexion) to the power transition phase (hip and lumber spine extension), rowing training may result in preferentially strengthened posterior chain muscles contracting during the power stroke including hip and knee extension (Thornton et al., 2016). Therefore, specific muscle strengthening training routines, typical of many competitive rowing programs, may directly lead to muscular strength imbalances and weaknesses, in turn hindering rowing performance, negatively impacting technique, and increasing the risk of injury (Stutchfield & Coleman, 2006).

The repetitive nature of rowing delivers repeated high compressive forces and extreme ranges of motion at the joints of the lumbo-pelvic hip complex (Rumball et al., 2005). If a reduced range of motion exists in a joint, it is often compensated by over-extending the range at another joint, which can in turn lead to injury. For example, reduced hip flexion ROM may lead to compensatory repetitive hyper-flexion of the lumbar spine and lumbo-pelvic junction when moving through the catch position into the driving phase, which can result in low back injury in rowers (McGregor et al., 2002; Smoljanovic et al., 2009).

It has been posited that the high forces and repetitive motions combined with high-volume and high-intensity training can lead to muscle hypertrophy of specific muscles (Mersmann, Bohm,

& Arampatzis, 2017). Specifically, in rowing, which involves strengthening of the posterior chain muscles, it has been noted that rowers have reduced gluteus maximus and hamstring length contributing to a loss in hip flexion ROM (McGregor et al., 2002; Parkin, Nowicky, Rutherford, & McGregor, 2001). This reduced muscle length is a common symptom in rowers and has been suggested to contribute to lower back and hip pain (Perrin, 2010; Thornton et al., 2016). Since it is hypothesized that excessive flexion in the lumbar spine may lead to hip and lower back injuries in rowing (McGregor et al., 2002; Wilson, Gissane, Gormley, & Simms, 2013), it is important to consider related muscular dysfunctions (e.g. muscle tightness, imbalances, and weakness) in relation to kinematic dysfunctions of hip, pelvis, and lumbar spine joints in high performance rowers. When a muscle is stretched to its maximum length in a functional movement or stretching protocol, fascia is also stretched and stressed (Findley, 2011). This maximally stretched position of the muscles and associated soft tissues may occur in rowers during the catch position as they reach the end range of hip flexion. Rumball et al. (2005) hypothesized that the hyperflexion and twisting forces in the catch position may put the rowers at a greater risk of injury in this position. Therefore, having full ROM at all relevant joints in the lumber-pelvic hip complex (LPH) afforded by optimal muscle length may reduce the risk of injury.

Rowing training typically focuses on improving specific rowing performance techniques, such as ergometer and on-water rowing practices (Wilson, Gissane, & Mcgregor, 2014), while strength and conditioning training focuses on functional strengthening exercises that target improving movements mainly associated with the sport technique (Gee, Olsen, Berger, Golby, & Thompson, 2011). These practices are beneficial for improving rowing performance, strength, speed, and power (Aaberg, 2002), but often do not focus on flexibility or muscular balance around joints necessary for injury prevention. The existing literature regarding sport-related hip and lower back injuries recommends various forms of strength and mobility enhancement exercises in training regimes (Page, 2012).

As reviewed by Adling and Bangar (2017), yoga practices have been incorporated by some sports to compliment traditional training programs in athletic populations. Iyengar yoga is a form of therapeutic yoga that incorporates slow and controlled multi-planar isometric postures (asanas), where specific supporting muscles are isometrically activated to augment the anatomical alignment of an individual's kinetic chains, muscular strength, ROM, and neuromuscular recruitment patterns (Amin & Goodman, 2014; Polsgrove, Eggleston, & Lockyer, 2016). This in turn can maintain or improve the protective benefit of muscular balance between agonist and antagonist muscle groups, and optimal ROM around the hips and pelvic region (Diamond et al., 2016).

Yoga incorporates physiological mechanisms that are involved with mitigating muscular strength and ROM imbalances (Polsgrove et al., 2016) such as proprioceptive neuromuscular facilitation (Hindle, Whitcomb, Briggs & Hong, 2012). While yoga focuses on the lengthening and strengthening muscles, it is also known to provide tension release to surrounding structures of the joint capsule such as fascia (Page, 2012). Myofascial release has been suggested to improve short-term ROM and neuromuscular efficiency (Avrahami & Potvin, 2014). With the proprioceptive neuromuscular facilitation stretches and subsequent reduction in muscle tension, this can improve ROM surrounding the joint (Avrahami & Potvin, 2014). Through the practice of yoga, the combined benefits of neuromuscular activation (Funk et al., 2003), muscle tension reduction, and the lengthening of surrounding connective tissue (Polsgrove et al., 2016), may translate to improved athletic performance (Ross & Thomas, 2010). Therefore, yoga can be used to supplement traditional training to assist in maintaining the muscle balance between agonist and antagonist muscle groups for strength and optimal ROM.

Yoga classes have been successfully implemented into competitive training programs by coaches and physiotherapists for injury prevention, sport performance optimization, neuromuscular efficiency, and improved joint mobility and strength (Polsgrove et al., 2016). Although the therapeutic application of Iyengar yoga is currently offered in Iyengar Yoga Centres, there has been no published scientific-related evaluation of this form of intervention with athletic populations. As described above, rowing exhibits risk of injury around the hip joint and lower back region. Therefore, a specifically curated “Yoga for Rowers” (ROWGA) program could help protect against these injuries by mitigating hip muscular strength imbalances and maintaining adequate hip flexion ROM for proper pelvic stabilization. To date, no studies have examined the feasibility of the potential efficacy of a ROWGA program with male varsity competitive rowers during their training and competitive season. The acceptability of yoga by young male varsity rowers as a complementary training regime, as well as the ability to accommodate the time commitments of the ROWGA program within the athlete’s time constraints, have not been explored in the literature. Further, the potential impact of a specifically curated yoga intervention on hip muscle strength or hip flexion ROM in male varsity rowers during their training and competitive season has not been tested.

1.1 Purpose

The purpose of this feasibility study was to determine the potential efficacy of implementing a specific 9-week “Yoga for Rowers” (ROWGA) program on male varsity competitive rowers during a training season.

1.2 Research Questions

1) Is the 9-week ROWGA program feasible to implement in a real-world setting as evaluated by:

a) the adherence to the program by the male varsity rowers and their ability to accommodate the time commitment associated with adhering to the program?

b) the effect on strength of the hip muscles which act in either the sagittal (flexors, extensors), frontal (adductors, abductors) and transverse (internal rotators and external rotators) planes?

c) the effect on hip muscle strength for the following agonist-antagonist muscle groups:

- flexors versus extensors?
- abductors versus adductors?
- internal rotators versus external rotators?

d) the effect on hip flexion range of motion?

1.3 Hypotheses (H_0)

The following null hypotheses were tested:

H_0: Following the 9-week program, ROWGA is not a feasible program to implement in a real-world setting considering:

a) low acceptance of the program by the male varsity competitive rowers and poor ability to accommodate the program time commitment.

b) no significant improvements in the outcome measures used to assess peak isometric hip muscle strength.

c) significant differences in the outcome measures used to compare peak isometric hip muscle strength for the agonist-antagonist muscle group ratios.

d) no significant improvements in the outcome measures used to assess hip flexion range of motion.

1.4 Delimitations

The study was delimited to competitive, male varsity rowers, between the ages of 18-28 years. The participants had no current hip or lower back injuries at the time of recruitment or testing. Participants were able to complete all parts of the ROWGA sequence.

1.5 Assumptions

The participants disclosed any injuries experienced throughout the study, including those in the lower back, hip, or hamstring regions. The participants performed to their best ability with each test. Testing protocols were followed precisely as directed.

1.6 Operational Definitions

Passive Range of motion (ROM) is the angular movement at a joint in a specific direction with an added, external assistance.

Maximal muscle strength is the maximum force produced by a skeletal muscle during a single contraction.

Peak isometric muscle strength is the maximum force produced by a skeletal muscle contraction that is not associated with any displacement or movement at a joint. It is used to measure strength of the muscle.

Hand-held goniometer is a device used for measuring hip range of motion (in degrees).

Hand-held force gauge is a device used to test peak isometric muscular force (in Newtons).

Varsity Athlete: is a student-athlete who competes for their university's most competitive team in their respective sport.

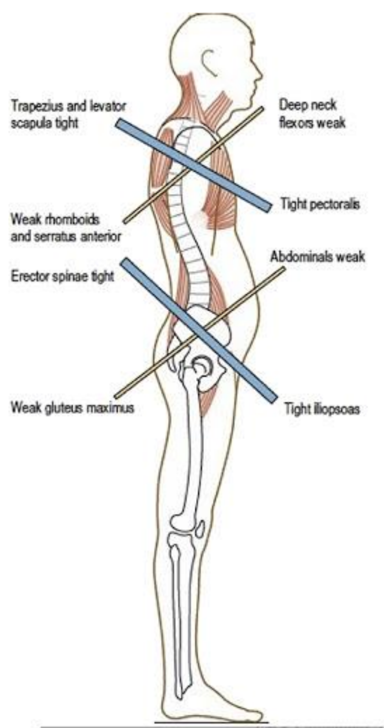
2. Review of Literature

2.1 Introduction

Rowing is considered a physically strenuous and precise sport that focuses on technique, and high-intensity, high-volume practices (Buckeridge, Bull, & McGregor, 2014). The majority of rowing-related injuries are largely due to overuse injuries (Perera & Ariyasinghe, 2016), sudden changes in training volume, compensatory changes to the rowing technique, or the side of the boat the rower rows on (Hosea & Hannafin 2012). In many cases, the decreased range of motion (ROM) asymmetries and strength imbalances around the hip joint, often seen in rowers, contributes to stress in the lumbar spine and pelvis (Buckeridge et al., 2014; Rumball et al., 2005). Certain injuries and conditions have been proposed to affect rowers such as femoral acetabular impingement (FAI), snapping hip syndrome (Cheatham, Chain, & Earnest, 2015), labral tears (Boykin et al., 2013) and iliotibial band (ITB) friction syndrome affecting the hip and knee due to constant movements involving flexion and extension (Hosea & Hannafin, 2012). Hip and trunk stabilization programs focus on improving the strength and stability of these regions by addressing improper muscle activation movement patterns (Fenwick, Brown, & McGill, 2009; Hoglund, Pontiggia, & Kelly, 2018). Since the body works as an entity, when specific areas of the body become inefficient or stiff with movements due to overuse or fatigue, the body finds an alternative movement pattern by using another muscle group or joint known as compensatory action, as summarized by Rumball et al. (2005). Injuries to the hip, pelvis, and lower back with rowers has been proposed to be linked to hip ROM asymmetries (Buckeridge et al., 2014), an imbalance between agonist and antagonist muscle groups (Rumball et al., 2005), and a tightness in posterior chain driven muscles such as the hamstrings and gluteal muscles, which consequently affect hip flexion ROM (Rumball et al., 2005). Tight or overactive hip flexors during the rowing stroke results in the pelvis rotating and tilting anteriorly as a compensatory action to the hyperextension in the lumbo-pelvic kinematics, consequently resulting in hip asymmetries (see Figure 2.1) (Buckeridge et al., 2014). Existing research regarding hip and lower back injuries from sports recommend various forms of strength and mobility enhancement exercises to supplement training regimes (Page, 2012; Riganas et al., 2010). It is therefore possible that the inclusion of an Iyengar therapeutic yoga program could help enhance hip and pelvic function by protecting against technique compensations of gluteal muscle tightness leading to lack of proper hip flexion ROM and muscular imbalances commonly seen in rowers.

Figure 2.1.

Schematic diagram of anterior pelvic tilt in an individual experiencing lumbo-pelvic hip complex dysfunction often associated with hip and lower back pain. (Wharton, 2017).



2.2 Feasibility Studies

Feasibility and pilot studies are an innovative approach to test whether a primary study is suitable for further research in preparation for future large-scale randomised control trials (RCT) or observational studies, while marking key problems of design uncertainty (Eldridge et al., 2016). Such studies are conducted to (i) test the efficacy and robustness of the study protocol for future application, providing validity in randomization, (ii) to obtain primary estimated sample size calculation for data collection, (iii) to test data collection and estimate rates of recruitment, consent, and adherence, (iv) to determine the acceptability of the intervention, and (v) to establish the post applicable primary outcome measurement(s) (Blatch-Jones, Pek, Kirkpatrick & Ashton-Key, 2018; Bowen, Kreuter, Spring, Cofta-Woerpel, Linnan, & Weiner, 2009; Eldridge et al., 2016). The purpose of feasibility studies is to evaluate if a specific intervention or program framework can be done effectively in preparation for an RCT, and if so, how (Eldridge et al., 2016). Pilot studies are considered a subset of feasibility studies, where the same questions are asked, but are conducted on a smaller scale for a future study. This style of research is more rigorously applied in the field of public health, health promotion, and disease prevention research with the goal of implementing and evaluating the efficacy of evidence-based interventions and larger-scaled RCTs for future studies within the field (Bowen et al., 2009). The primary purpose of conducting a feasibility study in the public health sector is to assess the prospective success of implementing an intervention and increase validity of future studies (Tickle-Degnen, 2013). Conducting an intervention in a feasibility study includes a program, service, policy, or product intended to influence a population's social, environmental, or organizational conditions, as well as their choice, attitudes, beliefs, and behaviours (Blatch-Jones et al., 2018; Tickle-Degnen, 2013). Objectives for conducting feasibility studies are unlike definitive large-scale empirical studies and are clearly expressed so. This preliminary research step provides a platform for researchers to address the key issues of methodological design for interventions, uncertainty upon planning further research, and help estimate an initial estimated sample size for data collections in further research (Bowen et al., 2009).

Previously, many feasibility studies have gone unpublished, however it is argued that this work is critical for successful implementation of interventions and definitive trials in order to improve effectiveness and transparency of the findings. This ensures that all intervention procedures run efficaciously by including qualitative work to recognize real-world health professionals' perspectives (Eldridge et al., 2016). Implications around reporting levels of appropriateness from pilot and feasibility studies are arguably influenced by the lack of transparency and recognition from other traditional study prerequisites. However, as an emerging area of research, there is still some uncertainty on how and why these studies are appropriate to lead future research (Blatch-Jones et al., 2018). Though there are many advantages to conducting feasibility studies, an evident limitation is the proficiency of calculating an effective sample size or a response rate for a larger-scale study, because of the initial smaller sample sizes (Cope, 2015).

Piloting new innovative interventions for applications towards future definitive RCTs, observational studies or testing the feasibility of aspects emerging in the development of large-scale studies, assures that the methodological design approaches are robust, efficacious, and feasible to implement for future large-scale research (Blatch-Jones et al., 2018; Eldridge et al., 2016).

2.3 Introduction to Rowing

2.3.1 Phases of The Rowing Stroke

It is important to have an understanding of the fundamental intricacies of the sport technique before characterizing the mechanism of injuries. Rowing is a cyclic, precise movement and dependent on the technique for efficiency in driving the boat forward (Buckeridge et al., 2014). Rowing athletes begin the sculling cycle by facing the back of the boat (stern) with their feet anchored to a foot stretcher on the boat. There are two types of rowing, known as the sweep and scull movement. Sculling involves rowing with two oars, whereas sweepers row with one. Sweep rowers are then divided into the side of the boat on which they row. The port-side is on the right, and starboard is on the left, when facing the stern of the boat.

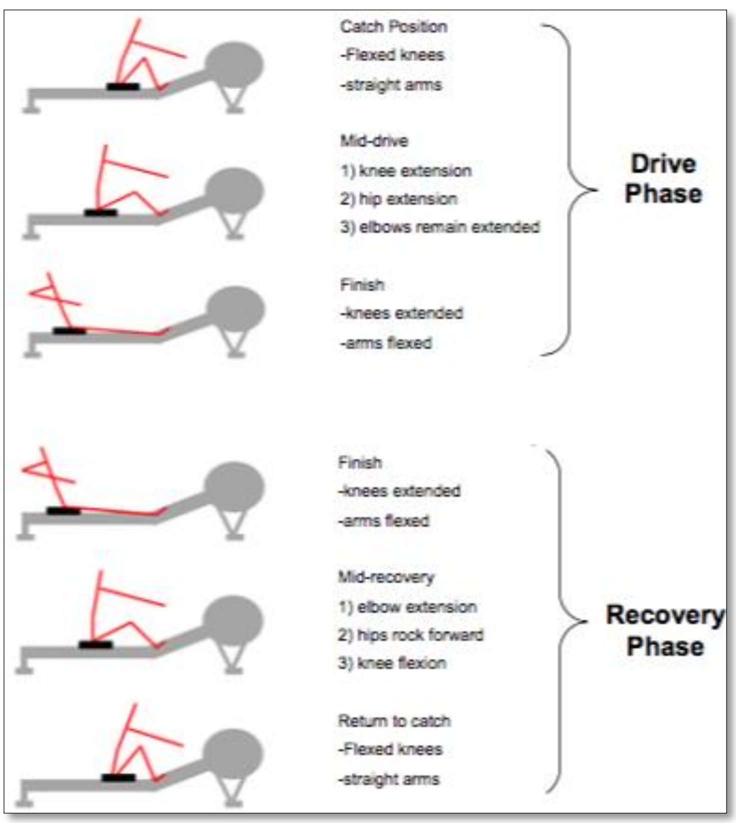
It is important to mention that there are three points of contact with the boat and the rower: 1) the hands and the oar; 2) the buttocks and the seat, and 3) the feet and the footrest strap (Rumball et al., 2005). The rowing stroke includes four phases: the catch, the drive, the finish or release, and the recovery (Figure 2.2). The catch phase is concluded with both knees, hips, and back extended, while the elbows are flexed close to the ribcage, and the hands are positioned on the oar at waist height. The recovery phase starts by extension of the elbows and hands away from the body while holding the oar, leading into forward flexion of the trunk and hips. The recovery phase positions the rower in the most powerful position of the catch. Once the hands pass the knees, hip and knee flexion begins leading into the catch position while the elbows are fully extended. Sweep rowing includes the oarsmen loading in the catch position where their back and torso are rotated and flexed.

2.3.2 Mechanism of Musculoskeletal Rowing-Related Injuries

During the catch position, there is a high amount of potential energy in the arms, legs, hips, and lower back, transferring to the driving stroke, which propels the boat forward accelerating the blade of the oar through the water (Hosea & Hannafin, 2012; Rumball et al., 2005). This specific moment and load are where the execution of the rowing stroke affects the efficiency of the energy exchange (Hannafin & Hosea, 2012; Thornton et al., 2016). The exchange of potential energy from the catch to the drive position is where consequences to the rowing performance arise if the technique is incorrect (Buckeridge et al., 2014). From the catch position, the legs continue to push the body away from the bow of the boat, while the arms, hips, and lower back remain in flexion (see Figure 2.2) (Buckeridge et al., 2014). Rectus femoris, and paraspinal muscles of the thoracolumbar region, the hamstring muscles, and the gluteus maximus are the major muscles providing the primary force during the driving phase of the rowing stroke as the knees and hips stabilize the pelvis.

Figure 2.2

Biomechanical breakdown of the drive and recovery phases during the rowing stroke (Buckeridge et al., 2014).



As reviewed by Rumball et al. (2005), the repetitive cyclical nature of the rowing stroke can often pose an excess amount of stress on particular muscle groups, bones, and joints. Fatigue related to high-volume, high-intensity training gives rise to overuse injuries related to muscular imbalances and improper muscle fibre contractile efficiency (Caldwell, McNair, & Williams, 2003; Karlson, 2000; Rumball et al., 2005). Rowing is a precise, technical sport that relies on proper alignment and efficient technique (Buckeridge et al., 2014). A lack of proper technique, or inappropriate compensatory movements, can result in an increase of injury, and improper training (Rumball et al., 2005). With a comprehensive understanding of rowing injury sequelae, current research helps address the chief risk factors, various forms of optimizing performance, and preventing injuries (Thornton et al., 2016). Common overuse injury patterns in rowing can also be caused by sudden movements, training volumes, as well as improper technique or an athlete's position in the boat (Hosea & Hannafin, 2012).

2.4 Anatomy of the Hip and Pelvis

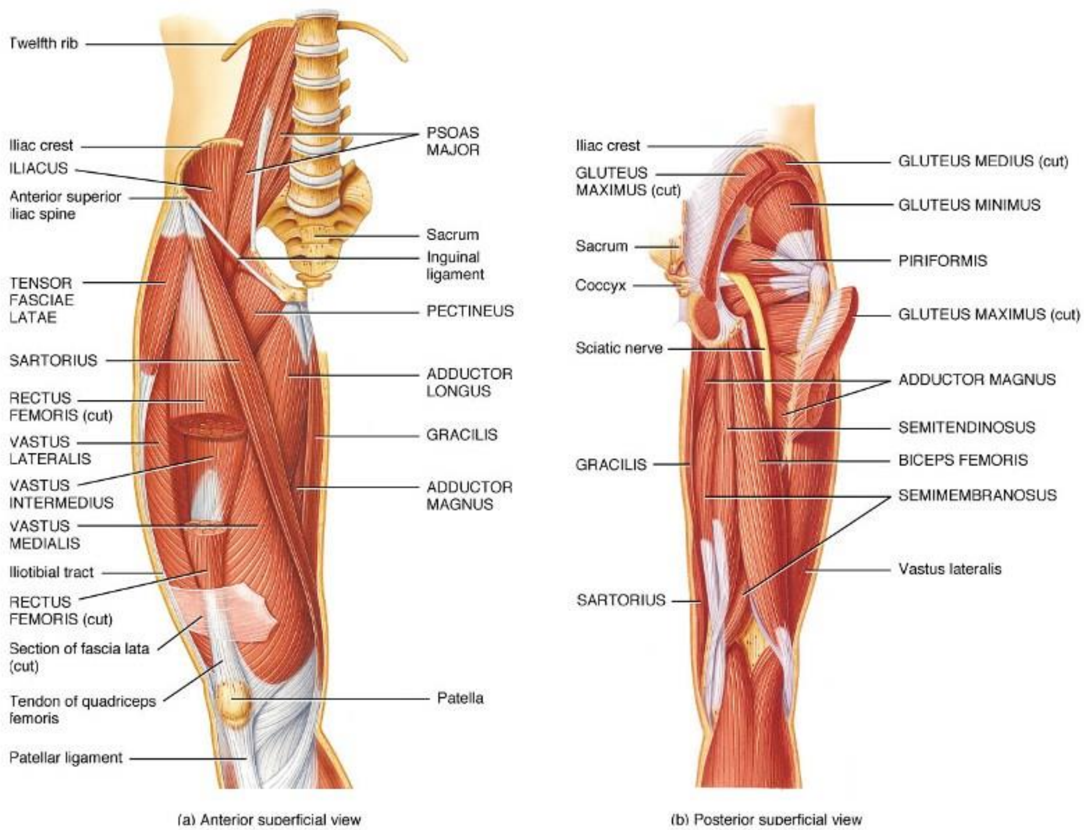
The hip is a joint permitting a great amount of strength and reasonable flexibility, which allows for weight bearing and broad ranges of motion (Tyler, Nicholas, Campbell & McHugh, 2001). The joint is situated where the head of the femur meets the socket of the pelvis (acetabulum), known as the ball-and-socket construction. There are three anatomical planes of action in which the hip allows for the femur to move: hip flexion and extension; abduction and adduction; and internal and external rotation. Fibrocartilage cartilage lines the boney surface of the acetabular labrum in the hip joint and the synovial fluid reduces friction during movement to protect the articulating surfaces (Molini, Precerutti, Gervasio, Draghi, & Bianchi, 2011). The muscles provide support surrounding joints, which secure bones to bones. The synovial membrane layer and fibrous layer encapsulate the entire joint providing lubrication (Page, 2012).

2.4.1 Muscles of the Hip Joint

The muscles surrounding the joint are comprised of the gluteal muscles (gluteus maximus, medius, and minimus), the external rotator muscles (quadratus femoris, gemellus inferior, obturator externus, gamellus superior, and piriformis), the adductor muscles (adductor brevis, longus, and magnus), the quadriceps muscles (rectus femoris, vastus intermedius, medialis, and lateralis), the hamstrings (adductor magnus, semimembranosus, biceps femoris, gracilis, and semitendinosus), and the tensor fascia latae, iliopsoas, and pectineus muscles (Figure 2.3). Altogether these muscles act to support the hip during daily movement and exercise (Hoglund et al., 2018).

Figure 2.3

Muscles of the hip joint and thigh. (Singh, 2020)



2.4.2 Hip Joint Range of Motion

Generally, the primary anatomical structures, which limit ROM originate from the articulating bones of the joint and the surrounding muscles (Page, 2012). This “ball-and-socket” type diarthrotic synovial joint permits good stability, however at the cost of a limited ROM (Molini et al., 2011). The capsuloligamentous tissues that may limit, or influence ROM include the iliofemoral, ischiofemoral, and pubofemoral ligaments. The proposed pathomechanism associated to hip microinstability or ROM limitations in sports originates with subtle anatomical abnormalities, weaknesses, and ligamentous laxity during the repetitive hip joint movement and axial loading (Kalisvaart & Safran, 2015). This etiology of symptomatic hip microinstability and limitations in ROM are identified as a possible cause of pain and injury in athletes (Kalisvaart & Safran, 2015). Passive or active tension in the hip musculature can influence joint flexibility. Passive tension is dependent on the surrounding structures of the muscles such as surrounding fascia, which also provide the viscoelastic properties to the muscle (Page, 2012). Active tension results from the dynamic muscular contraction and neuro-reflex properties from the peripheral alpha motor neuron and reflexive gamma motor neuron activation (Page, 2012). There are many factors contributing to reduced joint ROM, as described above, where only one of which is due to muscular tightness. Muscle tightness results from active or passive tension mechanisms or responses. Muscles can become shortened passively from postural adaptations or scarring, whereas active muscles can become shorter due to contractions. Despite the originating cause of muscular tightness, limitations to ROM in a joint may cause or lead to muscular imbalances (Page, 2012).

2.4.3 The Lumbo-Pelvic Hip Complex

The hip joint is part of the lumbo-pelvic hip complex (LPH), which is composed of the lumbar spine, pelvis, and hip musculoskeletal structure (Wilson et al., 2014). This complex, also known as “the core” connects the axial skeleton with the lower limb and acts as an area of force transmissions generated from the spine or lower limb. As a linking structure, it is of importance that the LPH complex remains stable for the kinetic chain to move optimally (Hoglund et al., 2018). In sports, including rowing, the movements involve transferring of forces and strength from one segment to another in the kinetic chain model (Sciascia & Cromwell, 2012). If there is muscular weakness or limits in ROM within this complex, this may cause other areas to overcompensate, which can result in injury. If there is a lack of postural control in sport technique of an athlete, this may lead to an insufficient transfer of energy to other limbs required to perform effectively, which makes the athletes more susceptible to injuries due to compensatory movements within the kinetic chain to support the lack of force production (Oliver, Dwelly, Sarantis, Helmer, & Bonacci, 2010). One study examined the lumbopelvic kinematics during ergometer rowing in 17 male adolescent rowers (Weerts, Bashkuev, Pan, & Schmidt, 2019). The authors suggested an unfavourable association to a restricted pelvic ROM, which may then lead to hyperflexion in the lumbar spine during the rowing stroke. This compensatory action may consequently lead to lower back pain. For this reason, it is important to maintain a stable pelvis to prevent the development of muscular asymmetries and imbalances in the LPH complex (Buckeridge et al., 2014).

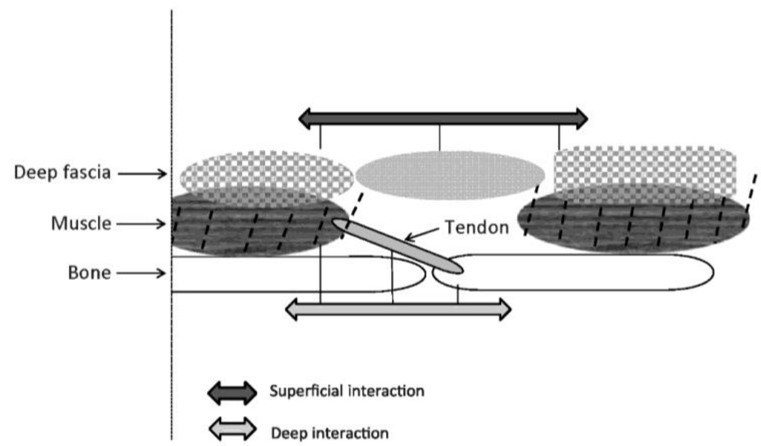
2.4.4 The Role of Fasciae

The deep and superficial fasciae around the hip, pelvis, and thigh muscles are structures worth noting when considering hip and pelvis movements. The term fascia describes a sheet or band of fibrous soft and dense connective tissue, primarily collagen, beneath the skin and around the muscles (Zügel, Maganaris, Wilke, Jurkat-Rott, Klingler, & Wearing, 2018). It predominantly supports the spine and transfer loads between the spine, pelvis, legs and arms (Mitchell, Bressel, McNair, & Bressel, 2008). Superficial facia is a sheet of tissues which attaches to the dermis and supports movement of the skin (Gerlach & Lierse, 1990). All fasciae are connected from superficial to deep tissue surrounding the fibres through to the epimysium. They are an integrated network and system providing multiple functions such as structure, protection, repair, force transmission, and body sense (Kumka & Bonar, 2012; Purslow, 2002). Fascia is a connected soft tissue scaffolding that provides movement, a connection of variable tissue structures, and systems of the body such as musculoskeletal, vasculature, neurological, visceral, and lymph (Kumka & Bonar, 2012).

It has been argued that a potential factor which limits muscles from lengthening during movements is the connective tissue fascia, as reviewed by Zügel et al. (2018). When the muscle elongates, the surrounding tissues become taut. Such limitations can decrease flexibility, strength, endurance, and coordination, which leads to potential risk of injury, as reviewed by Schroeder and Best (2015). Injury to the fascial system causes the tissue to become densely packed and bind to the muscles, hindering the functions of both strength and flexibility (Zügel et al., 2018). Modifications in the mechanical interactions at the superficial level surrounding the muscle fibres are based on fibre continuity of two myofasciae. The mechanical properties (i.e. altered stiffness) might therefore restrict muscular extensibility and, with this, ROM (Wilke, Macchi, De Caro & Stecco, 2018) (see Figure 2.4). Therefore, when stiffness, decreased flexibility and weakness occur, the muscle is unable to lengthen or shorten (Page, 2012). This limitation can cause a significant loss of athletic performance in competitive sports such as rowing, leading to changes of kinematic rowing techniques associated with musculoskeletal fatigue, changes in muscle activation, and decreased ROM in the lower back and pelvis (Trompeter et al., 2019). A systematic review critically assessed current evidence on the impact of fascial relaxation and self-myofascial release using foam rolling as well as specific stretching techniques that target ROM (Cheatham, Kolber, Cain, & Lee, 2015). The results of their analysis suggested an increase in flexibility, including hip ROM, after fascial release, relaxation, and targeted stretching techniques. The authors suggested this form of fascial release, combined with a static stretching technique, may be efficacious for the enhancement of joint ROM in sport performance (Cheatham et al., 2015).

Figure 2.4

Simplified illustration of the mechanical interactions that may limit joint ROM: mechanical interactions at the superficial level are based on fibre continuity of two myofasciae, while deep interactions indicate the myotendinous link between two articulating bones (Wilke, Macchi, De Caro & Stecco, 2018).



2.5 Mechanism of Common Rowing-Related Injuries

Asymmetrical activity and repetition in sweep rowing may lead to the development of muscular imbalances and strength deficiencies in the LPH complex increasing the chance of injuries (Buckeridge et al., 2014, Hodges & Richardson, 1996). Van Dillen, Maluf, & Sahrmann (2009) suggested differences in hip and lumbopelvic rotational movement patterns may affect the development of various contributing factors to lower back pain. Wilson et al. (2014) proposed the worsening of the rowing technique due to fatigue or volume of training demands, which can lead to additional risk for injury or re-occurring injuries. Due to repetitive movements during the drive and catch phases, the high-power output from the hamstrings, gluteus maximus, and lumbar muscles can lead to stress, compensatory kinematics, and common rowing-related injuries. College rowing athletes who develop hip and back injuries due to stress and overuse have a greater chance of reoccurring episodes throughout their life (Karlson, 2000). Hip and lower back injuries in rowing arising from repetitive movements in one anatomical plane originate from muscular strength asymmetries. According to Buckeridge, Bull, and McGregor (2014), it is expected that strength hip asymmetries affect a the lumbopelvic kinematics during the rowing stroke due to the insertion and origin points of the iliopsoas flexor muscle group that crosses the hips and lumbar spine. Therefore, tight or hyperactivation of these hip flexors will cause the pelvis to tilt anteriorly. In this study, the authors also found hip asymmetries to influence lumbo-pelvic flexion in the rowing participants (Buckeridge et al., 2014). These changes in musculature, whether in strength, active, or passive tension, have demonstrated a hindrance to performance and an increased risk of lumbopelvic hip injuries.

Imbalances between agonist and antagonist muscle groups due to the overuse of certain muscle groups are regarded as a primary factor that affects the risk of pain and injury in rowing (Nadler et al., 2002; Riganas at al., 2010). This can be attributed to the high training volume, technique modification, and movement compensations. These imbalances not only result in lessened movement efficiencies but lead to common short or long-term injuries in the lumbar and pelvic regions (Hosea & Hannafin, 2012). A review conducted by Rumball et al., (2005) believed that the increased risk of lower back and pelvic pain in rowers can be attributed to poor flexibility, strength deficiencies, and muscular imbalances. They concluded that if an athlete is unable to move into a specific phase of the stroke, their technique is modified due to tightened muscles, and therefore other muscle groups will need to compensate causing muscular strength imbalances, leading to increased risk of injury or pain. For example, if a rower exhibits tight hamstrings from a constant pulling action of the oar and hyperextension of the lumbar spine, the shortened muscles will prevent the necessary hip flexion ROM to occur for the rower moving into the catch position. Compensatory actions may then arise in the form of muscular imbalances, lower back or hip pain (Rumball et al., 2005).

Lower back and hip pain caused by compensatory rotation of the pelvis is also a common symptom in rowers due to tightness and poor hamstring strength relative to their quadriceps and gluteal muscles pulling on the pelvis (Buckeridge et al., 2014). According to a study by Page (2012), in terms of stretching, muscle tension is generally inversely related to muscle length, while oppositely, increased muscular tension is related to a decrease in muscle length. Without proper muscular length due to training regimes and performance techniques, imbalances and compensations may arise around the joint (Page, 2012; Rumball et al., 2005). These movement restrictions, postural asymmetries, and kinetic patterns with the lumbar spine and pelvis cause stress on the soft tissues of the lower back (Hannafin & Hosea, 2012).

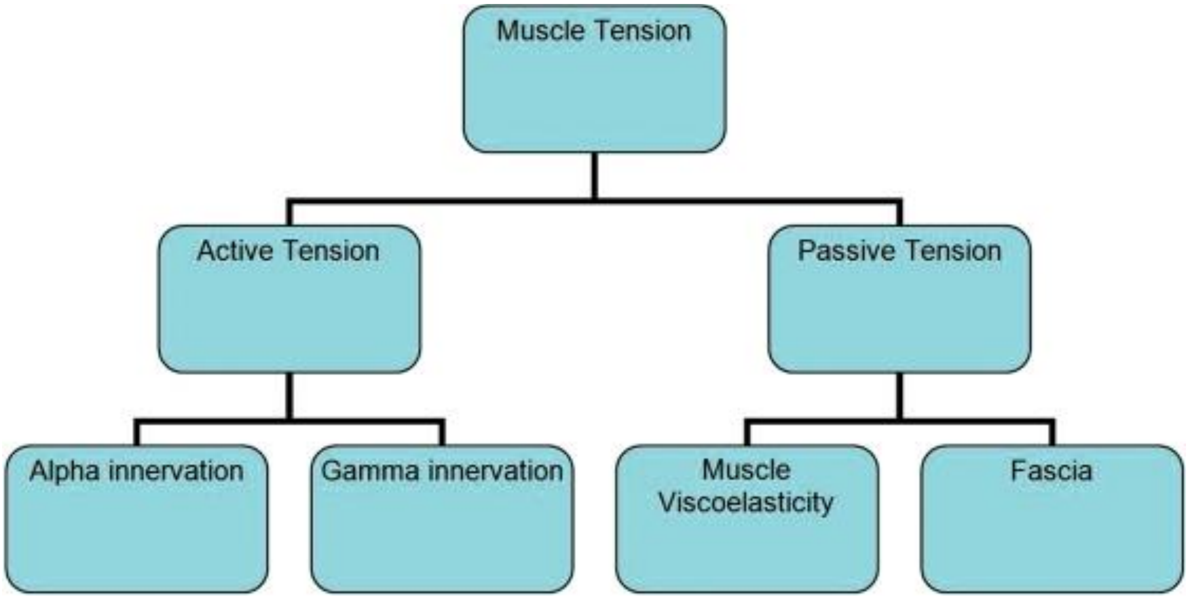
Passive ROM is the magnitude of angular movement at a joint in a specific direction with external assistance to produce the movement (Pratt & Ball, 2016). A restriction in joint passive ROM is associated to soft tissue and in particular muscular tightness (Page, 2012). Therefore, a lack of joint ROM in the lumbar and hip region due to tightness of hamstrings and gluteal muscles can contribute to an increase in stress, strain, and risk for injury (Reis & Macedo, 2015). Restricted hip rotation ROM can restrict the ability of pelvic and trunk rotation, thereby reducing the energy transmission through the kinetic chain (Robb et al., 2010).

One study assessed the clinical significance of prevention in lower back pain through measurements of hip ROM and hamstring extensibility (Reis & Macedo, 2015). The authors conducted a cross-sectional study to verify the relationship between risk of lower back and pelvic pain with hamstring length, anterior pelvic tilt, lumbar motion, and trunk flexion, during forward bending. Participants were divided into the lower back pain group (n=36) and asymptomatic group (n=32). Findings indicated that participants experiencing lower back pain have a restricted pelvic ROM, but greater amplitudes of lumber spine motion in comparison to asymptomatic individuals. Another study reported that a restricted ROM and extensibility of the hamstrings was highly correlated with low back injury (Halbertsma et al., 2001). However, both studies used forward folding to quantify this, which did not limit pelvic tilting as a form of compensation from the start position. Proper hip and pelvic ROM have a direct relationship on the force transmitted into the lumbar spine during the rowing stroke. Therefore, maintaining lumbo-pelvic alignment in rowers can reduce stress and higher amounts of force exerted on the spine (Thornton et al., 2017; Trompeter et al., 2019). After conducting a review, Wilson, Gissane, and McGregor, (2014) emphasized the importance of implementing training programs and addressing modifiable training components that focus on maintaining proper lumbar extension and hip ROM through flexibility, strength, and pelvic stability as an indicated prevention of back and hip injury.

ROM reflects joint movements that can be limited by soft tissues such as the capsule, fascia, ligaments and muscles (Page, 2012). Generally, ROM can be limited by two anatomical entities: joints and muscles. Joint restrictions and tightness can be affected by the capsuloligamentous structures surrounding the joint, or the muscular tension being active or passive (see Figure 2.5).

Figure 2.5

Variables affecting range of motion and muscle tension (Page, 2012)



2.6 An Introduction to Yoga

Yoga has been a lifestyle and practice for over 5000 years. In its full form, it unites physical postures (asanas), breathing exercises (pranayamas), meditation (chanda), and philosophy. The practice of yoga, as a branch of complimentary alternative medicine, has been shown to have numerous benefits to physical and mental performance, as well as overall well-being (Akhtar Yardi, & Akhtar, 2013; Tran, Holly, Lashbrook, & Amsterdam, 2001). Yoga has been demonstrated to enhance overall physical performance by improving walking and balance muscle strength (Beazley, Patel, Davis, Vinson, & Bolgla, 2017; Polsgrove et al., 2016), and health-related quality of life (HR-QOL) (Santana et al., 2013).

Hatha yoga is one of many forms of yoga practices, including Iyengar, that encompasses physical full body movements through *pranayamas* (breathing control techniques), *asanas* (physical postures and movements), and *chanda* (meditation and awareness techniques). A major benefit of the Hatha yoga practice is the focus on the equilibrium between flexibility and strength (Polsgrove et al., 2016; Prado, Raso, Scharlach, & Kasse, 2014). Iyengar yoga is a tier of Hatha yoga that emphasizes the importance of anatomical detail, precision, and alignment with each asana and pranayama, despite anthropometric differences of individuals. It is considered a therapeutic yoga that integrates strength, flexibility, stability, and proprioceptive awareness (Iyengar, 1998, p. 23).

Crow, Jeannot, and Trewhela (2015) systematically reviewed existing research of the Iyengar-style yoga method to assess the efficacy it provided on lower back and neck pain in symptomatic individuals. In their database research applying inclusion and exclusion criteria that selected only Iyengar yoga interventions, the authors found six randomized control trials assessing the effectiveness of yoga for back and neck pain compared to alternative forms of care. Findings demonstrated that the Iyengar yoga groups among studies had a significant and clinically notable reduction in muscular tightness and pain intensity (Crow et al., 2015). This was interpreted as evidence that yoga provides a dual effect of toning muscles, while stretching and releasing muscular tension. Transitions into and out of specific asanas or postures can also fall under the dual category of dynamic and active stretching. It was also recommended by Calder (2005) that following the training sessions, recovery practices maximize the prevention of residual muscular fatigue. This therapeutic practice can be applied to any muscle in the body. Athlete-based practices apply comparable sequences to alleviate muscular associated pain to re-establish flexibility, strength, balance, and muscle contractile efficiency (Polsgrove et al., 2016).

2.7 Yoga and Athletic Performance

The use of yoga has increased in athletic populations to enhance multiple facets of sport performance. The study by Lau, Yu, and Woo (2015) and review by Woodyard (2011) both reported the benefits of regular yoga practice which promoted muscular strength, improved endurance, flexibility, self-reported calmness, and well-being. Yoga has also been associated with the enhancement of overall athletic performance (Polsgrove et al., 2016). It has been demonstrated to enhance flexibility through prolonged postural alignment and stretching of muscular fibers, whilst also optimizing joint movement in the kinetic chain (Polsgrove et al., 2016). Yoga has been used to improve strength and target nerve activation in under-utilized supportive muscles, with variations of postures that gently release muscle tension, and open up joint spaces, (Williams et al., 2005). Similarly, yoga has also been shown to improve balance and stability of joints by enhancing muscle strength along with muscular length associated to joint ROM (Gothe & McAuley, 2016; Polsgrove et al., 2016). The Sivananda Yoga Vedanta Centre explains how the practice of yoga enhances athletic performance by improving anatomical alignment in joints, increasing ROM, and providing greater muscle fibre recruitment in muscles by reducing their active tension (Kindersley, 2010, p. 20). This alleviates the load on ligaments and joints, thereby allowing more movements to take place.

A preliminary study by Polsgrove et al. (2016) looked at a regular yoga practice over a 10-week period. They conducted sessions twice weekly in an attempt to increase overall flexibility and balance in male college varsity athletes. The authors recruited 26 college athletes and measured joint angles of the hip and lower back region for both the yoga group (N=14) and non-yoga group (N=12). The yoga group was comprised of soccer team players (mean age= 19.8 years), while the non-yoga group was comprised of baseball team players (mean age = 20.3 years). During the identical 10-week program duration, both teams followed their training protocols for their particular sports, which included activities such as static stretching, weight training, and running. The yoga group subjects attended yoga sessions run by a certified yoga instructor for two mornings (Tuesday and Thursday) each week, in addition to the regular training protocol, prior to any physical activity or training. Pre-post performance measurements took place before and after the 10-week period using sit-and-reach, shoulder flexibility, stork stance, and dynamic joint angles in specific yoga postures. Significant improvements were demonstrated in the yoga group for sit-and-reach, stork stance, shoulder flexibility, and joint angles in postures, while no significant values were shown in the non-yoga group around flexibility and balance. The researchers concluded that integrating the practice of yoga into regular training programs helped improve specific components of fitness for athletes and specifically flexibility and balance measurements. However, the authors specified difficulties in correlating the measurements towards specific aspects of athletic performance for a sport. It is possible, particular sports training programs for the non-yoga group regime might account for the loss of flexibility and balance. Research concerning yoga and athletic performance regarding specific sports, such as rowing, remains unknown. With clearer evidence of the influence of yoga on this specific repetitive, high-volume, high-intensity sport, improvements in athletic performance could possibly demonstrate a functional utility of yoga in regular training regimes (Siegel & Barros, 2015).

Yoga remains an evolving and emerging area of sport performance research. Clearer evidence of yoga as a useful complimentary training modal for athletic populations and the benefits of yoga as a role of optimizing athletic performance is of vital importance among rowers, coaches, athletic trainers, and sports medicine physicians.

2.8 Yoga for Sport-Related Hip and Pelvic Injury

The use of yoga in physical preparation and conditioning for sport performance is a contemporary area of research, with multiple approaches to this holistic practice. However, there is very limited evidence-based research on the direct relationship in which Iyengar yoga provides hip ROM, flexibility, and strength to an athletic population. Yoga therapy intervention has been based upon the fundamental framework teachings of BKS Iyengar, who has implemented therapeutic variations to address, prevent, and treat specific health conditions (Iyengar, 1998). Though it is perceived to deliver beneficial and therapeutic effects to the body as a whole (Akhtar Yardi, & Akhtar, 2013), the impact of yoga has not been directly quantified for athletes and their performance. There is also, currently few, empirical studies of demonstrating the effects of mitigating common sport related injuries experienced by rowers through yoga practice.

One study examined the effects of physical characteristics on NCAA baseball athletes (N=30) before and after a yoga intervention with a series of ROM tests. Performance tests included a sit and reach test, body weight squat, shoulder flexibility test, leg adductor test, and a standing transverse trunk ROM test (McLean, 2009). Measurements were taken before and after an Ashtanga Vinyasa yoga intervention. The intervention consisted of sessions occurring twice per week for a total of 25 sessions during the athletic training period. The population recruited included elite athletes ranging from the age 19.42 ±1.37 years. Though the findings regarding hip and trunk flexibility included a 24% increase post intervention for the sit and reach, the post intervention improvement was not sufficient to reach statistical significance for trunk ROM, or leg adduction.

Omkar, Mour, and Das (2011) examined the biomechanical effects on specific joints during a series of yoga postures (Sun Salutations), based upon reported clinical benefits. The objective was to measure the moments of force surrounding the joints at specific Sun Salutation postures where the muscles were in isometric contraction between flexion and extension in order to oppose muscles across the body axis (Omkar, Mour, & Das, 2011). Examiners found that standing postures elicited similar moments at the hip compared to those experienced during repetitive sports. The researchers also reported that during standing sequences, a greater moment force was put on the hip rather than the lower back, benefitting the hip flexors and extensors, and promoting lower back flexibility. These findings suggest that practicing sun salutations regularly provides a beneficial role to hip and back joint health by producing higher joint moments, but at submaximal joint loads.

Based on the findings by Omkar et al (2011), it is clear that yoga postures benefit strength and flexibility around hip joint moments, as well as alleviate lower back loads. There is a paucity of adequate research in current literature regarding the effects of yoga as a form of flexibility training, particularly in specialized populations such as varsity athletes.

2.9 Proprioceptive Neuromuscular Facilitation with Yoga

Proprioceptive neuromuscular facilitation (PNF) is a common stretching technique utilized to improve muscle elasticity and has been shown to improve active and passive joint ROM whilst benefitting muscular performance (Funk et al., 2003; Lucas & Koslow,1984). There are various theories regarding the physiological changes that occur during PNF. Literature has demonstrated PNF to be efficacious in therapeutic and athletic settings, specifically for the prevention and rehabilitation of injuries. Clinically, therapists use PNF as a form of restoring or maintaining functional ROM and strength of individuals who have reduced muscle length related to soft tissue damage or invasive surgeries (Hindle, Whitcomb, Briggs & Hong, 2012).

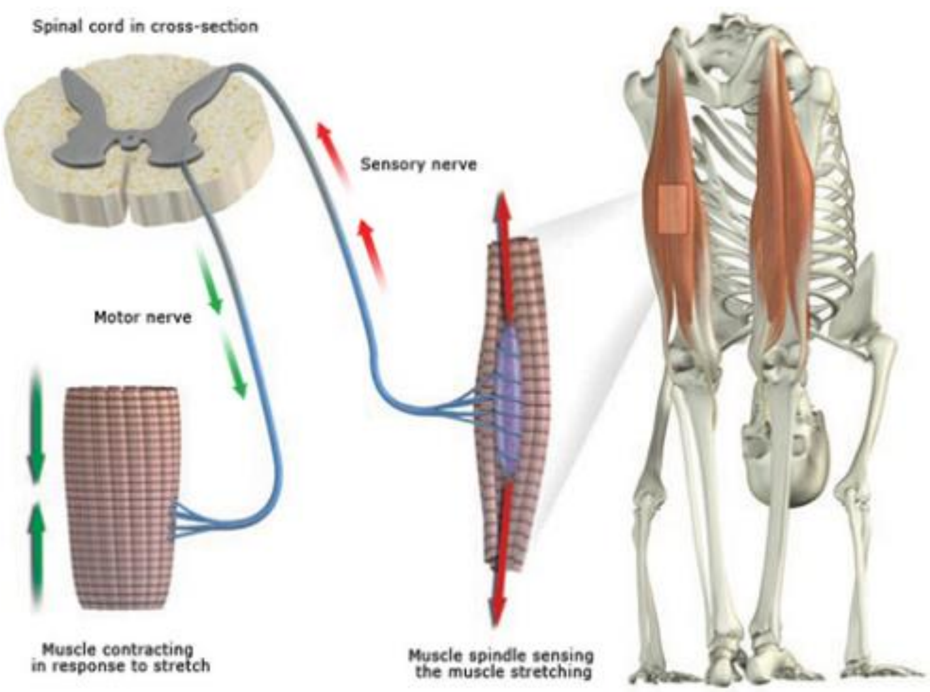
Much research has focused on the stretching techniques, comparable to yoga asanas, regarding PNF and athletic performance enhancement; however, these are mainly proposed theories on autogenic inhibition, reciprocal inhibition (Akbulut & Agopyan, 2015), stress relaxation, and the gate control theory (Hindle, Whitcomb, Briggs & Hong, 2012; Sharman et al., 2006). One systematic review objectively examined literature surrounding the proposed theories, physiological mechanisms and adaptations that take place in the body during PNF stretching (Hindle, Whitcomb, Briggs & Hong, 2012). The primary objectives were to provide credibility to the theoretical framework of improving muscular strength, ROM, and athletic performance from PNF techniques (Hindle, Whitcomb, Briggs & Hong, 2012). Autogenic inhibition based-theories suggest that inhibitory reflexes from the Golgi tendon organs (GTOs) at the muscle-tendon junction occur in response to detection of maximal tension related to high muscular contraction or stretch (Hindle, Whitcomb, Briggs & Hong, 2012). GTOs send a response from the Ib afferent nerves back to the spinal cord. Inhibitory stimuli are then sent to the motor neurons of the targeted muscle being contracted or stretched. This decreases the nerves' excitability and efferent motor drive due to the tension of the muscle fibres and GTOs detecting them. As a result, the muscle relaxes thereby preventing further muscular fatigue (Figure 2.6) (Hindle, Whitcomb, Briggs & Hong, 2012; Sharman et al., 2006).

Stretching techniques, including PNF, increase ROM by lengthening musculature surrounding joints and enhancing neuromuscular efficiency (Akbulut & Agopyan, 2015; Hindle et al., 2012). Funk et al. (2003) examined the outcomes of PNF stretching comparatively with regular static stretching for hamstring flexibility on 40 undergraduate student athletes, both male and female, after a bout of exercise took place. Within-group comparisons demonstrated that PNF resulted in a significant improvement of flexibility post-exercise compared to the baseline and without exercise, while no differences were observed with the static stretching protocol. Rowlands, Marginson, & Lee (2003) examined the effects of three different contraction durations with PNF involving flexion at the hip. The 43 female participants were divided into 3 stretching groups.

Groups included 5 second isometric contractions, 10 second isometric contractions, and a control group. Sessions were conducted twice weekly for a total of 6 weeks. Each session followed 1) a 5-minute warm up, 2) lengthening the target muscle, 3) holding the desired position, 4) isometrically contracting to a maximal level, then 5) passively stretching the muscle. Flexibility was significantly lower in the control group post-intervention relative to the groups that underwent isometric contractions. Additionally, flexion at the hip increased significantly for both contraction groups between 3 and 6 weeks of stretching groups. Based on the results demonstrating a larger increase in ROM with the 10-second group, the authors concluded that a longer duration of stretching yields a greater ROM post-intervention.

Figure 2.6

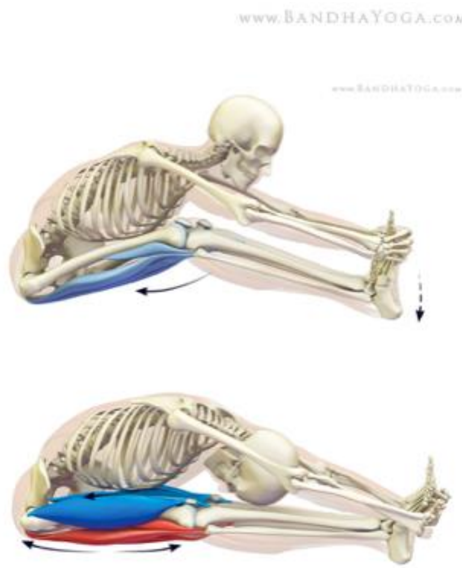
The physiological mechanism and neural involvement leading to PNF-induced improvement in flexibility. (Long, 2010, p. 8)



Many yoga asanas incorporate comparable neuromuscular activation as PNF techniques (Srinivasan, 2016). Instead of just passively stretching the target muscle, it lengthens muscles through the contract-relax-antagonist-contract (CRAC) technique (Hindle, Whitcomb, Briggs & Hong, 2012). This combination has been reported to have the most beneficial results in stretching and strengthening the targeted muscle, and improving ROM (Hindle, Whitcomb, Briggs & Hong, 2012). Stretching while simultaneously contracting the stretched muscle applies tension on the muscles and its tendon, thereby activating the GTOs receptors at the muscle-tendon junction through autogenic inhibition (Hindle, Whitcomb, Briggs & Hong, 2012). Autogenic inhibition occurs in a muscle being lengthened or contracted due to inhibitory signals decreasing the excitability of the same muscle sent from the GTOs (Sharman et al., 2006). The tension produced results in activation of the 1b afferent fibres in the GTOs to send an afferent signal to the spinal cord resulting in the activation of inhibitory interneurons in the spinal cord to put an inhibitory stimulus on the alpha motor neuron. As an outcome, this reflex decreases the nerves' excitability and target muscles' efferent motor drive (Sharman et al., 2006). Lengthening of muscles while dually engaging and contracting provides PNF stretching throughout the practice and postures of yoga. The GTOs are continually activated and recruited while the muscles are stretched and relaxed. This allows the individual to move "deeper" into the pose (see Figure 2.7). The target agonist muscle (or muscle group) is then stretched further through the contraction of the opposite antagonist muscle group. For example, during the asana Paschimottanasana (seated forward fold), as the individual begins to reach for their toes, the knees begin partially flexed, while the trunk flexes towards the legs. During this, the spine extensors can act to deepen the action in the hip joints, while the hamstrings begin to engage and activate the GTOs at the muscle-tendon junction (Hindle, Whitcomb, Briggs & Hong, 2012). By isometrically contracting and holding this posture for 5-8 breaths, relaxation is produced through autogenic and reciprocal inhibition, while the muscles are stretched and lengthened, further allowing the quadriceps to contract and knees to extend. This "slack" is produced by the reflex arc previously explained. These key concepts incorporate the contraction and relaxation benefits regarding yoga, "hip openers", and "forward bends", which is the chief emphasis of this study's yoga program.

Figure 2.7

Facilitated stretching involving contracting and lengthening in paschimottanasana (seated forward fold). (Long, 2010, p. 8)



2.10 Assessment of Peak Isometric Hip Muscle Strength and Hip ROM

2.10.1 Peak Isometric Muscle Strength Testing Protocol

Skeletal muscle strength tests are commonly used to assess the adaptive response of an intervention or program (Verdijk, van Loon, Meijer, & Savelberg, 2009). These testing protocols help assess changes in leg muscle strength following an exercise intervention. Standardized manual muscle tests (MMT) are used to clinically assess lower extremity muscular strength. However, as reviewed by Stark et al. (2011), in order to assess strength empirically this grading system, based on the gravity standard, potentially poses large gaps of error as the tests are subjectively assessed by the therapist. Hand-held isometric dynamometers (HHID) and force gauges have been commonly applied throughout previous studies when quantifying peak isometric muscular strength (Kim & Lee, 2015). Strength ratios have been used to identify muscular imbalances and weakness to assist in injury prevention and management (Alvarenga et al., 2012).

Thorborg, Bandholm, and Hölmich, (2013) examined the inter-tester reliability assessment of peak isometric strength for hip abduction, adduction, flexion, extension, and knee flexion using a HHID. The researchers examined peak isometric strength on an athletic population (N=21; 6 female, 15 male). Their findings included no systematic differences or bias between testers for any hip actions. The ICC ranged from 0.76-0.95, which indicated adequate to excellent inter-tester reliability on isometric hip strength measurements using the HHID on athletes. Similar applications are used to measure maximal isometric muscle strengths using hand-held electronic force gauges. Many recommend using HHID on athletes with hip and hamstring injuries, as these assessments may assist in identifying muscular deficiencies and imbalances (Askling, 2006; Schache, Crossley, Macindoe, Fahrner, & Pandy, 2011; Thorborg et al., 2013; Wikholm & Bohannon, 1991).

Another retrospective study analyzed the re-test reliability and assessment tool for muscular strength around the hip and shoulder (Bohannon, 1986). To assess the reliability, three identical tests were compared on the participants for 18 extremity muscle groups (n=30) using a one-way analysis of variance (ANOVA) for repeated testing measures. Using the Pearson product-moment correlation, the correlations were all significant ($p < 0.1$) with the median and modal correlations all at either 0.97 or 0.98. However, the ANOVA demonstrated significant differences in the repeated dynamometer scores for hip and shoulder abduction, displaying high reliability for the other 16 muscle groups. Based on these results, the researcher suggested that the force gauge is a reliable assessment technique when performed by a single trained tester.

2.10.2 Range of Motion Assessment Protocol

Goniometry is a standard methodology used to measure the angle and range of a joint during various flexibility tests (Bhamare, Ayare, Khandge, Shroff, & Herode, 2017). The joint angle is then used to provide empirical measures to establish a baseline and monitor progress. The goniometer is one of the most widely used assessment tools for measuring ROM in a clinical and research setting, is easily administered in a few minutes, poses minimal risk, and is inexpensive. It is a valuable tool used to evaluate the efficacy of rehabilitation treatment programs (Nussbaumer et al., 2010).

Reliability of hip ROM using standardized goniometric protocols poses some controversy between the findings of studies in association to the body region, joint, experience of the examiner, tool positioning, and the number of testers (Bhamare, Ayare, Khandge, Shroff, Herode, 2017; Gajdosik & Bohannon, 1987; Nussbaumer et al., 2010; Wakefield, Halls, Difilippo, & Cottrell, 2015). Gajdosik and Bohannon (1987) reviewed previous literature examining the reliability and validity of goniometric measurements for ROM as a clinical and research instrument. These researchers examined procedures that influenced body compensations for specific movements, various joint actions, passive versus active measurements, and intratester versus intertester accuracy. Overall, their review identified goniometry as a valuable assessment tool, as well as a standardized method of testing ROM for various joints. Another study examined possible limitations in the standardized protocols of goniometric evaluations for hip flexion and extension ROM (Elson & Aspinall, 2008). They recruited 200 healthy individuals and found a wide range of hip flexion (80-140º) and extension (5-40º). The authors specified that the ranges of motion were directly related to the anatomical position of the pelvis and that it was crucial to stabilize the pelvis when testing in order to achieve an accurate score. Elson & Aspinall (2008) proposed another method for measuring hip flexion ROM by palpating the lumbosacral junction in order to permit a sooner identification of lumbar spine flexion coinciding with hip flexion movement.

Based on these past reviews and studies, the use of a goniometer provides a valid and accurate form of measuring and assessing an individual's full ROM, when the investigator administered it appropriately. The two-armed goniometer remains to be the most commonly administered, economical, and portable device for the assessment of ROM, despite possible cautions with administration protocols (Bhamare et al., 2017; Elson & Aspinall, 2008; Gajdosik & Bohannon, 1987; Nussbaumer et al., 2010; Wakefield et al., 2015). The most crucial disadvantages to consider are the starting position, center of rotation, true vertical and horizonal landmarks on the participant (Lea & Gerhardt, 1995).

2.11 Summary

Feasibility and intervention-based studies provide an innovative preliminary platform for an emerging area of research and help alleviate uncertainties around methodological design protocols. This can lead to the effective development of large-scale definitive studies and can help ensure subsequent studies are robust, efficacious, and feasible (Blatch-Jones et al., 2018; Eldridge et al., 2016). Feasibility research designs incorporate multiple aspects around the methodology and design process, whilst providing critical information for future trials (Eldridge et al., 2016).

Rowing related injuries due to overuse and repetitive movements in the sagittal plane may increase risk for hamstring tightness, agonist-antagonist muscular imbalances, and strength deficiencies in the lumbo-pelvic hip complex.

3. Methodology

3.1 Experimental Design

This feasibility study used a single group, pre-test-post-test, quasi-experimental research design to assess the potential efficacy of implementing a 9-week ROWGA programme with male varsity rowers during the training and competitive season as measured by: a) program adherence; b) peak isometric hip muscle strength (HMS); c) peak isometric agonist-antagonist hip muscle strength ratios (AAHMS); and d) hip flexion ROM. The independent variable was the 9-week ROWGA programme. The dependent variables included attendance rates at the ROWGA sessions as well as pre and post intervention measurements of strength and hip flexion ROM. Two pre-test baseline measurements were performed by all participants over 1-week prior to the intervention. These were conducted to ensure reliable baseline scores and to reduce any effects of testing familiarization. All testing sessions were conducted at the same time of the day to decrease the effects of circadian rhythms. A single post-test of all DV was conducted following the 9-weeks of ROWGA classes. All participants were informed of the study rationale, objectives, and procedures before providing written informed consent. This study was approved by UVIC Human Research Ethics Board (see Appendix A).

Recruitment consisted of an onboarding email to the Varsity men's rowing coach requesting approval for the recruitment of their athletes, using a convenient sampling method. The coach was provided detailed information regarding the study and measurement protocol. After receiving consent from the coach, the team was contacted via an email outlining the study and was provided with full details of the ROWGA sequence in the recruitment package (Appendix B, C, D). Participants meeting the inclusion criteria were currently on the UVic Male Varsity Rowing Team, ranged between the ages of 18-25 years, and reported no hip or lower back injuries at the time of recruitment or testing.

3.2 Data Collection

The study occurred over the course of 11-weeks (Figure 3.1). Data collection took place within a laboratory setting at the University of Victoria. Testing was performed by the Primary Investigator (PI), a primary research assistant (RA-1) with goniometry and force gauge familiarization, and additional undergraduate research assistants. Following the completion of signed informed consent, all pre tests occurred separately over 7 days.

Weeks 2-10 consisted of the ROWGA intervention (sessions 1-17) conducted in the same campus facility as the team's dryland training sessions. Participants completed the identical Iyengar yoga sequence throughout each ROWGA session to ensure consistent movements. During each session, a full description of the sequence was explained to the participants. Each posture was demonstrated during each Iyengar yoga class (ROWGA). The ROWGA sequence during each session was directed by the primary investigator (a certified yoga instructor) using specific, standard Iyengar yoga instructions, which encouraged proper alignments, postures, and biomechanics.

Week 11 consisted of all post intervention testing measurements (Post Test). The measurement protocols were the same as in the pre-tests in Week 1. All post tests were completed within two days of the final ROWGA session (24 - 48 hours) (see Figure 3.1).

Figure 3.1

Timeline of testing and intervention

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1	1. Pre Test 1 2. Pre Test 2 (pre-tests 24 - 48 hrs apart)						
Week 2 –10		ROWGA Practice (60 minutes)		ROWGA Practice (60 minutes)			
Week 11	Post Test (all tests 24-48 hrs of final ROWGA session)						

Participants checked in at the beginning of each 60-minute ROWGA session; any injuries sustained preventing an individual from participation were reported by the participant in the recruitment package (Appendix B).

Pre-Test Day 1: Anthropometric measurements took place prior to strength and ROM testing. A personal information questionnaire was collected for the study recruitment (Appendix C).

Pre-Test Day 2: was conducted 24-48 hrs after the first session. Procedures and protocols were identical to Pre-Test Day 1, except for weight and height, which were not collected.

Post Test: was conducted 24-48 hours after the final ROWGA session. Procedures and protocols were the same as in all pre-tests, excluding height and weight collection.

3.3 Experimental Test Procedures and Protocols

The PI and RA-1 conducted the peak isometric hip muscle strength and range of motion tests, while additional assistants acted as scribes to record measurements on the data collection sheet for each participant (Appendix E). All testing was completed in a controlled laboratory setting on each participant separately. Prior to the beginning of each testing session, a standard timed 5-minute warm up took place on a cycle ergometer at low intensity in order to prepare the participants' muscles and joints for subsequent testing. Passive hip flexion ROM was measured along with peak isometric hip muscle strength for hip flexors, extensors, abductors, adductors, internal and external rotators. All tests were conducted in the same order. All pre-tests were conducted at the same time each day for each participant.

3.4 Anthropometric measurements

Pre-test Day 1 included the measurement of body height (Stadiometer, model Seca 700) and body weight in kilograms (Healthometer Bodyweight scale, model 753KL). Both measurements were recorded with participants in shorts and no shoes. Measurements were recorded to the nearest 0.1 unit (see Table 4.1).

3.5 Adherence Measurement

Attendance for each participant was recorded throughout the intervention for each session, as were reasons for any absences, such as compulsory competitions, illness or injury. During the duration of the study, participants were reminded of their ability to withdraw at any time. Adherence to the intervention, used to reflect compliance, refers to the extent of willingness and behavior of the participants to participate in the intervention throughout the study. In this study, the adherence rates were adjusted according to obligatory competitions for specific participants to better reflect their willingness to attend. Attendance rate is the percentage of classes attended out of the actual total number of sessions offered.

3.6 Performance Measurements

3.6.1 Peak Isometric Hip Muscle Strength Testing

Participants were positioned on the plinth and precise land marking on the thigh for the positioning of the force gauge was made prior to any testing. Land marking included marking and measuring 2 inches above the lateral epicondyle of the femur (for full details please see Appendix F). The peak isometric HMS tests were administered using an IMADA DPSH-440R hand-held digital force gauge to measure muscular strength about the hip (in Newtons). In each testing session, three maximal effort isometric trials, 3 seconds in length for each trial, were performed. Rest intervals of 15 seconds were allowed between contractions to prevent muscle fatigue during the tests. Results were displayed on the device screen and recorded as peak isometric force on the data collection sheet. Results were recorded for each movement tested with the two closest scores averaged for a final value (for full details please see Appendix F). Participants were instructed to exert maximal effort and were verbally coached to push as hard as they could through each trial. Participants performed two submaximal practice trials to familiarize with the testing procedure.

3.6.2 Range of Motion Tests

Passive hip flexion ROM tests were conducted immediately after the completion of the strength tests. ROM was measured while lying in supine position, hip at 0º of abduction, adduction, and rotation. Initially the knee was extended, but flexion was allowed as hip flexion continued. Following precise landmarking for the goniometer placement on each limb to be tested on a participant, the ROM tests were administered using a standard plastic double-armed Goniometer consisting of a 360-degree protractor, marked in one-degree increments (EMI Baseline® Plastic 12”). In each testing session, three trials were performed with rest intervals of 15 seconds between each movement. Results were recorded for each movement tested. The two closest scores were averaged for a final value. For full details please see Appendix G.

3.7 ROWGA Intervention

The ROWGA intervention was developed specifically for this study and was based upon BKS Iyengar's postural alignment framework book (Iyengar, 1998). This particular yoga method has been suggested to address imbalances, improve alignment flexibility, stability, mobility, in joints and muscles about the hip and spinal region. For the purpose of this feasibility study, the 60-minute ROWGA practice was specifically designed to target gluteal, hamstrings, and quadriceps muscle groups intending to lengthen, strengthen, and increase activation to such muscles that have shown to be underutilized in rowing training.

The ROWGA intervention consisted of 33 asanas (Appendix D). Poses followed the general Iyengar categories, specifically supine, seated, standing, forward bends, twists, and inversions. No back-bending postures were incorporated into this sequence in order to reduce potential strain and prevent back injuries. The initial portion of each practice included low impact restorative poses to relieve tension in the gluteal, lower back, and lower limb regions. Such poses aimed to focus on lengthening muscles which attach to the pelvis, femur, and/or spine. Standing poses followed to strengthen and open the hip and pelvic region. The athletes were instructed on the correct form of lengthening and strengthening smaller gluteal muscle groups. Twists were combined in the standing and seated portions of the practice to assist in alignment of the spinal cord, sacrum, pelvis, and hips by activating deep back and gluteal muscles. Inversions were performed to oppose any compression of joints throughout the practice. Throughout each session, the yoga instructor (PI) would correct any improper alignments and postures performed by the athletes.

3.8 Statistical Analysis

Full data sets for 16 participants were used in the analysis of results. The statistical analysis included descriptive statistics for each anthropometric measurement in addition to preliminary and post-intervention data. All analyses were conducted using MS® Excel for Mac (Version: 16.29.1). Significance was accepted at $p < 0.05$ for all statistical procedures.

Reliability of measurements was assessed with intraclass correlation coefficient (ICC) analysis. A two-way mixed effect model, absolute agreement, single rater/measurement ICC was utilized for assessing test-retest reliability between measurements from the two pre-tests days (i.e. ROM and peak isometric HMS) (Koo & Li, 2016). For single participant comparisons, the ICC utilized a 90% confidence interval (CI) established from the two preliminary testing values. The formula used for the ICC model was derived from McGraw and Wong (1996).

Descriptive data were analyzed including group means and standard deviations. All pre-post hip strength data (in Newtons) were normalized to each participant's body weight (in kg). To compare if the intervention differentially impacted the left versus right limbs, Student Newman Keuls (SNK) paired sample t-tests were performed for pre to post changes (%) in peak isometric HMS and hip flexion ROM results between left and right. No significant differences were found between left and right limbs pre and post intervention for any dependent variable and thus results from both sides were combined. Combining results from both limbs doubled the sample size (n=32) for all remaining analyses. SNK paired sample t-tests were used to test for significant pre-post differences in peak normalized isometric HMS in the sagittal (flexors, extensors), frontal (adductors, abductors), and transverse (internal and external rotators) planes and hip flexion ROM (flexibility).

Agonist-antagonist ratios were calculated for HMS within each movement plane for both pre and post peak isometric HMS by dividing flexors by extensors, adductors by abductors, and internal by external rotators. When direct comparisons were made between agonist and antagonist muscle groups for pre and post data, no differences were observed. Further, there were no significance differences between the left and right sides between the pre and post normalized ratios and therefore the peak isometric HMS data were pooled for left and right limbs for statistical analyses. SNK paired t-tests were used to compare each of these pre and post normalized ratios. Data are described as mean and standard deviation (SD).

4. Results

4.1 Participant Characteristics

Seventeen competitive male varsity rowers (aged 18-25 years) volunteered to participate in the current study and met inclusion criteria. Following the pre-tests, one of the seventeen participants left the rowing team for reasons unrelated to the study. Consequently, their data were removed from any analyses. As a result, sixteen participants completed the full study. A summary of the physical characteristics of participants who completed the full study are presented in Table 4.1. No participant reported any adverse events related to the ROWGA program throughout the duration of the study. Of the remaining sixteen rowing participants, eight participants were oarsmen on the port side, while eight were on the starboard.

Table 4.1 *Mean (SD) physical characteristics of participating rowers (n=16)*

Age (years)	Height (cm)	Weight (kg)
20.6 (2.1)	177.3 (28.8)	90.4 (3.6)

4.2 ROWGA Adherence

A summary of the protocol adherence and attendance rates are shown in Table 4.2. Initially, the attendance rate was determined to be 85% of all sessions and rated as high according to (Moore, Carter, Nietert & Stewart, 2011). However, since the ROWGA intervention was conducted concurrent to the high-volume training and fall competitive season, there were two ROWGA sessions that conflicted with national competitions. As a result, some participants were absent and unable to attend those ROWGA sessions due to their required participation at these competitions. When individual participant attendance records were corrected for these explained absences, the adjusted adherence rate was increased to 89% and rated as high (Moore, Carter, Nietert & Stewart, 2011). All participants attended more than 73% of all ROWGA sessions, and all but two participants attended 80% or more sessions of the intervention (see Appendix H).

Table 4.2 *Participant attendance and adjusted adherence rates following the 9-week ROWGA intervention (n=16).*

Participant	Missed Classes	Attendance Rate (%)	Missed Classes (Adjusted)	Adherence Rate (Adjusted) (%)
Participant 1	3	82	1	93
Participant 2	0	100	0	100
Participant 3	2	88	2	88
Participant 4	3	82	3	88
Participant 5	6	65	4	73
Participant 6	1	94	1	94
Participant 7	0	100	0	100
Participant 8	4	76	2	87
Participant 9	4	76	2	87
Participant 11	0	100	0	100
Participant 12	1	94	1	94
Participant 13	5	71	3	80
Participant 14	1	94	1	94
Participant 15	3	82	3	82
Participant 16	6	65	4	73
Participant 17	2	88	2	88
Mean	3	85	1.8	89

4.5 Measurement Reliability

The test-retest reliability of the two pre-intervention trials were evaluated using an ICC with 90% CI). Results are summarized in Table 4.3. Strength testing showed good-to-excellent reliability with an average ICC of 0.85 and individual test ICC values ranging from 0.70-0.93 (Koo and Li, 2016). The pre-test hip flexion ROM testing had ICC values of 0.70 and 0.75 for left and right hips, respectively. Hip flexion ROM showed moderate-to-good reliability.

Table 4.3 *Peak isometric HMS and ROM ICC of two pre-test days*

Hip Muscle Strength	Side	ICC Value*
Flexors	Left	0.82
	Right	0.71
Abductors	Left	0.81
	Right	0.93
Adductors	Left	0.88
	Right	0.87
Extensors	Left	0.89
	Right	0.81
Internal Rotators	Left	0.84
	Right	0.85
External Rotators	Left	0.88
	Right	0.94
Hip Flexion	Left	0.70
	Right	0.75

* ICC value interpretation: < 0.5 ICC = poor, 0.50-0.75 = moderate, 0.75-0.90 = good, > 0.90 = excellent. (Koo and Li, 2016)

4.5 Peak Isometric Hip Muscular Strength and Hip Flexion Range of Motion

Mean values for peak isometric HMS of the two pre-test days were averaged and used to represent the pre-intervention scores compared to the post intervention measurements. Mean (SD) pre and post intervention scores for peak isometric HMS normalized to body weight, and % change from pre to post-intervention, as well as passive bilateral hip flexion ROM are presented in Table 4.4.

Significant strength improvements following the ROWGA intervention were seen for the hip flexors, extensors, abductors, and adductors, and external rotators. No change was found for internal rotator strength. A significant 4.3% reduction in hip flexion ROM was also observed.

Table 4.4

Mean (SD) and percent (%) change for peak isometric HMS (N) normalized to body weight (kg) (n=32) and passive hip flexion ROM (in º) for PRE and POST nine-week ROWGA programme (n=16)

Hip Muscle Strength	PRE (N/kg)	POST (N/kg)	p Value	% Change
Flexors	3.5 (0.9)	4.3 (±0.6) *	0.00001	30.7
Extensors	3.5 (1.3)	4.1 (±1.0) *	0.002	26.0
Abductors	2.2 (± 0.7)	2.6 (± 0.5) *	0.004	22.7
Adductors	2.1 (± 0.7)	2.5 (± 0.4) *	0.0002	30.3
Internal Rotators	2.1 (± 0.6)	2.2 (± 0.5)	0.14	10.9
External Rotators	1.8 (± 0.6)	2.1 (± 0.4) *	0.03	22.5
Range of Motion				
Hip Flexion	117.6 (± 6.8)	112.5 (± 7.6) +	0.003	-4.3

* significant increase from pre-intervention, $p < 0.05$
+ significant decrease from pre-intervention, $p < 0.05$

4.5.1 Peak Isometric Agonist-Antagonist Hip Muscular Strength Ratios

There were no significant differences between the pre and post-test normalized peak isometric HMS ratios for any of the agonist-antagonist pairs comprising hip flexors/extensors, abductors/adductors, and internal/external rotators. Ratios and p values are shown in Table 4.5. No significance differences were observed between the peak isometric agonist and antagonist hip muscle groups (AAHMS) for both pre and post intervention.

Table 4.5

Mean (SD) pre and post nine-week ROWGA intervention for normalized peak isometric AAHMS ratios (n=32)

Agonist/Antagonist Muscle Group	Pre Normalized Ratio	Post Normalized Ratio	P value
Flexors/Extensors	1.1 (0.3)	1.1 (0.3)	0.46
Abduction/Adduction	1.1 (0.2)	1.1 (0.2)	0.10
Internal/External Rotators	1.1 (0.2)	1.1 (0.2)	0.09

5. Discussion

This preliminary study assessed the feasibility and efficacy of a 9-week Iyengar “yoga for rowers” (ROWGA) program for male varsity rowers in a real-world setting. The four aims of this research were to: 1) test the viability of implementing the program during the training and competitive season through measuring program attendance and adherence; 2) Evaluate its potential effect on peak isometric HMS acting in the sagittal (flexors, extensors), frontal (adductors, abductors), and transverse (internal rotators, external rotators) planes; 3) Compare the relative change in peak isometric HMS between the agonist versus antagonist muscle groups; and 4) Evaluate its potential effect on passive hip flexion ROM.

Prior to committing to the implementation of a full experimental design study of the ROWGA program, a reasonable first step was to assess the feasibility of this type of intervention with varsity male athletes during their competitive season. This study demonstrated the feasibility of implementing such a program as evidenced by the rowers’ willingness to regularly attend the ROWGA program and their ability to accommodate the time commitment within their schedule. The study also showed the potential positive impact of the ROWGA program on peak isometric HMS and maintaining strength balance between peak isometric AAHMS ratio muscle groups. Interestingly, a negative impact on hip flexion ROM was observed.

5.1 Attendance and Acceptability

Feasibility studies are used to determine if an intervention enables researchers to assess whether or not the findings and areas of focus are structured appropriately and sustainably (Bowen et al., 2009). Areas of focus include assessing implementation, acceptability, and adherence to an intervention. This study indicated that the inclusion of a biweekly rowing-specific yoga-based program in the training regime for male varsity rowers during a fall competitive season is feasible. Feasibility was evaluated using attendance and adherence rates of the ROWGA intervention. Acceptability is determined by adherence rates, and positive or unchanged quantitative data. The high acceptance and attendance rates of the ROWGA classes were further reflected by the ability to both accommodate the existing commitments within the rower's training constraints throughout the competitive season. Further, the acceptability of a complementary training regime within this rowing population conferred an additional benefit of increased strength in hip muscles (Moore et al., 2011).

Varsity rowers have a host of academic and sport requirements, particularly within the competitive season. Despite the evident time constraints, the rowers were still able accommodate the additional time commitment of the ROWGA program into their schedules as evidenced by the attendance rate of 85% of all ROWGA sessions. This attendance rate is consistent with the findings of another feasibility study measuring acceptability and adherence to an exercise-related intervention (Brooker et al., 2019). Brooker et al., (2019), reported to have a high measurement completion rate of > 80%, and high adherence rates for the two different exercise sessions provided (94% and 87%). In the current study, when the attendance rate was adjusted to accommodate for schedule conflicts between ROWGA sessions and the compulsory national regatta competitions and it was not possible for certain participants to attend ROWGA due to their attendance at these competitions, the adherence rate became 89% and was ranked as high, in accordance with the acceptable feasibility limits (Moore et al., 2011). It is also notable that the rowers had no designated obligation to attend every session offered. As specified in the recruitment package with the informed consent, participants were expected to attend as many ROWGA sessions as possible as part of participation in the study, however the athletes' compliance was self-determined. Further, participants were aware that their attendance, or their choice to withdraw from the study, would have no impact on team status.

During each ROWGA session, all participants completed the entire yoga sequence to the best of their ability for each asana, providing further evidence for the feasibility of the ROWGA. These attendance and adjusted adherence rates suggest that the rowers considered ROWGA to be an acceptable and appropriate supplement to their training. Therefore, the ROWGA program proved to be a feasible addition to a varsity male rowing training program during a competitive rowing season.

5.2 Peak Isometric Hip Muscular Strength

With respect to the physical performance measures, the primary findings suggest that the ROWGA program had a significant positive impact on peak isometric HMS. Significant improvements were observed in the hip flexors (30.7%), extensors (26.0%), abductors (22.7%), adductors (30.3%), and external rotator (22.5%) muscle groups. Admittedly, the ROWGA intervention occurred during the athletes’ fall competitive season, which included a demanding training program of on-water practices, dryland ergometer sessions, as well as a strength and conditioning program which focused on muscular power. It is expected that this high-volume, demanding training regime would confer strength improvements. However, strength gains were expected to be seen mainly in hip flexion and extension, as these sagittal plane lower body actions are typically the most dominant during on-water rowing and dryland ergometer training (Thornton et al., 2016). Compared with the hip flexors and extensor muscle groups, muscles acting outside of the sagittal plane, including the hip abductors, adductors, as well as internal and external rotator muscle groups, are generally less dominant in typical competitive rowing training programs. The ROWGA used in the present study included yoga asanas that focused on hip strengthening, such as Warrior 2, Warrior 3, Chair Pose, Forward Folds, and other asanas that function as deep hip openers. These yoga postures were designed to emphasize hip and pelvic muscle strength and ROM within all anatomical planes. Considering the highly repetitive movements of rowing within the sagittal plane (Wilson et al., 2014) and the tri-planar activation of muscles in the ROWGA program, the gains in strength measurements for hip actions outside of the sagittal plane can be interpreted as being, at least in part, due to the ROWGA intervention.

Previous work exploring the LPH biomechanics of competitive rowers (McGregor et al., 2002; Parkin et al., 2001; Rumball et al., 2005) demonstrated that hypomobility in one segment is often associated with hypermobility in another, which includes altered pelvic rotation and that mobility can be influenced by the strength and tightness of muscle groups such as the gluteal muscles, quadriceps and hamstrings. Findings of the current study are corroborated by those in the systematic review conducted by Waryasz and McDermott (2008) who collated comprehensive studies to determine potential risk factors associated to patellofemoral pain syndrome (PFPS) found in both athletes and non-athletes, including the rowing population (Thornton et al., 2016). Though PFPS is a pathology that involves anterior knee pain, potential risk factors are associated to hip muscular weakness and anterior pelvic tilt. The authors identified weaknesses measured of the gastrocnemius, hamstrings, and quadriceps, as well as iliotibial band tightness in those with PFPS. These hip muscle strength deficiencies can contribute to destabilization of the pelvis causing excessive tilt, as seen in rowers (Mackenzie, Bull, & McGregor, 2008). After identifying those at-risk for PFPS, Waryasz and McDermott (2008) proposed possible prehabilitation interventions including a dynamic warm-up, low intensity exercises, stretching protocols, power, multi-joint exercises and most notably, isolation exercises for identified muscle groups. These isolation exercises targeted strengthening a single muscle group, while providing a minor effect on other muscle groups that are not isolated during regular exercise. The intent of these prehabilitation stretching and isolating exercises are comparable to that of the yoga asanas in the current study in that muscle balance between flexion/extension, abduction/adduction, internal/external rotation actions is pursued for both strengthening and stretching in order to function optimally and prevent injury. Although the current study did not measure injury risk reductions, our findings concur with Waryasz and McDermott's (2008) conclusions in that the low intensity ROWGA program dually focused on enhancing strength and flexibility to improve hip muscle strength and balance in the LPH complex. By understanding the link between compensatory rowing-related techniques related to asymmetrical HMS, reduced hip ROM, and the lumbo-pelvic kinematics during a rowing stroke (Buckeridge et al., 2014), rowing-related injury prevention and rehabilitation may be augmented with yoga-based therapeutic practices.

Based on the evidence in the current study and relevant literature, the significant gains observed in the peak isometric HMS groups in more than just rowing specific muscles helps demonstrate the potential benefit of the ROWGA program in supporting and maintaining the musculature around the hip. Although not measured directly, the gains in peak isometric HMS could infer that the inclusion of a ROWGA programme into the training cycle of the participants may have enhanced strength and stability in the hip and pelvic region.

5.2.1 Peak Isometric Agonist-Antagonist Hip Muscular Strength Ratios

Muscular strength balance at specific joints is determined by the ratio of the forces produced between the agonist and antagonist muscle groups (Pontaga, 2004). Opposing muscle groups of a joint act reciprocally to assist controlled and coordinated movements of the limbs and prevent musculoskeletal injuries (Pontaga, 2004). Muscular weaknesses and asymmetries at the hip and lower limb during the rowing stroke have been reported to increase risk of injuries and negatively impact athletic performance in rowers (Buckeridge et al., 2014). Lower back, pelvic, and hip injuries have been attributed to strength imbalances between agonist and antagonist muscle groups within the rowing population (Rumball et al., 2005). Targeted stretching and strengthening programs to complement sport specific strengthening for athletes have been suggested by previous studies to improve strength imbalances, pelvic stabilization, and athletic performance (Nadler et al., 2002., Page, 2012; Polsgrove et al., 2016).

In the current study, the Iyengar yoga-based ROWGA was specifically developed to target hip and pelvic stability, which is achieved through balanced strength and ROM of hip and pelvis musculature for movement in the sagittal (flexors/extensors), transverse (abductors/adductors), and frontal (internal/external rotators) planes. We found no significant differences between the pre and post intervention peak isometric AAHMS ratios after normalizing to each participant's body weight (in kg). These findings confirm that muscular strength balance did not change and was maintained throughout the intervention. Due to the highly repetitive nature of rowing and high impact forces on the lumbar spine and hip joint (Thornton et al., 2016), it is logical to expect strength imbalances and compensatory action asymmetries within rowers. Based on the existing literature, there was an expectation that muscular imbalances might exist within a competitive rowing population, recognizing that the sport is posteriorly driven in the sagittal plane (Buckeridge et al., 2014; Rumball et al., 2005). Therefore, it is reasonable to infer that the ROWGA program potentially contributed to mitigating such muscular strength imbalances based on there being no significant changes in the peak isometric AAHMS ratios through training and competitive season.

Strength asymmetries around the hip may lead to pelvic tilt or ipsilateral asymmetries (McGregor et al., 2002), and affect load transfers from the pelvis to the feet (Mitchell et al., 2008).

The study by Niemuth, Johnson, Myers, and Thieman (2005) tested for peak isometric HMS differences on injured and non-injured legs of recreational runners. They reported no significant bilateral differences in HMS for the non-injured runners, whereas, the injured runners were more likely to exhibit bilateral imbalances in the hip abductor and also hip flexor muscle groups. Niemuth et al. (2005) hypothesized that strength asymmetries in the abductors/adductors, and internal/external rotators, could cause other surrounding muscles to be overworked, such as the hip flexors/extensors, therefore leading to an increased risk of injury and compensatory postures to the lower back and hips, such as pelvic tilt (McGregor et al., 2002). Although in their study, the participants were runners and the research was a descriptive analysis design, it is analogous to rowing as running is also a repetitive, sagittal plane posterior chain driven sport. The strength measurement protocols employed by Niemuth et al. (2005) were identical to the current study. Findings of Niemuth et al. (2005) support the importance of maintaining muscle balance strength ratios, and in particular abductor/adductors, to prevent injury as purported in the present study. This supportive mechanism can assist in stabilizing the hip and pelvic musculature during athletic performance. Although no cause-and-effect relationship was established between pain associated to overuse injuries and muscular weaknesses, the authors reported a link between the weak hip abductor/adductor ratios with injured legs and hip muscular imbalances. Therefore, according to Niemuth et al. (2005), the results of their prospective study measuring hip strength on a group of beginner runners infer that hip muscle imbalances may lead to associated overuse injury and that the addition of strengthening exercises which address weak hip muscles may assist with subsequent treatment and prevention. In keeping with the goal of injury prevention, the ROWGA asanas were aimed to address small supportive muscle groups in the LHP complex to support and maintain AAMHS ratios. Given that no changes were observed between the abduction/adduction muscle group ratios pre-post further demonstrates the feasibility of ROWGA program to achieve this goal.

In summary, the associations between muscular imbalances and injuries from repetitive sport specific actions support the ROWGA program's aim to maintain muscular balance within the agonist-antagonist hip muscle groups. Although the potential contributions of the concurrent on-water, on-land (rowing ergometer), and strength and conditioning training during the ROWGA intervention cannot be formally teased out, the current results indicate that the rowers maintained a consistent muscular strength balance between the peak isometric AAHMS ratios. These observations support the feasibility of the inclusion of a rowing-oriented yoga program within a typical competitive rowing training setting and provide evidence of the program's potential to contribute to biomechanical stability and supporting the LPH complex. The importance of such a training routine is supported in the extant literature (Chang, Slater, Corbett, Hart, & Hertel, 2017; Weerts et al., 2019).

5.3 Hip Flexion Range of Motion

The decreased hip flexion ROM observed may have been a result of a compensatory mechanism for excessive lumbar spine ROM, which is often seen in rowers during ergometer and on-water rowing training seasons (Wilson, Gisanne, & McGregor, 2014), though not measured in this study.

Restrictions in ROM at either the hip, pelvis and lumbar spine during rowing is suggested to lead to compensatory hypermobility at another segment (Weerts et al., 2019), and restricted ROM can be related to tight surrounding muscles such as hip flexors (Thornton et al., 2016). Hyperflexion of the lumbar spine, and limited hip and pelvic ROM has been related to higher loads with the spine and thus giving rise to pain in the LPH complex (Weerts et al., 2019). In light of the repetitive nature of rowing and the repeated high compressive forces and extreme ROM at the joints of the the LPH complex (Rumball et al., 2005), these potential restrictions in joint movement may predispose rowers to injuries of the acetabular labrum, particularly in individuals that have underlying anatomical abnormalities (Boykin et al., 2013). Since tight, overacting hip flexors have been attributed to pulling the pelvis anteriorly (Schache, Blanch, & Murphy, 2000), the asanas included in the ROWGA of this study focused on proper hip flexion and hip openers. Inadequate pelvic rotation due to muscular tightness not only interferes with efficient energy transfer but increases the chance of lower back injury associated with anterior pelvic tilt (McGregor et al., 2002). We observed a decrease in passive hip flexion ROM following the ROWGA program, and this decrease was seen bilaterally. These findings may be associated with the significant gains in hip extensor muscle strength also observed. Alternatively, the decreased hip flexion ROM observed may have been a result of a compensatory mechanism for excessive lumbar spine ROM, which is often seen in rowers during ergometer and on-water rowing training seasons (Wilson et al., 2014), though not measured in this study. It is also plausible that the ROWGA program did not focus heavily enough on eliciting greater hip flexion ROM while maintaining a neutral pelvis, as seen during the catch position. No normative hip ROM values for male varsity level rowing athletes were found in the literature. As there are no data against which to compare the current hip ROM scores, particularly for competitive male varsity rowers, this current study provides an original contribution to the existing relevant body of literature.

During the rowing stroke, there is repetitive transferring of power from the catch position (hip and lumbar spine flexion) to the power transition phase (hip and lumber spine extension) while rowing (Thornton et al., 2016). Due to the highly intensive training and competitive season and the overall increase in hip muscle strength, there could be increased tension in the hip and lumbar spine tissues which could, in turn, limit joint ROM. Specifically, increased strength in the posterior chain could result in tightening of the hip and lumbar spine extensor muscles and tendons, as well as the thoracolumbar fascia, which could explain the reduced hip flexion ROM seen in this study. Koutedakis, Frischknecht, and Murthy (1993) postulated that the presence of tight posterior pelvic muscles, such as the gluteal and hamstring muscle groups may impact the lumbo-pelvic rotation during the drive phase of rowing. During an asana, the muscle is stretched to its maximum length at end ROM in a functional movement (Adling & Bangar, 2017), while fascia is also placed under maximal tension (Findley, 2011; Kuruma et al., 2013; Stecco, Gesi, Stecco & Stern, 2013). It is plausible that the connective tissues could dynamically adapt to this loading, either from increased muscle strength or tensioning, by increasing in thickness, which, may have in turn contribute to the decreased hip flexion ROM (Wilke et al., 2018).

In the present study, the asanas chosen for the ROWGA sequence were balanced on both the right and left sides engaging in similar movements and thus were expected to achieve comparable results in muscular development and ROM. Riganas et al. (2010) have purported the importance that having symmetrical, adequate hip flexibility can assist in decreasing the risk of injury occurrence as it allows the lower limbs to better biomechanically position the trunk into the catch position. They found that oarside influenced hip muscle strength and flexibility patterns of the rower in order to accommodate for rowing techniques. They suggested exploring and designing both strengthening and stretching programs in order to compensate for muscular strength and flexibility imbalances in further research. In the current study, despite the participant group including 8 right and left oarside rowers, no significant differences between left and right sides for hip flexion ROM were exhibited. This provides additional evidence supporting the feasibility of the inclusion of a ROWGA program to enhance bilateral symmetry of hip flexion ROM.

5.4 Limitations

Several limitations of this study should be considered when interpreting the results. There are often risks of errors associated with the measurement of accurate goniometric results (Wakefield et al., 2015). There is contradictory research regarding the validity and reliability of hip goniometry (Gajdosik & Bohannon, 1987; Nussbaumer et al., 2010; Whittle & Levine, 1999). One study suggested that goniometer-based hip measurements may substantially overestimate hip joint ROM due to intersegmental angles such as hip flexion and trunk extension, resulting in limited validity (Nussbaumer et al., 2010). This is likely due to uncontrolled pelvic tilt and issues from inaccurate anatomical placement resulting in the overrating of the goniometric angles (Nussbaumer et al., 2010). Though the ROM measurement reliability was determined to be good in the current study, there may have been potential limitations associated to controlling the pelvis during the protocol.

The rowing team's strength and conditioning program occurred simultaneously with the ROWGA intervention, and focused on strength and power, but not flexibility. This confounding variable may have further influenced the post-intervention peak isometric HMS values. Based on such a high-level training commitment, limitations associated to musculoskeletal fatigue may have also in turn influenced the program outcome measurements. The post intervention measurements were taken 24-48 hours after the last ROWGA practice. However, on the days when post tests were conducted, the participants were required by their coach to attend an intensive morning on-water practice prior to their testing session. This confounding factor may have affected the accuracy of ROM measured that day. In fact, some athletes reported feeling tightness for certain hip actions during post testing ROM measurements.

Finally, the lack of a “non-yoga” control group created a limitation in definitively comparing the results to a population that did not participate in the ROWGA program.

5.5 Conclusions

This study examined the feasibility of a sport specific yoga program on male varsity competitive rowers during their training and competitive season. Based on the findings of the present study, the ROWGA program should be considered a feasible supplement to a current rowing training regime. This study demonstrates that a ROWGA program can be conducted concurrently with the high-volume, high-intensive rowing competitive season. The high adherence to the 9-week ROWGA program provides strong evidence of how feasible it is to implement such a program into a competitive varsity setting. The impact of the ROWGA intervention on peak isometric HMS, and peak isometric AAHMS ratios also provides supportive evidence on the feasibility of incorporating yoga training as a beneficial addition to typical competitive rowing training programs.

This study adds to the body of existing research with the inclusion of a yoga program into current training programs for male varsity rowers. The potential benefits may lead to the prevention of low back, hip and pelvic injuries related to repetitive rowing movements, although prevention remains to be demonstrated. The findings from this preliminary research can help inform coaches and athletes on how to optimize and support hip, pelvic, and lower back strength and flexibility. Further, the preliminary findings of this feasibility study may help inform the development and implementation of a subsequent larger-scale intervention.

5.6 Future Research

It is recommended that similar measures be included in future studies and that intra-tester reliability be well established prior to commencing data collection.

Future studies should include a follow up to the post intervention measurement in order to determine if any changes in hip flexion ROM, peak isometric hip muscle strength, and agonist-antagonist hip muscle strength ratio balances arise in the participants subsequent to ceasing the ROWGA intervention, while continuing with the regular rowing training. Moreover, research expanding on this current study should include a control non-yoga group, and randomly assign rowers to the yoga or control group to better determine the impact of the ROWGA program.

Although a 9-week yoga intervention is comparable to similar interventions in the existing literature, a longer intervention with more sessions might elicit greater outcomes. Since the rowers in this study were at a novice level in yoga practice, a higher proficiency may have created a greater impact. Having full hip flexion ROM is critical at the catch position in order to keep the pelvis out of posterior tilt and prevent injury to the LPH complex. For this reason, it would be useful for future studies to include a greater focus on asanas that promote optimal hip flexion ROM while maintaining a neutral pelvic position.

In order to successfully assess the effectiveness of yoga for athletic populations, the training regime outside the intervention must have controlled parameters, particularly around time of data collection and assigning a “non-yoga” control group. Though this study demonstrates a feasible yoga program during a highly intensive and competitive rowing season, it is important to note that other training components in the athletes' program be scheduled in a way that allows for optimizing ROWGA-induced benefits.

Although the current study provides a platform for future research to investigate the efficacy of a yoga as hip and pelvic injury prevention for rowers, they should also consider utilizing refined assessment tools.

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7. Appendix

Appendix A. Human Research Ethical Board

University of Victoria | Office of Research Services | Human Research Ethics Board
Administrative Services Building Rm B202 PO Box 1700 STN CSC Victoria BC V8W 2Y2 Canada
T 250-472-4545 | F 250-721-8960 | uvic.ca/research | ethics@uvic.ca

Certificate of Renewed Approval

PRINCIPAL INVESTIGATOR:	**Alanna Kit**	**ETHICS PROTOCOL NUMBER:** Minimal Risk Review - Delegated	**18-137**
UVic STATUS:	**Master's Student**	ORIGINAL APPROVAL DATE:	15-Jun-18
UVic DEPARTMENT:	**EPHE**	RENEWED ON:	02-May-19
SUPERVISOR:	**Dr. Kathy Gaul**	APPROVAL EXPIRY DATE:	14-Jun-20

PROJECT TITLE: **Effects of a Yoga Programme on Hip Flexibility, Strength, and Standing Balance with University Varsity Male Rowers**

RESEARCH TEAM MEMBER: Dr. Kathy Gaul, Supervisor (UVic); Dr. Sandra Hundza, Committee Member (UVic); Greg Mulligan, Lab Coordinator (UVic); Jed Leech, Research Assistant (UVic); Marie Schultz, Research Assistant (UVic); Gio Corlazzoli (UVic); Francesca Casciola (UVic)

DECLARED PROJECT FUNDING: **None**

CONDITIONS OF APPROVAL

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Modifications
To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.

Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

[redacted]

Dr. Rachael Scarth
Associate Vice-President Research Operations

18-137 Kit, Alanna

Certificate Issued On: 02-May-19

Appendix B. Recruitment Package Email to Athletes

University of Victoria | School of Exercise Science, Physical & Health Education

A Feasibility Study to Test the Potential Efficacy of a Rowing-Related Yoga Programme on Male Varsity Competitive Rowers

My name is Alanna Kit and I am a graduate student at the University of Victoria in the School of Exercise Science, Physical and Health Education. As a graduate student, I am required to conduct research as part of the requirements for a degree in Master of Science in Kinesiology. It is being conducted under the supervision of Dr. Kathy Gaul You may contact my supervisor at [redacted]

The purpose of this email is to formally invite you, as the coach of the University of Victoria's Vikes Male Rowing Team, to be involved in a research project being conducted entitled: **A Feasibility Study to Test the Potential Efficacy of a Rowing-Related Yoga Programme on Male Varsity Competitive Rowers**

The following is what we'd like to provide via email to your athletes should you agree by signing at the end this document to allow me to recruit your team members to volunteer in this study:

Background

Current research provides evidence around the practice of yoga and the isometric contractions that occur in every anatomical plane providing an increase in muscle length. This has been shown to improve joint strength, muscular flexibility and range of motion around the joint. Yoga classes have begun to be implemented into training programs for athletes due to the benefits of injury prevention, athletic performance optimization, neuromuscular efficiency, leading to joint mobility and stability by enhancing the muscles surrounding. Such practices are beginning to be introduced into rowing programs, however the effectiveness of specific pose sequence and yoga style on enhancing hip flexibility, mobility and function as yet to be determined[1]. By providing evidence that a specific yoga program can have enhance range of motion, strength, and muscular length around the hip joint, it is anticipated that coaches, athletes, and organizations may be encouraged to implement such programs. This could enhance athletic performance by preventing short or long term injuries in the hip and lower back regions.

[1] Kozak, C. Yoga for Rowers: Building Physical & Mental Strength. 2009

Purpose and Objectives

The purpose of this study is to determine the effects of a specific "Yoga for Rowers Programme" (ROWGA) on hip flexibility, hip muscle strength, and muscle length in male varsity rowers.

Importance of this Research

Muscles involved in repetitive hip movements become imbalanced, weakened, and lack proper muscle contractile efficiency. This may catalyze instability, decreased range of motion (ROM) and strength around the hip joint often seen in elite rowers and becomes chronic lifelong issues for rowers post competitive careers in many cases. Since rowing increases the risk around the hip and lower back, Iyengar yoga could help enhance the physical factors protecting against the injuries and imbalances common to rowers, thus improving hip and lower back function. The findings of this study may provide evidence to support the inclusion of a specific back and hip training program that may lead to improved movement technique through greater hip stabilization and muscle activation.

If a rowing-specific yoga program can improve range of motion, strength and muscular length around the hip joint, it could enhance athletic performance and potentially prevent short or long term injuries in the hip and lower back regions. The findings of this study could help to refine training programs by incorporating yoga as a means of improving hip function.

Participation

Members of the Vikes Men's Rowing Team are being invited to participate in this study. The team is representative of competitive male varsity rowers. Participation in this study will be open only to Vikes Men's Varsity Rowing Team.

Participation in this study will include 1 preliminary testing week consisting of 3 pre-test days (24-48 hours apart), 16 intervention sessions spread out over an eight-week period followed by 1 post intervention testing session in the next week, for a total of 10 weeks.

Participation in this study is completely voluntary. If you choose to volunteer, you maintain the right to withdraw from the study at any time. Participants will be reminded at the beginning of every testing session that they can withdraw without negative consequence if they so choose. If a participant choses to withdraw, any data collected up until that point will be destroyed and will not be included in the study. Participation in this study is not mandatory. Whether or not you choose to participate, it will not impact your status on the team in any way. This has been agreed and signed by your coach.

Participation in the study will cause minimal inconvenience to the team. Participants may experience fatigued muscles and soreness from the testing procedures, although the intensity will not be as high as typically experienced in regular team training. To reduce this possibility, testing sessions will be spaced approximately 24-48 hours apart to allow for adequate recovery. There will be minimal risk of obtaining an injury; the possibility of injury during testing being no greater than that of your regular training, which is typically of greater intensity than any of the physical performance testing in this study.

If an injury is sustained, or any discomfort is experienced by a participant, the principal investigator is well trained to treat primary injuries. If the injury appears to require additional care, on-site Vikes staff are accessible and prepared to take the necessary steps within the University's protocols in response to the situation.

In the case of a medical emergency the onsite Vikes staff will handle injuries and discomfort. The principal investigator (Alanna Kit) is certified in standard first aid and CPR/AED level C (expires 06/15/2020) and will assist as needed. The research assistants will be present for all data collection sessions however they will not take on any responsibilities during medical emergencies other than to offer assistance as directed by those in charge. All research staff has knowledge of human anatomy and will refer a participant to the team's trainers and staff if they feel a participant is showing signs of an injury or discomfort throughout the testing sessions.

Volunteers will be excluded from participation in the study if they have sustained an injury that may prevent safe performance of any research related performance tests. Injuries that have prevented participation in the team training may include (but are not limited to): sprains, breaks, muscle and/or, ligament tears, and unresolved concussions.

There are no known inconveniences to the participants. Research and testing will be conducted around the participant's schedules and take place at the regular training facility (UVIC, Centre for Athletics, Recreation, and Special Abilities). Those team members who chose not to volunteer will engage in a rowing specific training session organized by the coach.

Benefits

The yoga program will allow the team to gain knowledge of the importance around appropriate yoga sequences for rowing performance, personal physical characteristics related to hip function, and possibly reduced injury risk. They will also have the opportunity to participate in an academic research project.

You may contact me, the primary researcher, by email [redacted] or you may contact my supervisor, Dr. Kathy Gaul: [redacted], if you have any further questions. In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Appendix C. Personal information for study recruitment

Thank you for your interest in the research study. Please answer the following questions to make sure you meet the criteria for the study.

1. What is your birthdate?

2. How many years have you competed on the Vikes Rowing Team at UVIC?

3. Do you participate in any additional training outside of the Vikes Rowing Team?

3. Have you experienced an injury that has restricted your participation in your team training program? If so, explain.

4. Have you experienced a hip, knee, lower back, or hamstring related injury within the past 12 months? If so, explain.

6. Do regularly attend yoga classes? If so, when was your last class?

Appendix D. ROWGA Sequence in Sanskrit (and English) for Sessions 1-17

Warm Up Sequence

Bharadvaja's Twist
Marjaryasana (Cat pose)
Bitilasana (Cow pose)

Standing Sequence

Utkatasa (Chair pose)
Tadasana (Mountain pose)
Uttanasana (Standing forward bend)
Adho Mukha Svanasana (Downward dog)
Virabhadrasana II (Warrior II)
Viparita virabhadrasana II (Reverse warrior pose)
Trikonasana (Triangle pose)
Parivrtta Trikonasana (Revolved triangle pose)
Parsvottanasana (Intense side stretch pose)
Virabhadrasana II (Warrior II)
Virabhadrasana (Warrior I)
Baddha Virabhadrasana (Humble warrior pose)
Padangusthasana (Big toe pose)
Parasarita Padottanasana (Wide-legged forward pose)

Adho mukha svanasana (Downward dog)
Uttanasana (Standing forward bend)
Adho mukha svanasana (Downward dog)
Utthita Ashwa Sanchalanasana (Lunge pose)
Dekasana (Airplane pose)
Virabhadrasana III (Warrior 3)
Utkatasa (Standing forward bend)
Utthita Ashwa Sanchalanasana (Lunge pose)
Parivrtta Anjaneyasana (Twisted lunge)

Seated Closing Sequence

Adho Mukha Svanasana (Downward dog)
Utthan Pristhasana (Lizard pose)
Eka Pada Rajakapotasana (Pigeon pose)
Agnistambhasana (Fire log pose)
Ardha Matsyendrasana (Half lord of the fish pose)
Paripurna Navasana (Boat pose)
Salamba Sarvangasana (Supported shoulder stand)
Halasana (Plow pose)
Dandasana (Staff pose)
Paschimottanasana (Seated forward fold)
Janu sirasana (Head to knee forward bend)
setu bandhasana (Bridge pose)
Ananda Balasana (Happy baby pose)
Supta Matsyendrasana (Cross twist pose)
Savasana (Corpse pose)

Appendix E. Data Collection Sheet

Participant Number:
Date:

Anthropometrics

Table 1. *Body weight (kg) and height (cm)*

Anthropometrics	
Body weight	
Body height	

Peak Isometric Hip Muscle Strength Testing

Table 2. *Muscle strength testing of* ***left*** *hip (in N)*

Left hip	**Trial 1**	**Trial 2**	**Trial 3**	**Average of 2 Closest**
Hip flexors				
Hip abductors				
Hip adductors				
Hip extensors				
Hip internal rotators				
Hip external rotators				

Table 3. *Muscle strength testing of* ***right*** *hip (in N)*

Right hip	**Trial 1**	**Trial 2**	**Trial 3**	**Average of 2 Closest**
Hip flexors				
Hip abductors				
Hip adductors				
Hip extensors				
Hip internal rotators				
Hip external rotators				

Hip Flexion Range of Motion

Table 4. *Passive* ***left and right*** *hip range of motion (ROM; in °)*

Hip Flexion	Trial 1	Trial 2	Trial 3	Average of 2 Closest
Left				
Right				

Appendix F. Peak Isometric Hip Muscle Strength Testing Protocols

Tester A resisted the force of the movements produced by the muscle force. Once permission was obtained from the subjects to mark their bodies using anatomical landmarks, the device was positioned 5 cm above the most prominent point of the lateral epicondyle prior to measurement within the participant, except when measuring internal and external rotators. Tester A positioned the device on the tibia 5 cm from the lateral aspect of the malleolus. Each measurement was taken three times each test and averaged to assure accuracy and limit intra-testing variability. Testing protocols were followed precisely adhering to accurate results.

Abductors and Adductors

To measure hip adductor strength, the same digital force gauge was placed on the medial surface of the thigh proximal to the medial femoral epicondyle and on the lateral surface of the thigh proximal to the lateral femoral epicondyle to access hip abductor strength (Figure F.1).

Figure F.1 *Force gage testing (abductors)*

Internal and External Rotators

To measure lateral (external) hip rotation, the force gauge was placed at the distal medial lower leg, proximal to the medial malleolus of the ankle. Medial (internal) hip rotators were measured with the dynamometer placed on the lateral surface of the distal lower leg (see Figure F.2).

Figure F.2

Force gage testing (external rotation)

Flexors and Extensors

The subject was in prone position, while the force gauge was placed on the anterior surface of the thigh isolating psoas major and iliacus for the measurement of hip flexors, then on the posterior surface of the thigh isolating gluteus major for hip extensors (see Figure F.3).

Figure F.3

Force gauge testing (hip extensors)

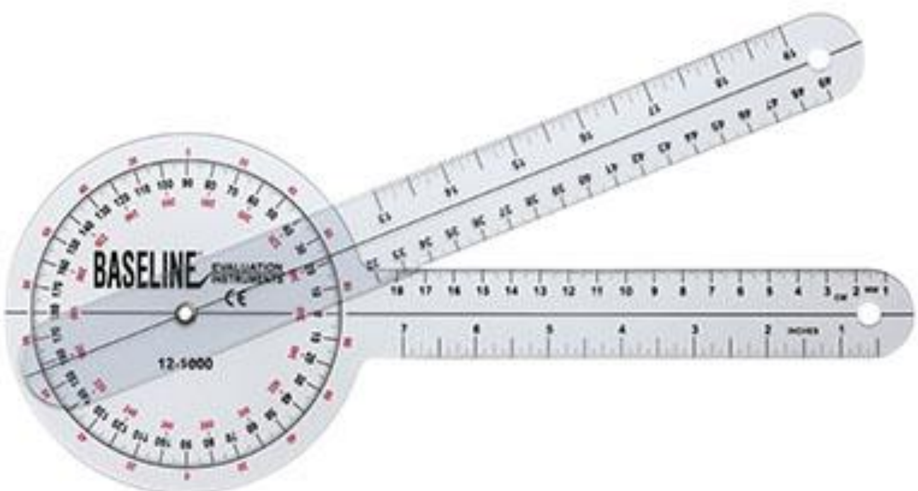
Appendix G. Range of Motion Testing Protocol

Range of Motion

The stationary arm of this device was positioned parallel to the long axis of the stationary thigh, while the second device arm (moveable arm) was held parallel with the moving segment of the limb being measured (see Figure G.1). The intersecting pin (axis) was positioned directly over the acetabular articulation of the hip.

Figure G.1

Standard plastic double-armed baseline® plastic goniometer with a 360-degree protractor, in one-degree increments – to measure range of motion.



Hip Flexion

For hip flexion, the subject was in supine position with the knee initially extended. The subject's knee was flexed as hip flexion occurred to ensure hamstring length did not limit the movement. The contralateral leg was extended to prevent posterior tilting of pelvis. Primary investigator began with the fulcrum of the goniometer placed on the reference point of the greater trochanter (see Figure G.2). The proximal goniometer arm was aligned with the lateral midline on the pelvis and trunk, while the moving goniometer arm was aligned along the lateral midline of the subject's thigh, using the lateral femoral epicondyle as a landmark. Primary investigator set the goniometer at 90° for every subject ensuring the baseline starting point was identical. As the secondary assistant, Examiner B began to raise the flexed leg to the point at which they felt pelvic tilt to begin. Measurements were taken at this time by testing assistant, RA-1.

Figure G.2

Goniometer testing (hip flexion)

Appendix H. Attendance Rate Per ROWGA Session (n=16)

Figure H.1

Attendance rate per ROWGA session (1-17)

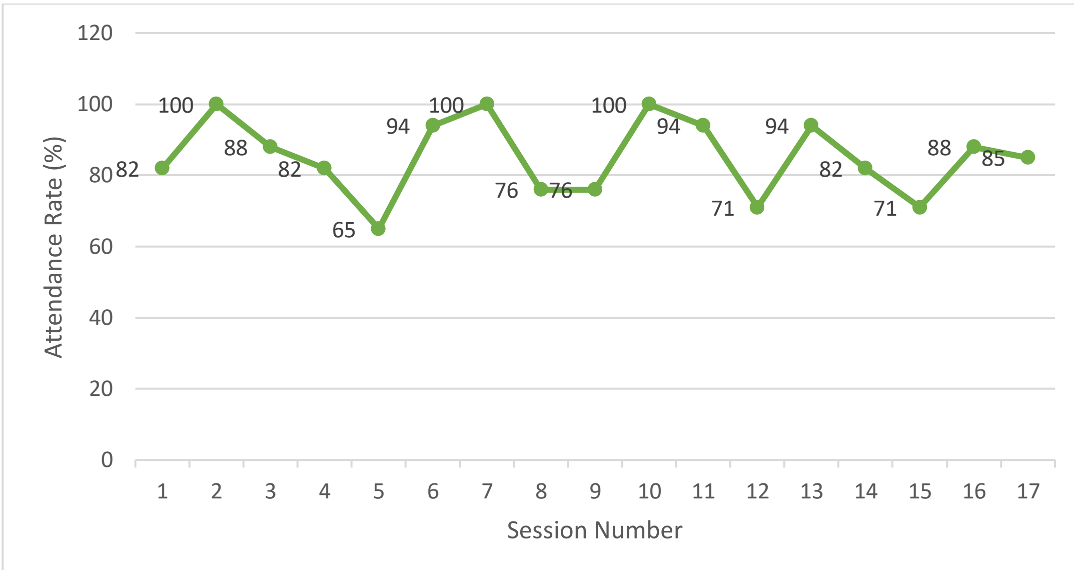


Figure H.2

Number of classes attended per participant