The Effects of Self-Induced Multi-Bar Massage Rolling on Physical Performance in Collegiate Level Athletes

Milos Popovic

Department of Education and Sports Science

University of Stavanger

Universitetet i Stavanger

FAKULTET FOR UTDANNINGSVITENSKAP OG HUMANIORA

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Abstract

Purpose: The purpose of this study was to examine the effects of 5-, 10-, and 15-minute massage with a mechanical self-induced multi-bar massage roller on balance, anaerobic power, and anaerobic and aerobic capacity. **Methods:** Thirteen (volleyball, n = 7; basketball, n = 2; lacrosse, n = 2; handball, n = 1; strength training, n = 1) male collegiate level athletes (mean ± SD; age = 25.15 ± 5.6 years; height = 1.84 ± 0.7 m; body mass = 82.4 ± 9 kg) completed the study. The treatment consisted of massage-rolling 4 different muscle groups in the following order: 1) gastrocnemius, 2) hamstrings, 3) quadriceps, and 4) gluteus maximus. Total massage time was split equally between the 4 muscle groups. Participants completed 4 testing sessions (1 control condition and 3 experimental conditions). During experimental conditions participants received the treatment before proceeding to testing. Each testing session participants completed a static single-leg balance test, followed by a standardized warm-up, then a squat jump test, a countermovement jump test, Bosco's 30-second jump test, and a 20 m shuttle-run test. **Results:** None of the differences were statistically significant ($p > 0.05$). Results indicated that the effects were not massage length dependent. Trivial to large ($d = 0.1 – 0.8$) effects were observed for the static single-leg balance test after the massage protocols. For the squat jump test, an overall trivial ($d \geq -0.09$) effect was observed after the massage protocols. For Bosco's 30-second jump test, adverse results were observed after the massage protocols, with moderate to trivial ($d \geq -0.6 – d = \leq 0.2$) negative and positive effects. Overall trivial ($d \leq 0.1$) effects were observed for the 20 m shuttle-run test after the massage protocols. The magnitude-based inference analysis indicated the effects of the massage protocols were unclear for most physical performance parameters. For sway velocity on left foot, 5-, 10-, and 15-minute massage protocols were shown to be likely beneficial (88.8%, 90%, and 86.4%, respectively). The 5-minute massage protocol was shown to be 76.5% unlikely beneficial for the number of vertical jumps at 15 seconds, while the 10-minute massage protocol was shown to be 56.8% unlikely beneficial for heart rate during Bosco's 30-second jump test. **Conclusion:** Five, 10, and 15 minutes of self-induced multi-bar massage rolling may have some positive effects on balance performance, but does not appear to affect anaerobic power and anaerobic and aerobic capacity in any way that would have an impact on athletic performance.

Keywords: pre-exercise, self-myofascial release, roller-massager, physical performance

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1 Introduction

It is well documented that massage has been used as a method to enhance performance and facilitate recovery after vigorous exercise (Harris, 1966). Massage has been defined as: "*a mechanical manipulation of body tissues with rhythmical pressure and stroking for the purpose of promoting health and well-being*" (Cafarelli & Flint, 1992, p. 1). For instance, Classic Western massage (Swedish massage), which is the most widespread massage method, is being utilized by coaches and athletes globally with the notion that it improves performance and facilitates recovery through various mechanisms (Weerapong, Hume, & Kolt, 2005). However, evidence that supports these claims is lacking in the research literature (Cafarelli & Flint, 1992; Weerapong et al., 2005).

In recent years, the use of a massage therapy technique known as myofascial release has become increasingly popular in athletic settings (Schroeder & Best, 2015). Barnes (1997) describes myofascial release as: "*a hands-on soft tissue technique that facilitates a stretch into the restricted fascia*" (p. 232). Myofascial release is therefore meant to restore the length and the elasticity of the fascia, thus improving mobility (Barnes, 1997). Massage therapy isn't always accessible in certain athletic settings due to time constraints (Barnett, 2006). Self-myofascial release has instead been introduced as a more accessible method that could offer effects similar to myofascial release (Schroeder & Best, 2015). While myofascial release is performed by a clinician, self-myofascial release is performed by the individual themselves with the help of a foam roller or roller massager (Beardsley & Škarabot, 2015). In recent years, self-myofascial release has become a trend and foam rollers and roller massagers are now commonly used in commercial gyms and strength and conditioning facilities (Healey, Hatfield, Blanpied, Dorfman, & Riebe, 2014). Because of the growing trend of self-myofascial release and the use of foam rollers and roller massagers, unscientific claims of its effects are being made (Schroeder & Best, 2015). Apart from increasing joint range of motion, foam rolling and roller massaging is also believed to increase performance and blood lactate removal through various biomechanical (Schleip, 2003), physiological (Schleip & Müller, 2013) and neurological (Tozzi, 2012) mechanisms.

Because of conflicting results, to this date, there is no consensus regarding myofascial release's various mechanisms (Cheatham, Kolber, Cain, & Lee, 2015), effects on performance (Beardsley & Škarabot, 2015), muscle recovery (Schroeder & Best, 2015), blood lactate concentration, and optimal massage duration (Mine, Lei, & Nakayama, 2018). An abundance of research has focused on the effects of self-myofascial release on joint range of motion and power

development.

MacDonald et al. (2013) examined the effects of foam rolling on knee joint range of motion and neuromuscular performance of the quadriceps. The results showed a statistically significant increase in knee joint range of motion ($p < 0.001$) and no statistically significant difference in neuromuscular performance of the quadriceps between the control and foam rolling condition (MacDonald et al., 2013). Sullivan et al. (2013) examined the effects of self-myofascial release with a mechanical roller massager on joint range of motion, muscle activation using electromyography, and maximum voluntary contraction force. The study's results showed a statistically significant increase in joint range of motion ($p < 0.0001$) and no statistically significant difference in muscular activation and maximum voluntary contraction force (Sullivan et al., 2013). However, some studies found no statistically significant differences in joint range of motion after self-myofascial release with a foam roller and roller massager (Couture, Karlik, Glass, & Hatzel, 2015; Murray, Jones, Horobeanu, Turner, & Sproule, 2016; Hodgson, Lima, Low, & Behm, 2018).

Other studies focused mainly on the examination of the effects of self-myofascial release with a foam roller or roller massager on various aspects of performance (Healey et al., 2014; D'Amico & Paolone, 2017; Giovanelli et al., 2018). Healey et al. (2014) examined the effects of foam rolling compared to planking on vertical jump height and power, agility, and isometric force. The results showed no statistically significant differences in vertical jump height, power, agility, and isometric force between the foam rolling and planking condition (Healey et al., 2014). In another earlier study by Peacock et al. (2014), the results showed a statistically significant increase in vertical jump ($p = 0.012$), standing long jump ($p = 0.007$), 18,3 m pro-agility test ($p = 0.001$), 37 m sprint ($p = 0.002$), and indirect 1 repetition maximum bench press ($p = 0.024$) performance after a total-body warm up consisting of foam rolling. D'Amico and Paolone (2017) examined the effects of foam rolling on performance and blood lactate levels between two 800 m runs. The results showed no improvement in running performance and blood lactate levels between the two 800 m runs (D'Amico & Paolone, 2017). In a recent study, Giovanelli et al. (2018) examined the effects of self-myofascial release with a foam roller on running economy, squat jump, and countermovement jump performance. The results showed an increase in running economy, no statistically significant difference in squat jump, and a statistically significant difference in countermovement jump performance ($+7.9 \pm 6.3\%$, $p = 0.002$) after a 16-minute foam rolling protocol (Giovanelli et al., 2018).

There is a lack of research that examines and compares the effects of shorter and longer bouts of self-myofascial release on performance. Research examining the effects of self-myofascial release with foam rollers or roller massagers on blood lactate concentration is lacking. Only few studies (Sullivan et al., 2013; Bradbury-Squires et al., 2015; Couture et al., 2015) have examined and compared the effects of foam rolling and roller massager protocols of different duration. Furthermore, Schroeder and Best (2015) have pointed out that the performance benefits of self-myofascial release may be lenght dependent. Only two studies (D'Amico & Paolone, 2017; Giovanelli et al., 2018) have examined the effects of self-myofascial release on blood lactate concentration in addition to performance. Previous studies (MacDonald et al., 2013; Peacock et al., 2014; D'Amico & Paolone, 2017) mostly had subjects self-administering foam rolling (using their own bodyweight) or roller-massaging (using their own force), with one study (MacDonald et al., 2013) also using a standard cadence. Foam rollers that were used varied in size and length and were either made of polyethylene or a hollow polyvinyl pipe and outer ethylene acetate foam (Cheatham et al., 2015). Only two studies (Sullivan et al., 2013; Bradbury-Squires et al., 2015) used the same roller-massager apparatus which could apply a constant force and cadence. To the researcher's knowledge however, no study has used a mechanical self-induced (where athletes use their body weight to apply force on a fixed rolling cadence) multi-bar massage roller. Therefore, the purpose of this study is to examine the effects of 5-, 10-, and 15-minute massage with a mechanical self-induced multi-bar massage roller on balance, anaerobic power, and anaerobic and aerobic capacity.

1.1 Research Question and Hypothesis

1.1.1 Research question.

What effect 5-, 10-, and 15-minute massage with a mechanical self-induced multi-bar massage roller has on balance, anaerobic power, anaerobic and aerobic capacity?

1.1.2 Alternative hypothesis.

The alternative hypothesis is that the mechanical self-induced multi-bar massage roller will increase balance, anaerobic power, and anaerobic and aerobic capacity, compared to the control condition, with the effects being massage length dependent.

1.1.3 Operational definitions.

Balance in this study, refers to the static single-leg balance and the ability to maintain a specific posture (Panjan & Sarabon, 2010).

Anaerobic power is defined as: "*the ability of muscle tissue to exert high force while contracting at a high speed*" (McGuigan, 2016, p. 260). Tests which measure anaerobic power are of very short duration and consist of explosive movements (McGuigan, 2016).

Anaerobic capacity in this study, refers to the: "*maximal rate of energy production by the combined phosphagen and anaerobic glycolytic energy systems for moderate-duration activities*" (McGuigan, 2016, p. 261), which is quantified as the "*maximal power output during muscular activity between 30 and 90 seconds*" (McGuigan, 2016, p. 261).

Aerobic capacity in this study, refers to the "*maximum rate at which an athlete can produce energy through oxidation of energy sources*" (McGuigan, 2016, p. 261).

2 Theory

The theory chapter consists of five parts: 1) the muscular and neuromuscular system, 2) the plyometric mechanics and physiology, 3) biomechanical factors in human strength, 4) biological energy systems, and 5) how massage can affect physical performance.

2.1 Muscular and Neuromuscular System

There are more than 600 skeletal muscles and approximately 206 bones in the human body, all connected through tendons, ligaments, joints, and nerves (Kenney, Wilmore, & Costill, 2012; Triplett, 2016). This intricate arrangement of muscles and bones is what makes it possible for humans to move (Triplett, 2016).

2.1.1 Muscle anatomy and function.

Each skeletal muscle consists of connective tissue, muscle tissue, blood vessels, and nerves (Figure 1). A connective tissue known as the epimysium covers the entire muscle, from tendon to tendon, and holds it together. All bones are covered by a specialized connective tissue called bone periosteum, to which the tendons are connected (Triplett, 2016). Underneath the epimysium there are small bundles of muscle fibers (fasciculi), each surrounded by a connective tissue called perimysium. Surrounding each of the muscle fibers is a connective tissue called endomysium, that is contiguous with muscle fiber's membrane, sarcolemma (Kenney et al., 2012; Triplett, 2016). Muscle fibers are made up of myofibrils that contain myofilaments called actin and myosin, which are the muscles contraction apparatus (Triplett, 2016).

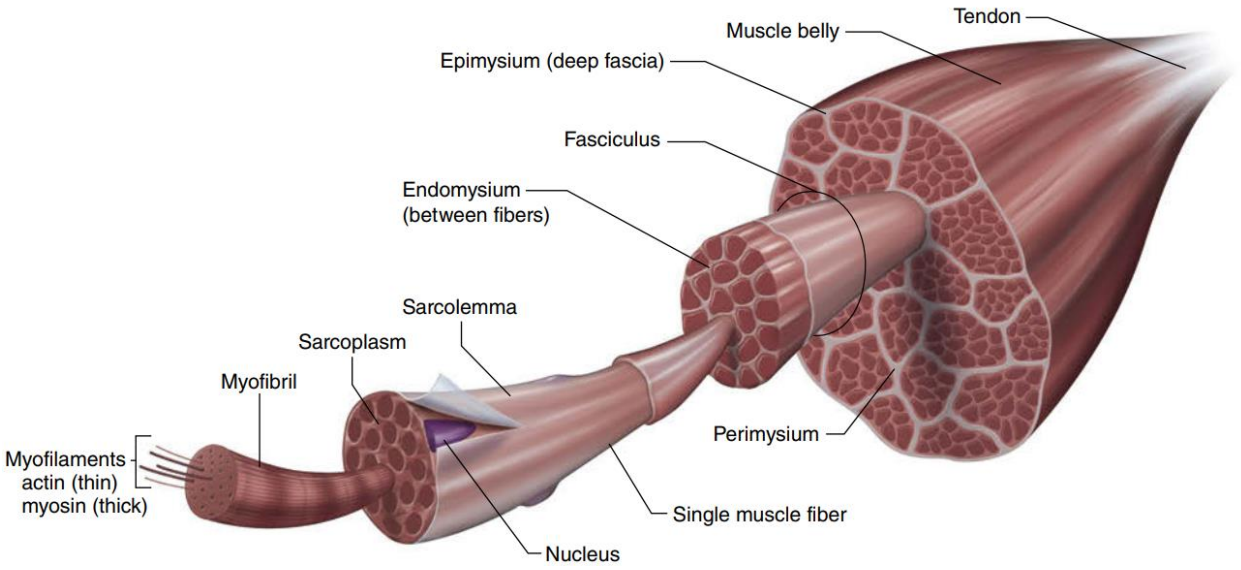

Figure 1. Schematic drawing of the muscle and the connective tissues (Triplett, 2016).

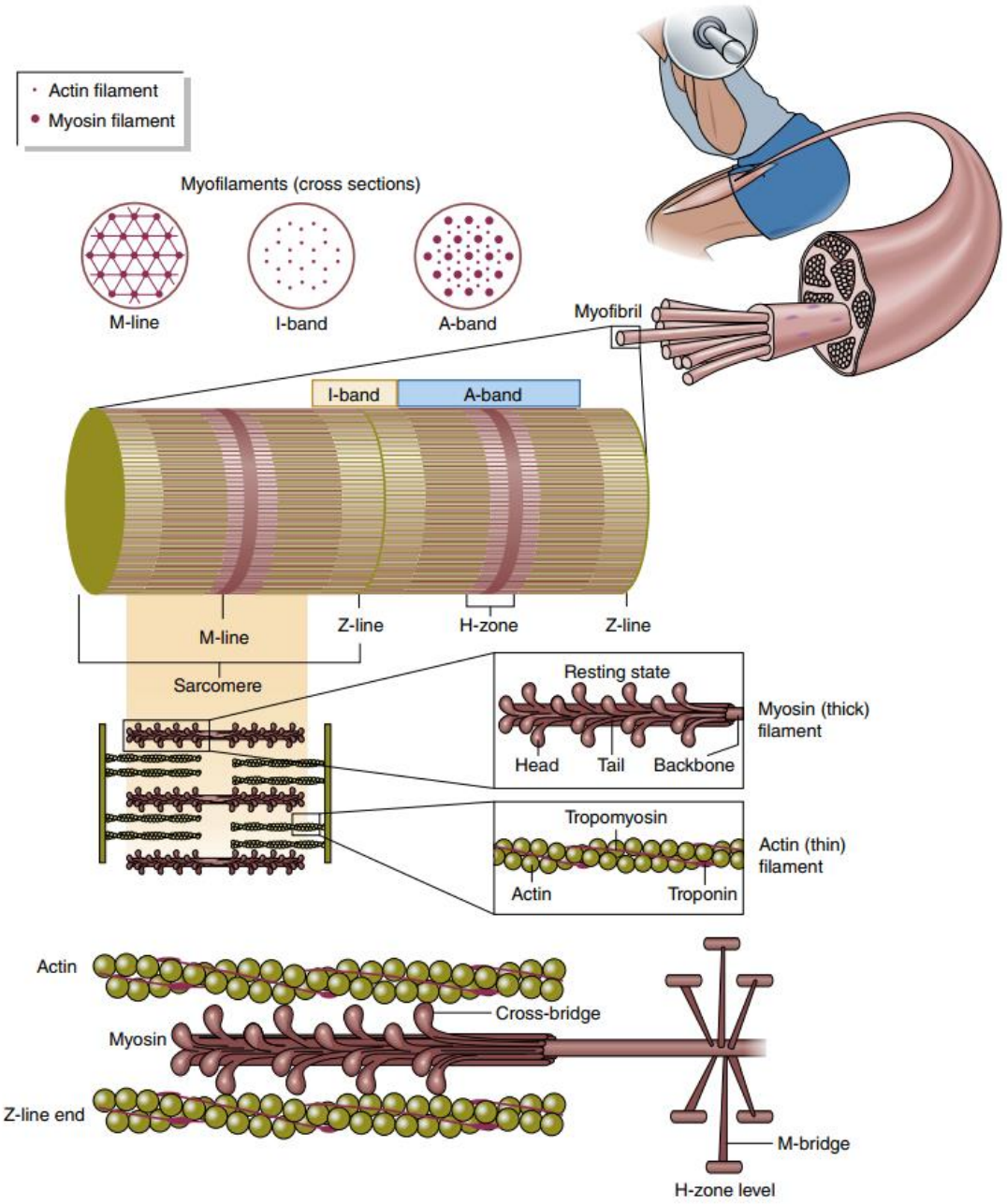

Figure 2. An illustration of the muscle filaments actin and myosin (Triplett, 2016).

Myofilaments are organized longitudinally (Figure 2) into small sarcomeres, which are the basic contractile units of the skeletal muscle (Kenney et al., 2012). Each sarcomere is joined end to end by a thin, dark line called the Z-line. The Z-line is located in the middle of a lighter zone called the I-band, which contains only thin actin filaments (Katch, McArdle, & Katch, 2011;

Kenney et al., 2012). The darker zone, called the A-band, contains both the thin actin and the thick myosin filaments. In the middle of the A-band is an area called the H-zone, which contains only the thick myosin filaments (Triplett, 2016). This longitudinal arrangement of actin and myosin filaments is what gives the muscle fibers its striated appearance (Katch et al., 2011).

When the muscle is stretched, the Z-lines and the H-zone lie furthest apart (Figure 3*a*). During muscle contraction (Figure 3*b*), the actin filaments slide inwards towards the myosin filaments, pulling the Z-lines towards the H-zone and shortening the sarcomere. During this phase, the H-zone and the I-band shrink as well. When the muscle is contracted (Figure 3*c*), the distance between the H-zone and the I-band is the shortest and the actin filaments start overlapping each other (Triplett, 2016). This action of muscle contraction is known as the *sliding-filament theory* (Katch et al., 2011).

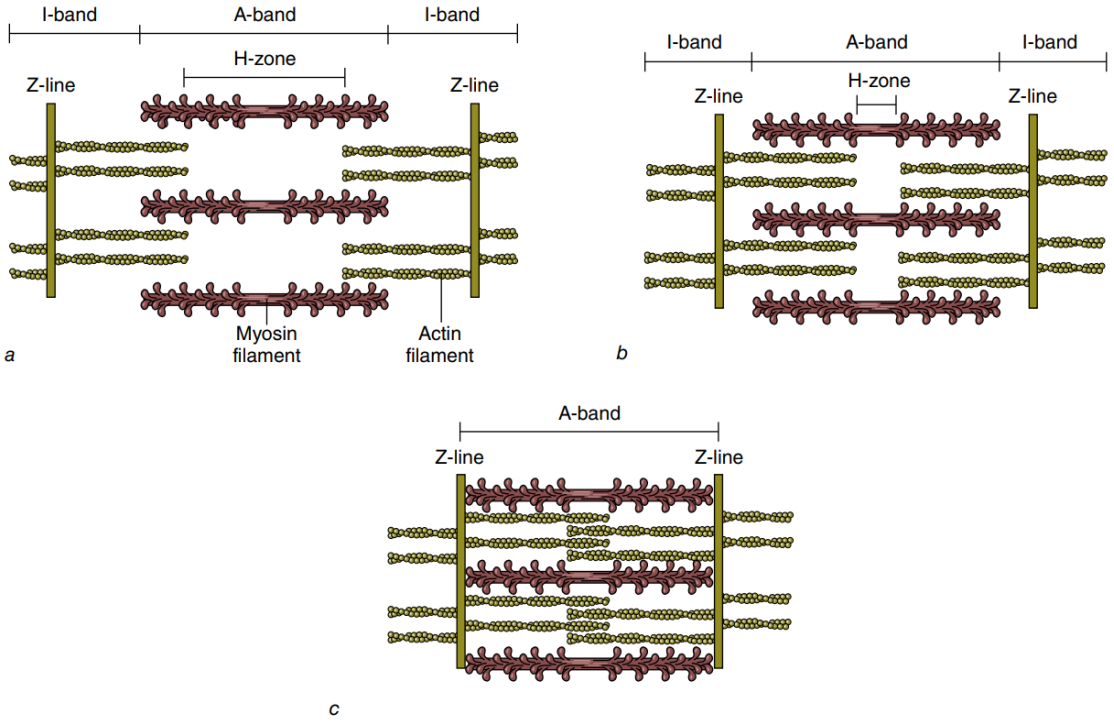

Figure 3. An illustration of muscle contraction (Triplett, 2016).

2.1.2 Muscle activation.

All muscle fibers are activated by an α-motor neuron (nerve cell) via a neuromuscular junction (motor end plate). One α-motor neuron can innervate many muscle fibers. However, each muscle cell has only a single neuromuscular junction (Triplett, 2016). One α-motor neuron and the muscle fibers it activates make up a motor unit (Figure 4). When an α-motor neuron sends an action potential (impulse) to the muscle, it simultaneously activates all of the muscle fibers it serves to. The stimulus from an α-motor neuron can't only activate some of the muscle fibers. Furthermore, the α-motor neuron can't generate weak or strong contractions; the stimulus either elicits a contraction or it doesn't (Katch et al., 2011). This phenomenon is called the all-or-none principle of the muscle (Triplett, 2016).

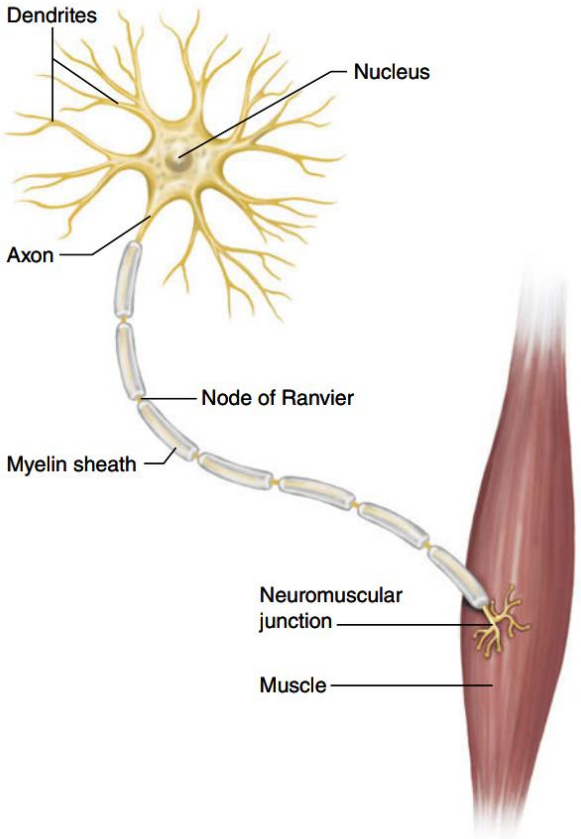

Figure 4. An illustration of a motor unit (Triplett, 2016)

The skeletal muscle contains multiple types of muscle fibers that have different shortening speeds and abilities to generate maximal force (Kenney et al., 2012). The different muscle fiber types are referred to as muscle fiber Type I (slow-twitch), Type IIa (fast-twitch), and Type IIx (fast-twitch). Type I muscle fibers are characterized by slow contraction speeds and higher level of aerobic endurance. In contrast, the Type II muscle fibers have a faster contraction speed, but are less aerobically efficient. Type IIa muscle fibers differentiate from Type IIx muscle fibers in that they have a slightly greater aerobic capacity (Kenney et al., 2012; Triplett, 2016). Even though genetics are mostly responsible for determining the amount of different muscle fiber types an individual has, small changes of muscle fiber type can occur through training (Kenney et al., 2012).

There are two mechanisms by which the muscle activation force is regulated, from slight to maximal: 1) increasing the frequency of the impulses and 2) increasing the number of motor

units recruited (Katch et al., 2011). A single impulse fired from an α-motor neuron leads to a brief contraction, also known as a twitch, of the muscle fibers in the motor unit. If a second impulse received before the muscle fibers have relaxed completely, the force from the two twitches combines, resulting in a force greater than a single twitch. The firing frequency of the α-motor neuron can also be so high that the twitches start merging and eventually completely fusing, resulting in a condition called tetanus. This would be the maximal force that the motor unit could develop (Triplett, 2016). The amount of muscle fibers that an α-motor neuron innervates can range from about a hundred to more than a thousand muscle fibers (Triplett, 2016). Actions that require lower amounts of force will activate only a few motor units, beginning with the ones that innervate Type I muscle fibers. When and action starts requiring higher amounts of force, more motor units with Type II muscle fibers will be activated. This progressive motor unit recruitment pattern is known as the *size principle* (Katch et al., 2011; Triplett, 2016).

2.1.3 Proprioceptors.

Within the skeletal muscles, tendons, ligaments, and joints lie specialized sensory receptors (proprioceptors), which are sensitive to pressure, stretch, and tension. Proprioceptors constantly provide information about muscular dynamics, limb position, and kinesthesia to the conscious and subconscious parts of the central nervous system (Katch et al., 2011; Triplett, 2016). Muscle spindles (Figure 5*a*) are proprioceptors that lie parallel to the main muscle fibers and provide

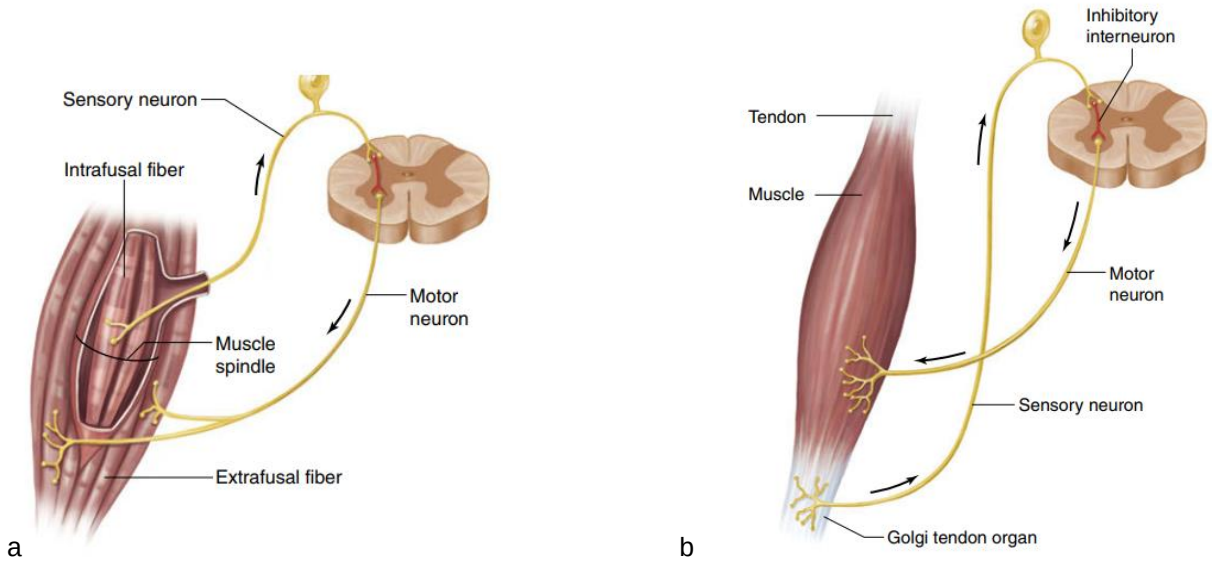

Figure 5. An illustration of the muscle spindles (left) and the Golgi tendon organ (right) (Triplett, 2016).

mechanosensory information about changes in muscle fiber length and tension. Relative to the stretch of the muscle, the muscle spindles respond through reflexive action to counteract the stretch (Katch et al., 2011). Golgi tendon organs are proprioceptors that lie in the tendons and are responsible for detecting differences in muscular tension (Figure 5*b*). If a muscle were to experience excessive tension, the Golgi tendon organs would be activated and transmit signals that would cause muscular inhibition, thereby relieving the tension in the muscle (Triplett, 2016).

2.2 Plyometric Mechanics and Physiology

Developing maximal force in the shortest time possible is crucial in many athletic settings (Hansen & Kennelly, 2017). The product of force and velocity is power. Plyometric action utilizes the stretch reflex and the natural elastic components of the muscles and tendons to maximize power production. Two proposed models (mechanical and neurophysiological) best explain the increase in power through plyometric action (Potach & Chu, 2016).

2.2.1 Mechanical model of plyometric action.

In the mechanical model of plyometric action, the musculotendinous components store the elastic energy derived from a rapid stretch (Cavagna, Saibene, & Margaria, 1965; Hill, 1970). The main element of plyometric action is the series elastic component, which is formed mainly in the tendons (Potach & Chu, 2016). The series elastic component acts as a spring in the musculotendinous unit. When the musculotendinous unit is rapidly stretched, the series elastic component lengthens, and stores elastic energy. If a concentric action of the muscle follows immediately, the elastic energy stored in the series elastic component is released, thereby increasing the total amount of force the muscle produces. However, if the muscle's eccentric phase is too long or the concentric action does not occur immediately after, the stored elastic energy will disperse and be lost as heat (Potach & Chu, 2016).

2.2.2 Neurophysiological model of plyometric action.

In the neurophysiological model of plyometric action, the stretch reflex from the muscle spindles is utilized (Bosco & Komi, 1979; Bosco et al., 1982). The rapid eccentric phase in the muscle causes the muscle spindles to react, which initiates a reflexive response that increases the muscles activity. This increased muscle activity allows for a greater shortening speed, which increases the total amount of force that the muscle produces (Potach & Chu, 2016). Just like in the

mechanical model, concentric muscle action must follow immediately after the eccentric phase, otherwise the potentiating ability of the stretch reflex gets negated.

2.2.3 Stretch-shortening cycle.

The stretch-shortening cycle is the basis of all plyometric action and is a combination of the mechanical and neurophysiological model of plyometric action (Potach & Chu, 2016). The combination of the mechanical and neurophysiological model of plyometric action facilitates a maximal increase in the force produced over a shortest amount of time.

The stretch-shortening cycle involves three phases. Phase I is the eccentric phase where the agonist muscle(s) get preloaded; elastic energy gets stored in the series elastic component and the muscle spindles get stimulated (Potach & Chu, 2016). Phase II is the amortization phase and is the transition from the eccentric phase to the concentric phase. In the amortization phase, the Type Ia afferent nerves synapse with the α-motor neurons, and the α-motor neurons then send signals to the agonist muscle(s). It is essential that the amortization phase is as short as possible, otherwise the elastic energy that was stored will dissipate as heat, and the stretch reflex won't stimulate the muscle(s) (Cavagna, 1977). In phase III (concentric phase) the elastic energy that was stored is used and the produced force of the muscle(s) is increased. Simultaneously, the α-motor neurons further stimulate the muscle(s), resulting in a reflexive concentric muscle action (stretch reflex). Together, the stored elastic energy from the series elastic component and the stretch reflex increase the total amount of force produced far beyond that of an isolated concentric muscle action (Cavagna, Dusman, & Margaria, 1968)

The large contribution of the stretch-shortening cycle to maximal force production can be illustrated when comparing a squat jump to either a countermovement jump an approach jump. Higher stretch rates will result in greater accumulation of force (Potach & Chu, 2016). During the squat jump, the athlete squats down into a semi-squat position (90° angle in knee joint) and jumps up from that position; no elastic energy is stored here, and the stretch reflex is not activated. The jump height during the squat jump would therefore be lowest. During the countermovement jump, the athlete would utilize the elastic energy stored in the series elastic component and the stretch reflex; this would result in a higher jump than the squat jump. During the approach jump, the athlete would create an even greater stretch in the muscles, which would result in an even greater increase in force production and the highest vertical jump height (Potach & Chu, 2016).

2.3 Biomechanical Factors in Human Strength

There are several biomechanical factors affecting human strength. These are: neural control, muscle cross-sectional area, muscle fiber arrangement, muscle length, muscle contraction velocity, joint angle, and joint angular velocity (McBride, 2016).

2.3.1 Neural control.

As explained previously, the force output of the muscle is determined by which and how many motor units are involved in muscle contraction (recruitment) and the frequency at which the impulses are fired at (rate coding). When more motor units, which are greater in size, are involved in a muscle contraction and the firing frequency of the impulses is high, the muscle will produce more force (Chou, Kesar, & Binder-Macleod, 2008; McBride, 2016).

2.3.2 Muscle cross-sectional area.

If all else is equal, the amount of force that a muscle can produce is related to its cross-sectional area rather than the volume (Maughan, Watson, & Weir, 1984; Funato, Kanehisa, & Fukunaga, 2000). For instance, two athletes that differ in height, but have similar percent body fat and biceps circumference, would have approximately the same upper arm cross-sectional area. Even though the taller (and therefore heavier) athlete's longer muscles mean greater muscle volume, the strength of the athletes' biceps would still be approximately the same. Since the shorter athlete has approximately the same biceps strength as the taller athlete, but less bodyweight, the taller athlete would have more advantage in lifting or accelerating his/her own body (McBride, 2016).

2.3.3 Muscle fiber arrangement.

Skeletal muscles have a wide variety of muscle fiber arrangements, which are partially responsible for the differences in force production and contraction velocity between the muscles (Ikegawa et al., 2008). Some muscles are pennate, meaning the sarcomeres align obliquely with the tendon. The angle of pennation is the angle between the muscle fibers and an imaginary line between the muscle's origin and insertion. Many muscles have a varying degree of pennation (Rutherford & Jones, 1992; Ichinose, Kanehisa, Ito, Kawakami, & Fukunaga, 1998), but few muscles have a pennation angle greater than 15°. Greater pennation angles enable a muscle to produce greater force but restrict its maximal contraction velocity. In contrast, muscles that have smaller angles of pennation are able to produce higher contraction velocities but have lower

maximal force production capabilities (McBride, 2016). The pennation angle also affects muscles' ability to produce eccentric, isometric, and low-speed concentric force (Scott & Winter, 1991).

2.3.4 Length of the muscle.

Muscles' potential for force production varies depending on its length. A muscle is able to produce the highest amount of force when it's at its resting length because of the maximal number of potential crossbridge sites that are available (McBride, 2016). A muscle that is stretched beyond its resting length has less force generating capability because there are fewer potential crossbridge sites available. A muscle that is contracted bellow its resting length also has less force generating capability because the actin filaments overlap and there are fewer potential crossbridge sites available (McBride, 2016).

2.3.5 Muscle contraction velocity.

The force capabilities of a muscle also depend on the contraction velocity of the muscle. Earlier research has shown that the force-velocity relationship is not linear (Hill & White, 1968). During a concentric action, the force capabilities of a muscle decline as its contraction velocity increases (Kenney et al., 2012; McBride, 2016). For example, if a person is to lift a heavy object, doing it slowly will maximize the force that they can apply to the object. If a person were to grab a heavy object and try to lift it quickly, it is likely that they will fail and/or injure themselves.

2.3.6 Joint angle.

When any body movement occurs, it does so through a rotation about a joint or several joints. Because a muscle makes a limb or body part rotate about a joint, the force that it produces must be manifested as torque. Depending on the joint's range of motion, its internal structure, and the muscles and tendons that surround it, the amount of torque that can be exerted on a specific joint can vary (McBride, 2016).

2.3.7 Joint angular velocity.

Movement can occur through three types of basic muscle action: concentric, isometric, and eccentric (McBride, 2016). Through concentric muscle action, the muscle shortens because the contractile force is greater than the resistive force. When muscle action is isometric, the muscle length remains the same because the contractile force is equal to the resistive force. In eccentric muscle action, the muscle generates force to shorten it, but the resistive force is greater than the contractile force, and the muscle lengthens (McBride, 2016). According to the type of muscle

action, muscle torque varies with joint angular velocity. As joint angular velocity increases, torque capability decreases. Muscles are therefore able to exert the greatest amount of force during eccentric muscle action (McBride, 2016).

2.4 Biological Energy Systems

To be able to function, the human body requires energy. Endergonic (energy consuming) reactions such as muscle contraction and different anabolic processes require energy (Kenney et al., 2012; Herda & Cramer, 2016). Through exergonic (energy releasing) reactions, the human body produces this energy in the form of an intermediate high-energy molecule, adenosine triphosphate (ATP). Adenosine triphosphate consists of adenosine and three inorganic phosphate groups (Figure 6).

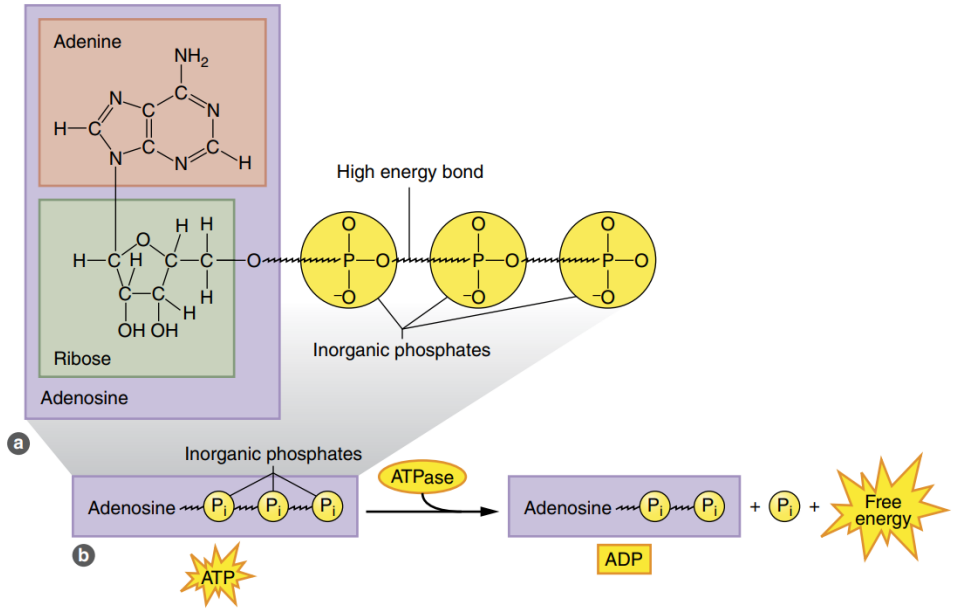

Figure 6. a) An illustration of the structure of an adenosine triphosphate (ATP) molecule. b) An illustration of the process of the third phosphate molecule splitting off and releasing energy (Kenney et al., 2012).

Adenosine consists of a nitrogen-containing base called adenine and a five-carbon sugar called ribose. When the last phosphate group splits from one molecule of adenosine triphosphate, energy is released (approximately 7.3 kcal per mole of adenosine triphosphate) (Kenney et al., 2012). This process known as hydrolysis is catalyzed by an enzyme called adenosine triphosphatase (ATPase). After hydrolysis, an adenosine triphosphate molecule is reduced to

adenosine diphosphate (ADP). Through phosphorylation, a single phosphagen group is then added to adenosine diphosphate, generating adenosine triphosphate again, and the process continues. Because limited amounts of adenosine triphosphate are stored in the muscle cells, and muscle activity requires a constant supply of energy, adenosine triphosphate must constantly be reproduced in the muscle cells (Kenney et al., 2012; Herda & Cramer, 2016).

This reproduction of adenosine triphosphate occurs through three basic energy systems: phosphagen system, glycolysis, and the oxidative system (Poortmans, 1984). The phosphagen and glycolytic systems are anaerobic mechanisms which do not require the presence of oxygen. The oxidative system is an aerobic mechanism which requires the presence of oxygen.

2.4.1 Phosphagen system.

Because a very small amount of adenosine triphosphate is stored in the muscle cells directly, the phosphagen system relies on breakdown of a molecule called phosphocreatine (PCr) in addition to hydrolysis of adenosine triphosphate (Herda & Cramer, 2016). Phosphocreatine is catalyzed by the enzyme creatine kinase (Figure 7), which splits off the phosphate molecule, releasing energy. The released energy is then used to add the phosphate molecule to an adenosine diphosphate molecule, re-forming it to adenosine triphosphate (Kenney et al., 2012). Therefore, the phosphocreatine levels slowly decline while adenosine triphosphate is maintained at a relatively constant rate during the first few seconds of high-intensity muscular activity. However, as phosphocreatine is depleted, the adenosine triphosphate gets used up quickly as well. Thus, the capacity of phosphocreatine to maintain adenosine triphosphate levels is limited. While this process can occur in the presence of oxygen, it does not require oxygen (Kenney et al., 2012).

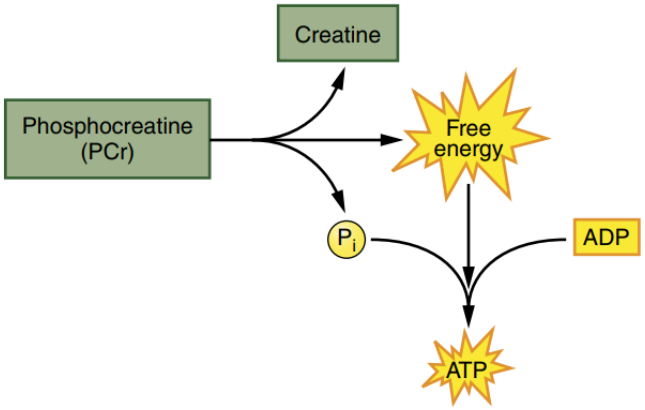

Figure 7. An illustration of the Phosphagen energy system (Kenney et al., 2012).

2.4.2 Glycolysis.

The second, slightly more complex method of adenosine triphosphate production is glycolysis (Kenney et al., 2012). Glycolysis involves the breakdown of either glucose (from carbohydrate) or glycogen into pyruvate through 10 to 12 enzymatic reactions (Figure 8). Although not as rapid, this process has a greater capacity for generating energy than the phosphagen system (Herda & Cramer, 2016). Glycolysis can occur in two forms: 1) rapid glycolysis or 2) slow glycolysis; the difference being in what happens to pyruvate at the end of the process (Katch et al., 2011). During rapid glycolysis pyruvate is converted into lactate resulting in a rapid, but limited adenosine triphosphate re-synthesis. During slow glycolysis pyruvate gets shuttled into the mitochondria to go through the Krebs cycle, which produces substantial amounts of adenosine triphosphate at a slower rate. The fate of pyruvate depends mainly on the energy demands within the cell, but also on the amount of molecular oxygen present in the cell (Katch et al., 2011; Herda & Cramer, 2016). High energy demand means pyruvate gets converted into lactate to further support rapid glycolysis. If the energy demand is low and enough oxygen is present in the cell, pyruvate goes through the Krebs cycle.

Glycolysis begins with either glucose or glycogen converted into a compound called glucose-6-phosphate. Glucose-6-phosphate is further converted into fructose-1.6-biphosphate which splits into two phosphorylated molecules (glyceraldehyde-3-phosphate) that then decompose into pyruvate (Katch et al., 2011; Kenney et al., 2012; Herda & Cramer, 2016). Some lactate is constantly formed and oxidized during rest and low intensity exercise (Katch et al., 2011). Lactate can also be transported to the liver, where it is converted into glucose; a process known as the Cori cycle (Herda & Cramer, 2016). However, when the energy demands exceed either the oxygen supply or the utilization rate, lactate begins accumulating in the muscle at a greater rate than it is removed. This point of lactate inflection is known as the onset of blood lactate accumulation (Sjödin & Jacobs, 1981; Tanaka et al., 1983). The rate at which lactate accumulates in the muscles depends on the exercise intensity and duration, muscle fiber type, state of training, and initial glycogen levels (Gollnick, Bayly, & Hodgson, 1986).

Lactate is sometimes mistaken for lactic acid and thought to be the cause of muscular fatigue. However, even though high concentrations of lactate often correlate with muscular fatigue, lactate isn't the cause of muscular fatigue (Busa & Nuccitelli, 1984; Robergs, Ghiasvand, & Parker, 2004). What may cause muscular fatigue is a process known as metabolic acidosis, where

intracellular pH is reduced. In fact, lactate works to decrease metabolic acidosis rather than accelerate it (Robergs et al., 2004). Other factors such as an increased interstitial K^+ concentration and phosphate that impairs Ca^{++} release have been reported to play an important role in muscular fatigue (Sahlin & Ren, 1989; Skurvydas, Jascaninas, & Zachovajevas, 2000; Nielsen et al., 2004).

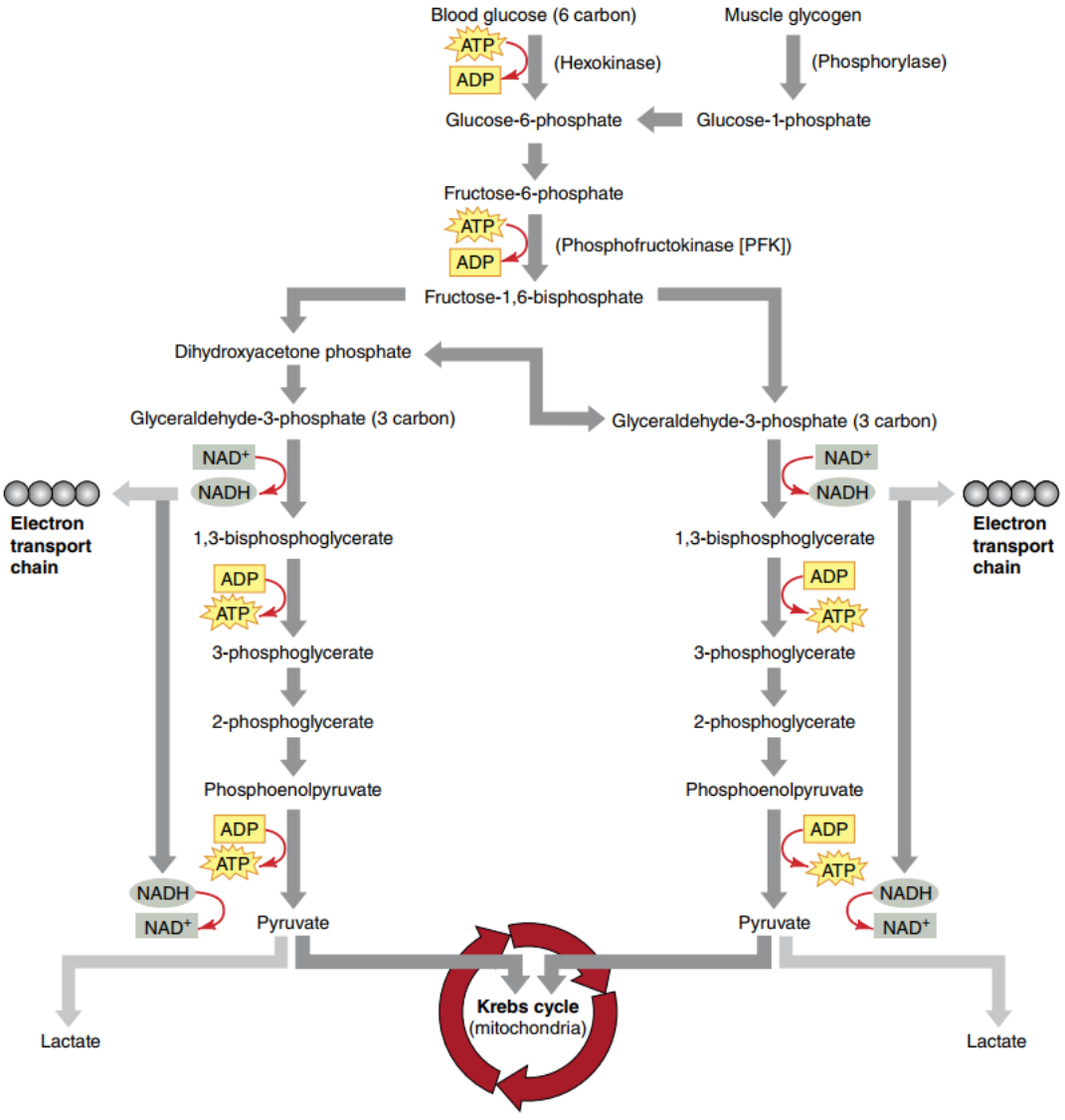

Figure 8. An illustration of the process of glycolysis. ADP = adenosine diphosphate; NAD^+, NADH = nicotinamide adenine dinucleotide (Herda & Cramer, 2016).

2.4.3 The Oxidative system.

The third and most complex energy system is the oxidative system (Kenney et al., 2012). At rest and during low-intensity activities, it is the primary source of adenosine triphosphate

(Herda & Cramer, 2016). The Oxidative system consists of breaking down carbohydrates, fat, and protein through various processes which require oxygen.

2.4.3.1 Glucose and glycogen oxidation.

The oxidation of glucose and glycogen begins with glycolysis. Glycolysis is therefore involved in both anaerobic and aerobic production of adenosine triphosphate (Kenney et al., 2012). As explained earlier, when sufficient amounts of oxygen are present in the cell, the end product of glycolysis (pyruvate) is transported to the mitochondria and converted into acetyl-CoA, which enters the Krebs cycle (Figure 9). Krebs cycle is a complex series of reactions through which acetyl-CoA is oxidized completely (Herda & Cramer, 2016). Because one glucose molecule forms two molecules of pyruvate, it amounts to two complete Krebs cycles per glucose molecule (Kenney et al., 2012). This means that the oxidative system (including glycolysis, the Krebs cycle, and the

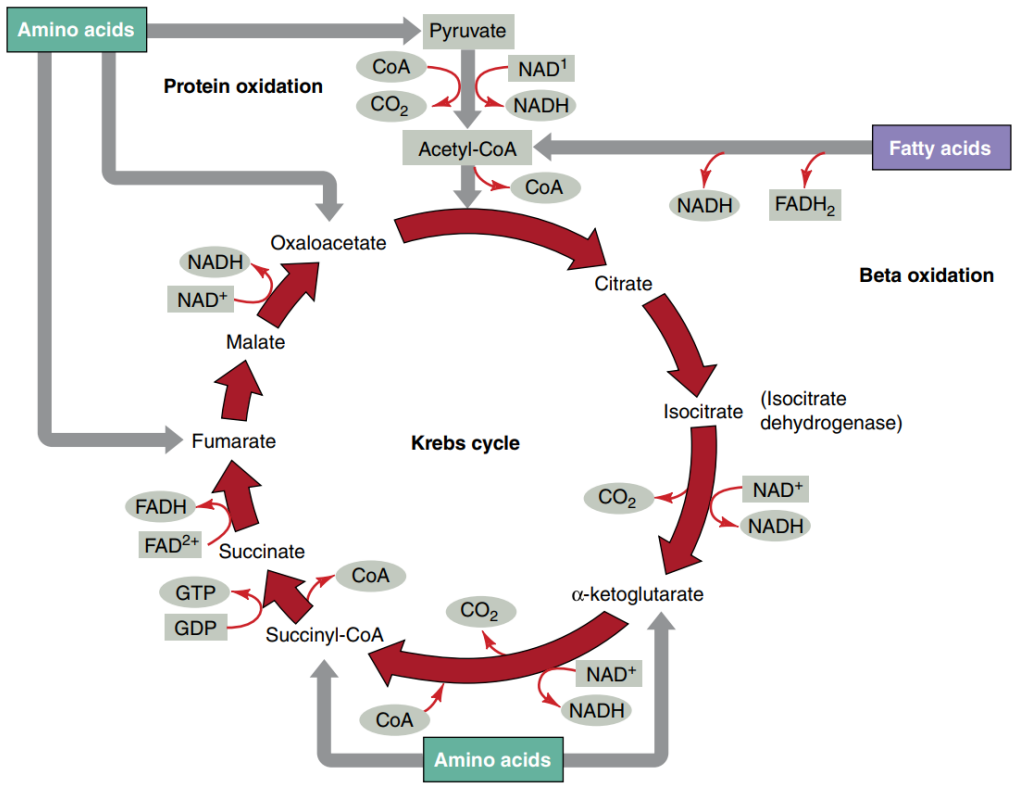

Figure 9. An illustration of the Krebs cycle. CoA = coenzyme A; FAD^{2+}, FADH, $FADH_2$ = flavin adenine dinucleotide; GDP = guanine diphosphate; GTP = guanine triphosphate; NAD^+, NADH = nicotinamide adenine dinucleotide (Herda & Cramer, 2016).

electron transport chain) can produce approximately 36 to 38 adenosine triphosphate molecules per glucose molecule (Kenney et al., 2012; Herda & Cramer, 2016).

2.4.3.2 Fat oxidation.

Before fat can be used for energy, triglycerides need to be broken down into glycerol and free fatty acids (Herda & Cramer, 2016). Free fatty acids then undergo β-oxidation, which breaks them down into acetyl-CoA and hydrogen protons that enter the Krebs cycle. Because β-oxidation supplies the Krebs cycle with larger amounts of acetyl-CoA and hydrogen protons, fat oxidation has tremendous capacity for production of adenosine triphosphate molecules compared to glycose and glycogen oxidation. For instance, a single triglyceride molecule containing 16-carbon chain free fatty acids can yield over 300 adenosine triphosphate molecules (Herda & Cramer, 2016).

2.4.3.3 Protein oxidation.

As explained earlier, proteins are not a significant source of energy, but can nonetheless be converted into amino acids and used in various metabolic processes. Amino acids can be converted into glucose through a process called gluconeogenesis. Amino acids can also be converted into either pyruvate or acetyl-CoA to enter the Krebs cycle (Kenney et al., 2012; Herda & Cramer, 2016). Protein also contains nitrogen, which cannot be oxidized by the body. The nitrogen is therefore converted into urea and exerted through urine (Kenney et al., 2012).

2.4.4 Energy systems: interaction, depletion, and repletion.

All of the three energy systems are constantly active; however, how much each energy system contributes to overall work performance depends primarily on the intensity and secondarily on the duration of the activity (Herda & Cramer, 2016). The anaerobic energy systems are predominant during high-intensity, short-duration activities, while the aerobic energy systems are predominant during low-intensity, long-duration activities (Herda & Cramer, 2016). Because of the slow response of the aerobic energy system, some of the energy is always supplied by the anaerobic energy systems at the start of a physical activity (Herda & Cramer, 2016).

It is mainly the phosphagen energy system that supports the energy needs of the body at the start of any physical activity, regardless of intensity (Herda & Cramer, 2016). The process is rapid and only able to sustain the energy needs of the muscles for a short period of time. During the first 5 to 30 seconds of a high-intensity physical activity, phosphocreatine decreases for about 50% to 70%, and can even be almost completely depleted following an intense all-out physical

activity (Jacobs, Tesch, Bar-Or, Karlsson, & Dotan, 1983; McCartney et al., 1986; Hirvonen, Rehunen, Rusko, & Härkönen, 1987). The phosphagen system is therefore predominant during activities such as a 100 m sprint, Olympic lifting, and a squat or countermovement jump, which are of high intensities and last for a few seconds. After physical activity phosphagen repletion occurs quickly, with adenosine triphosphate being completely resynthesized within 3 to 5 minutes and phosphocreatine being completely resynthesized within 8 minutes (Harris et al., 1976; Hultman & Sjoholm, 1986). However, if the physical activity continues for longer time periods, the muscles gradually shift towards glycolytic and oxidative systems for generating energy (Herda & Cramer, 2016).

While the muscles store around 300 g to 400 g of glycogen in total, only 70 g to 100 g is stored in the liver (Sherman & Wimer, 1991). This amounts to about 2,500 kcal of energy (Kenney et al., 2012). During physical activity of moderate- and high-intensity the muscle glycogen is prioritized as an energy source; while liver glycogen is prioritized during low-intensity physical activity (Herda & Cramer, 2016). The glycolytic energy system can contribute substantially to the energy production during many of the same activities where the phosphagen system is predominant; however, during activities such as a 100 m swim, Bosco's 30-second jump test, or the later stages of the 20 m shuttle-run test, the glycolytic energy system is predominant. At very low exercise intensities (bellow 50% of VO_2max) blood glucose levels remain relatively stable, and as the exercise intensity increases, so does the rate at which glycogen depleted (Sherman & Wimer, 1991; Herda & Cramer, 2016). During exercise intensities which are above 60% of VO_2max, muscle glycogen becomes more and more important as an energy source, and if the exercise duration exceeds 90 minutes, blood glycogen concentrations may drop significantly (Herda & Cramer, 2016). The repletion rate of muscle glycogen after exercise depends on ingestion of carbohydrates; with the optimal repletion rate being when 0.7 g to 3 g of carbohydrates per kg of body weight is ingested every 2 hours. At this rate, muscle glycogen can replenish completely within 24 hours after exercise (Friedman, Neufer, & Dohm, 1991; Sherman & Wimer, 1991).

At rest or very low-intensity exercise, the body relies on the oxidative system for energy production. Although slow, it has the greatest energy producing capacity at rest, with 70% and 30% of adenosine triphosphate deriving from fats and carbohydrates, respectively (Lemon & Mullin, 1980; Dohm, Williams, Kasperek, & van Rij, 1982; Gastin, 2001). Fat stores inside muscle fibers and fat cells can provide the human body with around 70,000 to 75,000 kcal of energy,

which is way more than glycogen can provide (Kenney et al., 2012). A steady-rate low-intensity exercise that is supplied by fat can last for extremely long periods of time. Fat is therefore the main energy source during activities such as marathon running, cycling, hiking, or the initial stages of the 20 m shuttle-run test. As the intensity gradually increases during these types of activities, so does the reliance on carbohydrates for energy production. At higher aerobic exercise intensities, almost 100% of adenosine triphosphate is derived from carbohydrates with minimal contributions from fats (Herda & Cramer, 2016).

Protein doesn't contribute significantly to total energy; when broken down through combustion in laboratory settings, its energy yield is only about 4.1 kcal/g (accounting for energy spent during conversion of nitrogen to urea) (Herda & Cramer, 2016). During short-term exercise, the contribution of amino acids to the production of adenosine triphosphate has been estimated to be minimal (Kenney et al., 2012). However, during long-term starvation and long bouts of exercise the contribution of protein to total energy increases significantly (Herda & Cramer, 2016).

The knowledge of how different energy systems work and interact at varying intensities is crucial in many different settings. First and foremost, knowing which energy systems are predominant during a specific intensity and how long it takes for the energy systems to recover, enables athletes and coaches to specify the training for different sports. Choosing the appropriate exercise intensity and rest intervals allows for "targeting" specific energy systems which would be predominant during certain sports (Weir & Cramer, 2005; Katch et al., 2011). This knowledge also affects test selection and order. An understanding of how the energy systems interact enables the coach to choose a specific test that would be a valid measure of athletic ability for a certain sport (Buchheit & Laursen, 2013; Turner & Stewart, 2013; Joyce & Lewindon, 2014). Furthermore, the tests should be conducted in proper order with adequate rest intervals to allow for optimal performance during each test. The tests which are least fatiguing (i.e., static single-leg balance test, squat jump test, and the countermovement jump test) are therefore conducted first while the test which would cause fatigue (i.e., Bosco's 30-second jump test and the 20 m shuttle-run test) are conducted last (McGuigan, 2016).

2.5 Massage

In the introduction, massage was defined as: "*a mechanical manipulation of body tissues with rhythmical pressure and stroking for the purpose of promoting health and well-being*" (Cafarelli & Flint, 1992, p. 1). While there are many different methods of massage, the most

popular one, Swedish massage, consists of five techniques: effleurage (stroking), petrissage (kneading), friction, tapotement (percussion), and vibration (Cafarelli & Flint, 1992). Myofascial release, which is another massage method, also consists different techniques such as cross-hand release, longitudinal plane release, compression release, and transverse plane release (Duncan, 2014). Some of these myofascial release techniques are similar to effleurage, petrissage and friction techniques in Swedish massage. Self-myofascial release is a form of myofascial release in which the athlete uses a foam roller or roller-massager (Beardsley & Škarabot, 2015). The mechanical self-induced multi-bar massage roller which is used in this study is meant to provide a massage which simulates foam rolling.

2.5.1 How can massage affect physical performance?

There is no current consensus regarding the mechanism(s) through which massage affects performance (Beardsley & Škarabot, 2015). Researchers have previously categorized proposed mechanisms in various ways (Chen & Ingber, 1999; Schleip, 2003; Weerapong et al., 2005). Weerapong et al. (2005) summarizes the mechanisms into biomechanical, physiological,

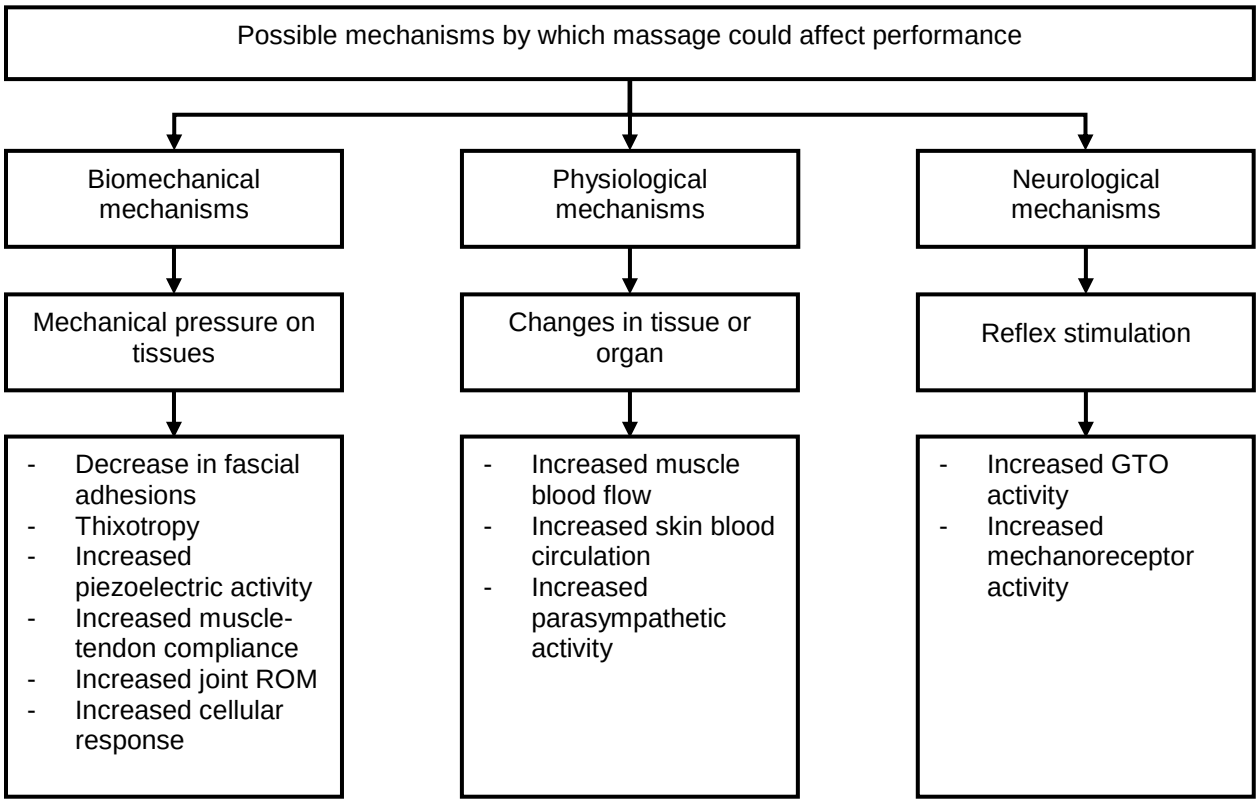

Figure 10. Overview over the possible mechanisms by which massage could affect performance. ROM = range of motion; GTO = Golgi tendon organ. Adapted and modified after Weerapong et al. (2005).

neurological, and psychological. However, this chapter will only the biomechanical, physiological, and neurological models. Several other mechanisms proposed by other researchers (Bron & Dommerholt, 2012; Tozzi, 2012; Rodríguez & del Río, 2013) can also be summarized through the model (Figure 10) developed by Weerapong et al. (2005). Knowing how these mechanisms work and the basics of human physiology can aid in understanding the possible changes in performance after a bout of massage therapy.

2.5.1.1 Biomechanical mechanisms.

Because massage evokes mechanical pressure on the muscle tissue, it can cause a number of changes within the muscle tissue and the fascia surrounding it (Weerapong et al., 2005). In a model known as the fascial adhesions model, it has been proposed that the fascia layers which would normally slide relative to each other can be altered so that they stick to each other instead (Hedley, 2010; Rodríguez & del Río, 2013). Applying mechanical pressure to the tissue is thought to relieve these fascial adhesions (Hedley, 2010). Rolf (1977) proposed a similar model in which applying mechanical pressure or heat to the muscle tissue cause the fascia to change its form, from a more dense "gel" state to a more fluid "sol" state. This "gel-to-sol" model is also known as thixotropy (Juhan, 1987). Both the fascial adhesions model and the gel-to-sol model are thought to further contribute to an increase in muscle-tendon compliance and joint range of motion (Schleip, 2003) which could aid in performance.

Another proposed mechanism for increased fascial plasticity is piezoelectricity, which treats the connective tissue as a "liquid crystal" that can respond to electric charges when mechanical pressure is applied (Juhan, 1987; Oschman, 2000). It is proposed that the electric charge stimulates cells which are responsible for producing collagen fibers (fibroblasts) which increases their collagen fiber production rate. Furthermore, it is proposed that the electric charge also stimulates the cells that are responsible for digesting collagen fibers (fibroclasts), which respond with selective behavior and don't digest the collagen fibers (Schleip, 2003). In other words, mechanical pressure causes an electrical charge that increases collagen fiber production which results in an increase in fascial plasticity (Schleip, 2003).

It has also been suggested that mechanical stress applied to the fascia can be "sensed" at the cellular level (Tozzi, 2012). According to the principle of tensegrity, cells are held in a state of continuous tension and when mechanical stress is applied the cells respond by engaging various chemical processes (Chen & Ingber, 1999). Reactions may evoke changes in the cell's cytoplasm

and nucleus, and additionally regulate fibroblasts (Chen & Ingber, 1999; Tozzi, 2012), all of which could possibly have an effect on performance.

2.5.1.2 Physiological mechanisms.

Physiological mechanisms such as hyperaemia have been proposed to explain the effects of massage on performance (Weerapong et al., 2005). During massage, skin friction increases the local skin and muscle temperature which results in an increase in skin blood circulation and muscle blood flow (Weerapong et al., 2005). This increase in muscle blood flow could then aid in delivery and removal of substances necessary for the energy metabolism, which can be beneficial for performance (Cafarelli & Flint, 1992).

Another physiological mechanism which has been suggested to have an effect on performance is the increase in parasympathetic activity. It is possible for massage to affect heart rate and blood pressure, which could also result in changes in performance (Weerapong et al., 2005).

2.5.1.3 Neurological mechanisms.

It has been suggested that massage increases neuromuscular excitability by stimulating the sensory receptors (Weerapong et al., 2005; Beardsley & Škarabot, 2015). The two main neurological mechanisms which have been proposed involve the Golgi tendon organs and the mechanoreceptors known as Ruffini and Pacini corpuscels (Schleip, 2003). According to the Golgi reflex arc model, massage stimulates the Golgi tendon organs which are located in tendons and responsible for regulating muscular tension (Triplett, 2016); this results in Golgi tendon organs sending inhibitory signals to the muscle which reduces its firing rate and decreases its tension (Schleip, 2003). Ruffini and Pacini corpuscels, which can be located in dense proper connective tissue, respond to massage in a manner similar as Golgi tendon organs (Schleip, 2003). While Pacini corpuscels relay proprioceptive feedback for movement control, Ruffini corpuscels respond to massage by inhibiting the sympathetic nervous system (Schleip, 2003). These inhibitory responses from the Golgi tendon organs and Ruffini corpuscels could have an effect on force production capabilities of the muscle, which could affect performance (Beardsley & Škarabot, 2015).

3 Methods

3.1 Experimental Approach to the Problem

Answering the research question: "*what effect 5-, 10-, and 15-minute massage with a mechanical self-induced multi-bar massage roller has on balance, anaerobic power, anaerobic and aerobic capacity?*" would require measuring performance multiple times after every treatment (independent variables) which would result in numerical data that could then be analyzed through statistical procedures; a quantitative approach with an experimental design was therefore chosen for this study. There are several types of experimental design, however, a crossover design was chosen for this study.

3.2 Participants

Twenty-five collegiate level athletes, from different sports teams at the University of Stavanger (volleyball, n = 9; basketball, n = 7; lacrosse, n = 4; handball, n = 2; futsal, n = 2; strength training, n = 1) volunteered to participate in this study. Twelve participants dropped out of the study because of injury or other personal reasons, leaving the study with 13 (volleyball, n = 7; basketball, n = 2; lacrosse, n = 2; handball, n = 1; strength training, n = 1) male collegiate level athletes (mean ± SD; age = 25.15 ± 5.6 years; height = 1.84 ± 0.7 m; body mass = 82.4 ± 9 kg). Inclusion criteria for participants was that they had to have been above the age of 16, physically active, and free from any injuries prior to testing. Participants were regularly participating in their various team sports and physical activities on a collegiate level for over 2 years. None of the participants had any previous experience with laboratory athletic testing. All participants were healthy and free from injury at the time of the study.

3.3 Ethical Considerations

This study was conducted in accordance with the guidelines described by the National Committee for Research Ethics in the Social Sciences and the Humanities (NESH, 2016), which apply to the University of Stavanger. This study was also a part of a larger research project, which was reported to, and approved by the Norwegian Center for Research Data, with the reference number 58950 (Appendix 1). All participants were provided with detailed information about the study's purpose, background, methods, procedure, and potential risks. Participation in the study was voluntary. If the participants were willing to take part in the study, they were required to sign an informed consent (Appendix 2 and 3). Participants were informed that they could withdraw

from the study at any given time without providing any reason. No personally identifiable information was gathered during the study. Only some descriptive information such as age, gender, height, body mass, and sports occupation were gathered during this study.

3.4 Treatment

3.4.1 Massage procedure.

The mechanical self-induced multi-bar massage roller (Figure 11) used in this study was a Z-Roller, version 2 (Zen Products, Jessheim, Norway). The size of the apparatus was 70 cm × 31 cm × 55 cm, weight was 15 kg, and it had 8 bars which were designed for deep massage. The mechanical self-induced multi-bar massage roller had five options for different rolling speeds. In this study, the rolling speed option 3 was used, which was equal to 7.36 m/min. Additionally, an air mattress (type Z-Madrass, Zen Products, Jessheim, Norway), that was designed specifically for the mechanical self-induced multi-bar massage roller, was used (Figure 12). The massage

Figure 11. Z-Roller, version 2 (Zen Products, Jessheim, Norway).

Figure 12. Z-Mattress (Zen Products, Jessheim, Norway).

procedure consisted of massaging 4 different muscle groups in the following order: 1) gastrocnemius, 2) hamstrings, 3) quadriceps, and 4) gluteus maximus (Figure 13). Total massage durations were 5, 10, and 15 minutes. The total massage time was split between the 4 muscle groups so that each muscle group would get the same amount of massage time. Thus, 5 minutes total massage time was equal to 75 seconds, 10 minutes was equal 150 seconds, and 15 minutes was equal to 225 seconds of massage time per muscle group. Changes in massage position took approximately 10 seconds. Before participants were about to receive the massage for the first time, detailed explanations and instructions about the massage procedure were given to the participants by the researcher. Participants were supervised by the researcher during the entire massage procedure. When participants were in position, the researcher turned on the mechanical self-induced multi-bar massage roller and started the countdown. When the countdown was over, the researcher turned off the mechanical self-induced multi-bar massage roller while the participant was changing positions. Once the participant was in position, the researcher turned on the mechanical self-induced multi-bar massage roller and started the countdown again.

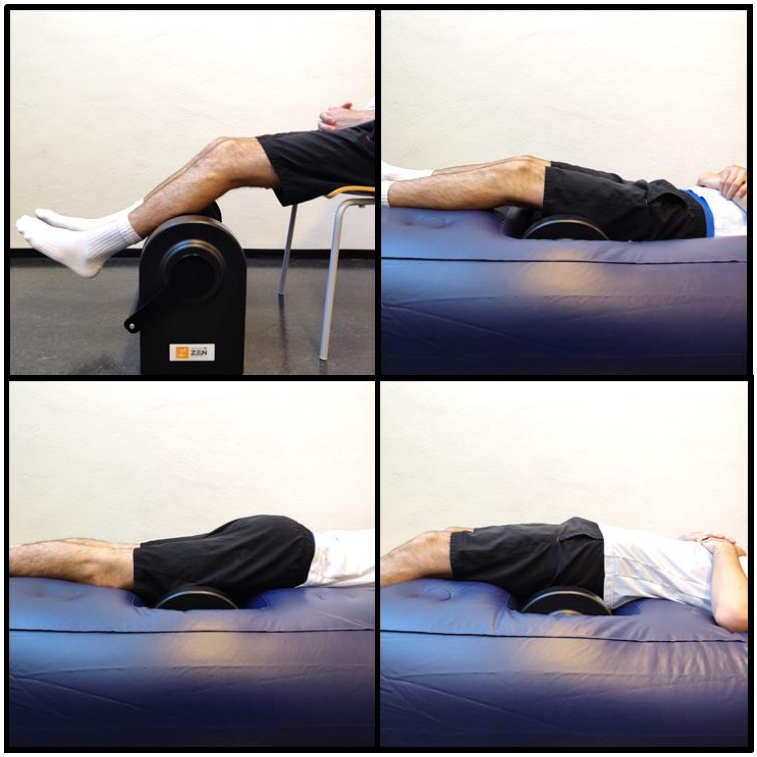

Figure 13. The different massage positions used in the experimental condition. Performed in the following order, starting from top left, going clockwise: gastrocnemius, hamstrings, quadriceps, and gluteus maximus.

3.5 Test Descriptions and Instruments

3.5.1 Static single-leg balance test.

The static single-leg balance test was conducted on a MuscleLab force plate (Ergotest Innovation A.S., Porsgrunn, Norway) and with the use of a software (MuscleLab for Windows 10, version 10.5.69.4809, Ergotest Innovation A.S., Porsgrunn, Norway). The force plate (Figure 14) was connected to the computer via a MuslceLab single data interface (Ergotest Innovation A.S., Porsgrunn, Norway). The static single-leg balance test consisted of following parameters: mean center of pressure distance (COP; mm), sway velocity (mm/s), sway area (mm^2).

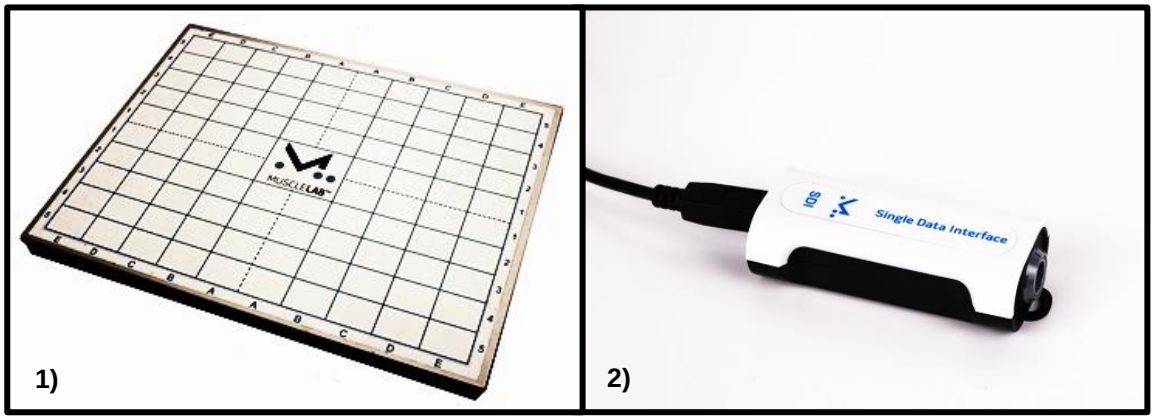

Figure 14. 1) The MuscleLab force plate and 2) the MuscleLab single data interface (Ergotest Innovation A.S., Porsgrunn, Norway).

Participant's balance was tested while they had their eyes opened first, then while they had their eyes closed. Two, 10-second trials were carried out per foot (i.e., left foot, left foot, right foot, right foot), with a break of approximately 10 seconds between each trial (Goetschius, Feger, Hertel, & Hart, 2018). Before starting the test, participants were asked to remove their shoes. Using the grid on the force plate, participants placed the foot that was being tested on the center of the force plate and placed their opposite foot on the force plate so that they stood normally. When the participant positioned themselves on the force plate, the researcher asked the participant "Are you

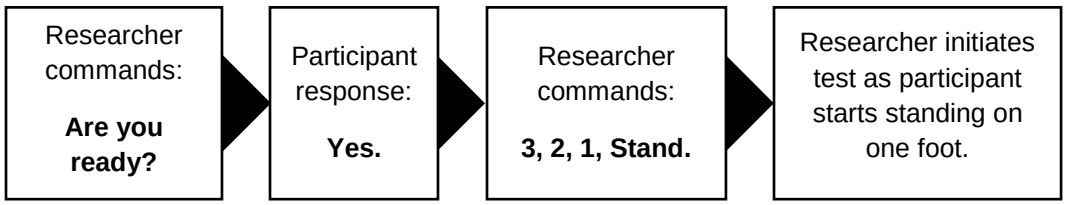

Figure 15. Schematic showing the communication between the researcher and participant during the static single-leg balance test.

ready?". If the participant answered "Yes", the researcher proceeded to count down "Three, two, one", then saying "Stand" and initiating the test on the computer as the participant started standing on one foot (Figure 15). The participants had to look straight at the wall in front of them, stand upright, with one foot in the center of the plate, the opposite foot held at approximately a 90° angle at the knee joint, and arms flat to the side of the body (Figure 16). The participants had to try and maintain this position during the entire 10-second trial (Goetschius et al., 2018). The same position was held when the participants were tested with their eyes closed. If the participants didn't manage to stay on one foot during the trial (i.e., fell off the force plate or touched the force plate with the opposite foot etc.) or the data didn't get registered by the software, the participants redid the trial until a valid registration occurred. The best of the two registered trials of one foot was retained for statistical analysis.

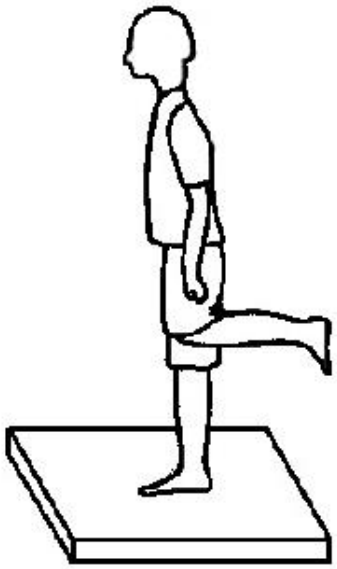

Figure 16. An illustration of the stance during the static single-leg balance test. Adapted and modified after Panjan & Sarabon (2010).

3.5.2 Squat jump test.

The squat jump test was performed on the aforementioned MuscleLab force plate, through the use of the same MuscleLab software. For the squat jump test, participants placed their feet on the force plate so that the horizontal dotted line of the force plate grid went through the middle of their feet (Figure 17). When it comes to the width of the stance, participants were instructed to place their

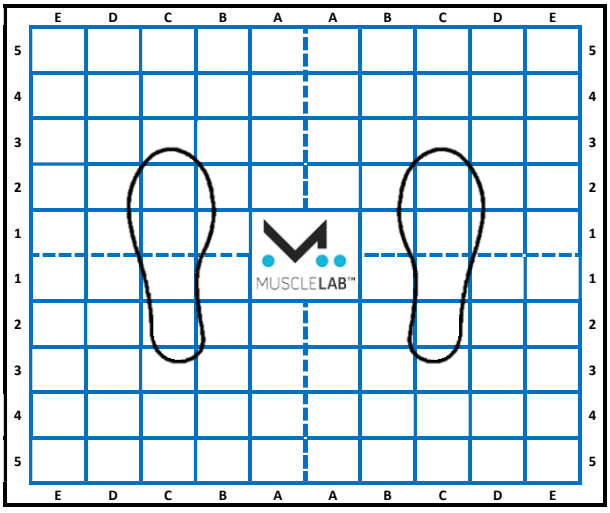

Figure 17. Approximate foot placement on the force plate during the squat jump test.

feet approximately at shoulder width apart. Participants were also instructed to keep their hands on their hips throughout the entirety of the jump (Markovic, Dizdar, Jukic, & Cardinale, 2004). When the participant positioned themselves on the force plate, the researcher asked the participant "Are you ready?". Upon the participant answering "Yes", the researcher gave the command "Go down". The participant started lowering themselves into a partial squat, and when they reached a 90° knee joint angle (Figure 18), the researcher said "Stop!" and then "Jump!". Participants had to

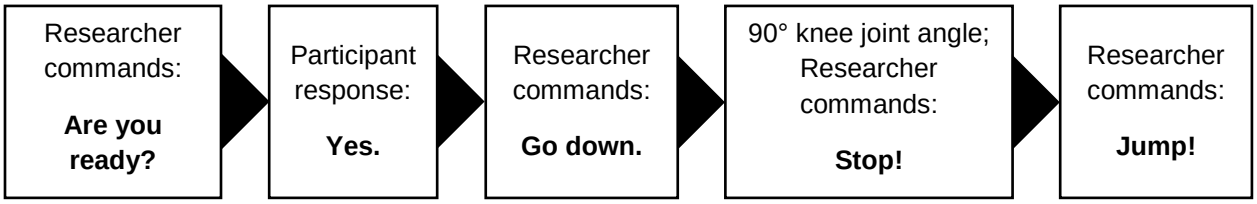

Figure 18. Schematic showing the communication between the researcher and participant during the squat jump test.

jump from the partial squatting position without any countermovement (Figure 19), land with their legs extended, with toes making the first contact with the force plate (Markovic et al., 2004). To ensure that the software recorded the data correctly, participants were required to stand still after landing on the force plate. Three squat jump trials were recorded, with a 90-second passive rest between the trials. Data from the best of the three trials was retained for statistical analysis.

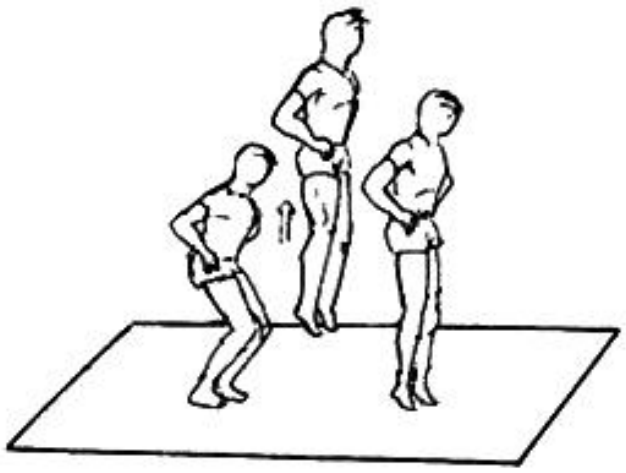

Figure 19. Schematic drawing of the squat jump test. Adapted and modified after Bosco (1992).

3.5.3 Countermovement jump test.

The same force plate and software that was used for the squat jump test was used for the countermovement jump test. For the countermovement jump test, the participants placed their feet on the force platform the same way they did during the squat jump test. Participants were instructed to keep their hands on their hips throughout the entirety of the jump during this test as well (Markovic et al., 2004). When the participant positioned themselves on the force plate, the researcher asked the participant "Are you ready?". When the participant answered "Yes", the researcher proceeded to counting down "Three, two, one", then saying "Jump!". From an upright standing position, the participant then performed a countermovement until reaching a 90° knee joint angle and then immediately jumped (Figure 20). Participants were informed to perform maximally for each countermovement jump trial (Markovic et al., 2004). To ensure that the software recorded the data correctly, participants were required to land on the force plate with their legs extended and stand still after landing. Three countermovement jump trials were recorded, with a 90-second passive rest between the trials. Data from the best of the three trials was retained for statistical analysis.

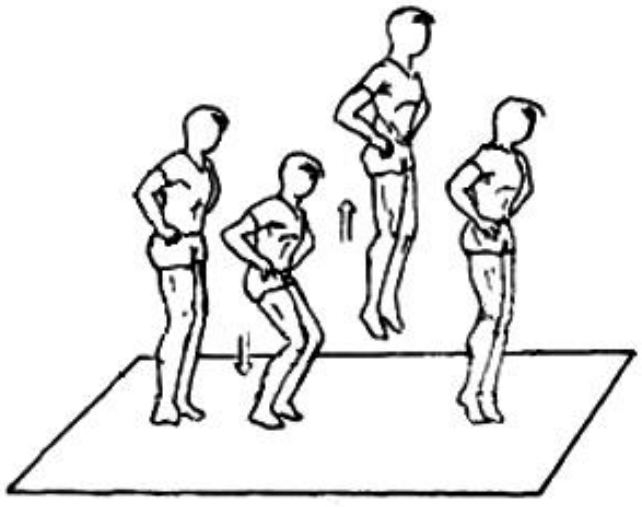

Figure 20. Schematic drawing of the squat jump test. Adapted and modified after Bosco (1992).

3.5.4 Bosco's 30-second jump test.

Bosco's 30-second jump test consisted of following parameters: peak power at 15 seconds (PP15sec; $W \cdot kg^{-1}$), mean power at 30 seconds (MP30sec; $W \cdot kg^{-1}$), fatigue index (FI; %), number of vertical jumps at 15 (NVJ15sec) and 30 seconds (NVJ30sec), reactive strength index (RSI), and stiffness (kN/m). Before the test, participants were equipped with a heart rate sensor (type Polar H3, Polar Electro Oy, Kempele, Finland) which was connected to a heart rate monitor (type RC3 GPS, Polar Electro Oy, Kempele, Finland) with sampling rate intervals of 1 second. Participants positioned themselves on the force plate with the same stance that was used during the squat jump test. Participants were instructed to perform the highest number of jumps with maximum height during a 30-second trial. Participants were also instructed to have their hands on their hips throughout the entire 30-second trial. Each jump, the participants had to squat down until they reached a 90° angle in the knee joint, jump vertically, land on the force plate with both feet at the same time, and then repeat the jumping process (Dal Pupo et al., 2014).

When the participant was in position, the researcher asked the participant "Are you ready?". When the participant answered "Yes", the researcher proceeded to counting down "Three, two, one", then saying "Jump!" and initiating the test on the computer as the participant started jumping. During the entire 30-second trial, the participants were verbally encouraged by the researcher to perform maximally. When the 30 seconds were up, the researcher said "Stop!", and the participant was required to stop jumping and stand still on the force plate for a split second

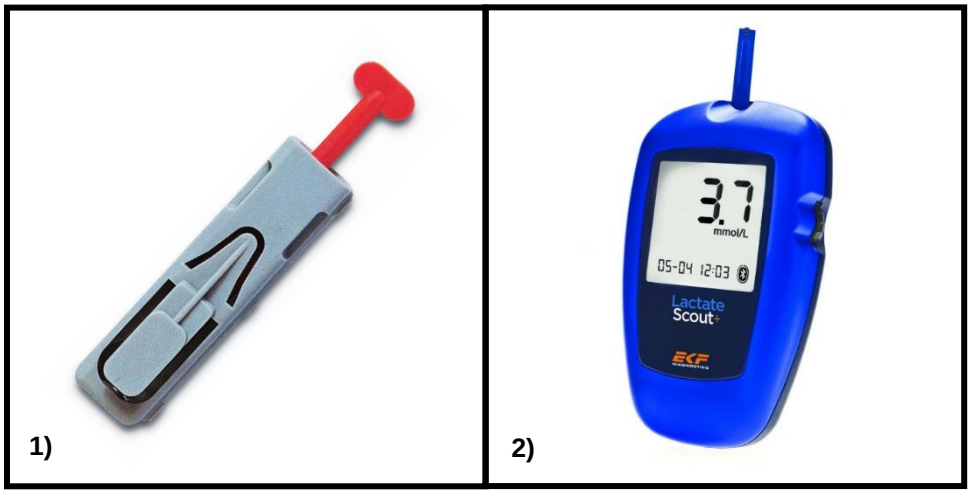

Figure 21. 1) The Unistik 2 Neonatal safety lancet (Owen Mumford Ltd., Woodstock, Great Britain) and 2) the Lactate Scout+ analyzer (EKF Diagnostics, Cardiff, Great Britain).

while the software allowed the researcher to save the recorded data. The researcher simultaneously looked at the heart rate of the participant when they stopped jumping and noted it down. Immediately after the recorded data was saved, the researcher obtained a blood sample from the participant's finger using the Unistik 2 Neonatal (Owen Mumford Ltd., Woodstock, Great Britain) safety lancet and measured the participant's blood lactate concentration using the Lactate Scout+ analyzer (EKF Diagnostics, Cardiff, Great Britain; Figure 21). The participants were then provided with a small piece of tape and paper towel to tape up the finger from which the blood sample was taken.

3.5.5 Twenty-meter shuttle-run test.

The 20 m shuttle-run test consisted of participants running back and forth on a 20 m course in accordance with sound signals (beeps) which were emitted from a recording (Leger, Mercier, Gadoury, & Lambert, 1988). In this study, a multi-stage fitness test mobile application (type Bleep Test Solo for iOS, version 2.0, Bitworks Design, Leckhampton, Great Britain) was used to administer the test. The mobile phone was connected to a portable speaker and placed by the gymnasium wall to the side (Figure 22). Because the gymnasium itself was 20 m in length, the participants were required to touch the wall before turning around and running again.

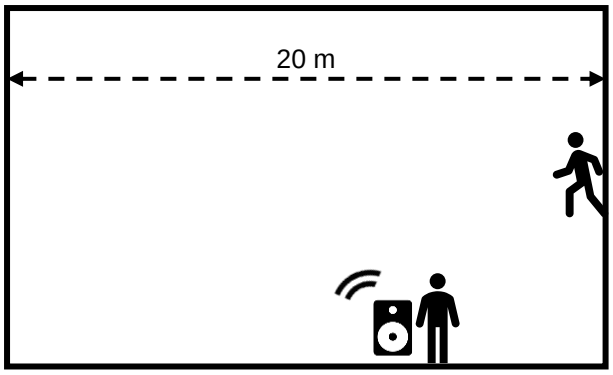

Figure 22. An illustration of the gymnasium and procedure set up during the 20 m shuttle run-test.

Participants positioned themselves on one side of the gymnasium with one of their hands placed on the wall. Before starting the test, the researcher played the recording for the participant and adjusted the volume so that the participant could hear the recording loud and clear. The researcher then asked the participant "Are you ready?". If the participant answered "Yes", the researcher counted down "Three, two, one" and said "Go!", and initiated the recording.

Participants started running at a speed of 8.5 km/h, with the frequency of the beeps increasing by 0.5 km/h every minute (Leger et al., 1988). Throughout the test, the researcher provided verbal encouragement so that the participants would push themselves to perform maximally. If the participant made it to the wall before the beep, they had to wait for the beep before continuing to run. If the participant couldn't reach the wall before the beep, they were given a warning by the researcher, and were required to catch up to the pace before the next beep. If the participant couldn't manage to catch up to the pace and couldn't reach the wall before the beep again, they got a second warning and the test ended. The last level that the participant completed was recorded and retained for analysis.

Immediately after the test was over, the researcher first wrote down participant's heart rate and then obtained a blood sample from the participant's finger using the Unistik 2 Neonatal (Owen Mumford Ltd., Woodstock, Great Britain) safety lancet and measured the participant's blood lactate concentration using the Lactate Scout+ analyzer (EKF Diagnostics, Cardiff, Great Britain). The participant was then provided with a small piece of tape and paper towel to tape up the finger from which the blood sample was taken.

3.6 Procedure

The researcher contacted the team leader of each of the sport teams at the University of Stavanger and arranged a team meeting. Team meetings were held either before or after a practice. During these meetings the study's purpose, methods, procedures, and potential risks were presented. After the team meeting, participants who volunteered to participate in the study were required to sign the informed consent. Participants also decided their preferred date and time of the testing sessions in accordance with the researcher.

Participants who agreed to take part in this study were required to participate in 4 testing sessions (1 control condition and 3 experimental massage conditions). To ensure participants were fully recovered, testing sessions were separated by at least 48 hours (Herda & Cramer, 2016; McGuigan, 2016). However, to minimize the possibility of changes in performance being attributed to factors other than massage, testing session weren't separated by more than a week. Testing sessions were conducted in a university laboratory and gymnasium and lasted approximately an hour each. The treatment order was randomized for each participant before they arrived at the university laboratory.

Upon submission to the university laboratory, during the first testing session only, anthropometric measurements were taken. Measurements of height were taken using a wall mounted Seca stadiometer model 222 (Seca Medical Measuring Systems and Scales, Hamburg, Germany). Measurements of weight were taken using a scale (type BC – 1000, Tanita, Tokyo, Japan) with a health monitoring software (GMON Pro for Windows 10, version 3.4.1, Medizin & Service GmbH, Chemnitz, Germany). Then, if the condition was experimental, participants received the treatment, if not, participants proceeded to testing. Each testing session, participants performed the same series of tests (Figure 23).

Firstly, participants performed the static

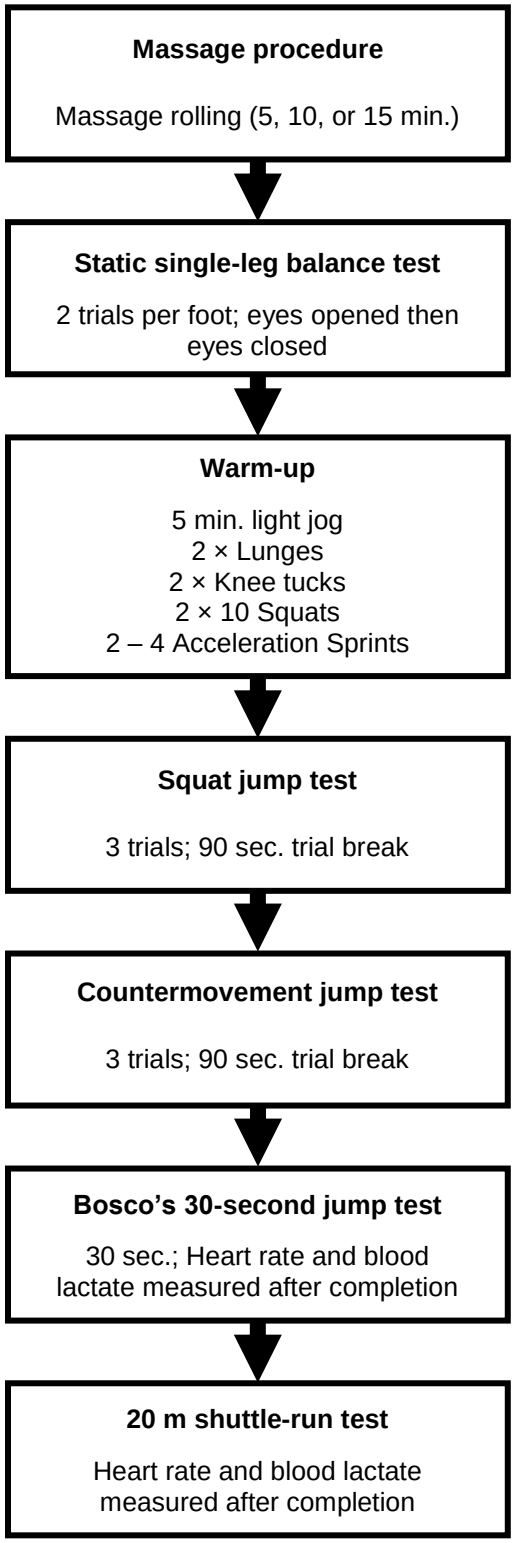

Figure 23. Overview of the procedure for the control and experimental condition.

single-leg balance test. After the static single-leg balance test, participants were escorted upstairs to the gymnasium (20 m × 10 m) where they performed a standardized warm-up. The standardized warm-up was based on the Raise, Activate, and Mobilize and Potentiate (RAMP) principle, and it incorporated a general and specific warm-up (Jeffreys, 2007). The general warm-up consisted of a 5-minute light jog at a self-selected pace. Participants were jogging in a circle while the researcher stood with a stopwatch on the side of the court. After the general warm-up, participants proceeded to the specific warm-up which consisted of two gymnasium lengths of lunges, two gymnasium lengths of knee tucks, 2 series of 10 repetitions of squats, and 2 – 4 gymnasium lengths of acceleration sprints. There was a 30-second passive rest between the squat series. After participants completed the standardized warm-up, the researcher escorted them back downstairs to the laboratory for further testing.

After the standardized warm-up, the participants performed the squat jump test. Before the next test, participants had a passive rest period of 150 seconds. Participants then performed the countermovement jump test. Participants were provided with a passive rest period of 150 seconds after the countermovement jump test as well. After the countermovement jump test, participants performed Bosco's 30-second jump test. After Bosco's 30-second jump test, participants were escorted upstairs to the gymnasium for the next test; the passive rest period after Bosco's 30-second jump test was approximately three and a half minutes. Lastly, the participants performed the 20 m shuttle-run test. After the 20 m shuttle-run test was completed the testing session was over and the participants were escorted downstairs to the laboratory.

3.7 Validity and Reliability

When different test and instruments are used to measure certain variables, the validity and reliability of those tests and instruments should always be considered (Thomas, Nelson, & Silverman, 2011). There are several types of validity which can be considered, in this case logical validity and construct validity. Logical validity (face validity) exists when a measure obviously involves the performance being measured (Thomas et al., 2011). This means that the test is valid by definition. For example, the static single-leg balance test has logical validity because it is supposed to measure static balancing on one foot. Construct validity refers to the degree to which a test or an instrument measures what it is supposed to measure (Thomas et al., 2011). The tests and instruments which were chosen for this study were chosen because they would measure those specific physical performance parameters. Another example would be that while a 1 repetition

maximum test would be valid for measuring low-speed strength (maximal muscular strength) it would not be valid for measuring anaerobic power (McGuigan, 2016).

Reliability refers to the consistency or repeatability of a measure. There are several sources of measurement error which could reduce the reliability of the results, in this case mainly system reliability and participant reliability (Thomas et al., 2011). System reliability refers to the reliability of the instrument, meaning does the instrument give precise and consistent measurements each trial. Similarly, participant reliability refers to the consistency of participant's performance, in other words, will the participant perform at the same level physically each trial and each test (Thomas et al., 2011). Testing order is one way of maximizing participant reliability. By structuring the tests in the proper order with adequate rest intervals between the trials and the tests, the participant can perform to the best of their ability each test and ensure high reliability. Thus. the tests which are least fatiguing (i.e., static single-leg balance test, squat jump test, and the countermovement jump test) are conducted first while the test which would cause fatigue (i.e., Bosco's 30-second jump test and the 20 m shuttle-run test) are conducted last. Reliability is an important part of validity. If a test or an instrument yields very different results on consecutive trials, it is not reliable and therefore cannot be trusted; in other words, the instrument would be unable to capture the changes in performance (Thomas et al., 2011).

3.8 Data Registration and Statistical Analyses

All data from the force plate was recorded and saved in the MuscleLab software (MuscleLab for Windows 10, version 10.5.69.4809, Ergotest Innovation A.S., Porsgrunn, Norway), while data from the 20 m shuttle-run test was recorded and saved in the multi-stage fitness test mobile application (type Bleep Test Solo for iOS, version 2.0, Bitworks Design, Leckhampton, Great Britain). Other data, such as heart rate and blood lactate concentration, was written down in a notebook. Data was handled confidentially, meaning it was kept secure under lock and key throughout the entire research period and only the researcher and his supervisor had access to the data. When data collection was complete, all raw data was transferred into Microsoft Excel (for Windows 10, version 1904, Microsoft, Washington, USA) and sorted. Data was then backed up onto an external flash drive which was also kept in a locked and secure place throughout the research period. Upon sorting the data, it was decided that the data from the static single-leg balance test (eyes opened only) and the countermovement jump test would be excluded from the statistical analysis. The data from two of the participants for Bosco's 30-second jump test was also

excluded from the statistical analysis.

Statistical analysis was performed using GraphPad Prism (for Windows 10, version 8.0.2, California, USA) and Microsoft Excel. All data was normally distributed as indicated by the Shapiro-Wilk test ($p > 0.05$). To determine the degree of reliability, the intra-class correlation coefficient (ICC) was calculated for all test results; this is the most commonly used method for expressing the degree of reliability of tests or instruments (Thomas et al., 2011; Koo & Li, 2016). The ICC can range from 0 to 1 with; ICC < 0.5 indicating poor reliability; ICC = 0.5 – 0.75 indicating moderate reliability; ICC = 0.75 – 0.9 indicating good reliability; and ICC > 0.9 indicating excellent reliability (Koo & Li, 2016).

To examine the effects of the different massage protocols on static single-leg balance, anaerobic power, and anaerobic and aerobic capacity, a one-way analysis of variance (ANOVA) was used to compare the means between massage protocols; with confidence intervals set to 95% and significance levels set at $p \leq 0.05$ for all measurements. All test results were expressed as means and standard deviations. To determine the effect size of each massage protocol, effect sizes (Cohen's *d*) were calculated, with the effect size; $d = 0.2$ considered small; $d = 0.5$ considered moderate; and $d = 0.8$ considered large. Effect sizes $d < 0.2$ were considered trivial (very small) (Cohen, 2013).

Data was further analyzed using magnitude-based inference method; for this analysis, confidence intervals of 90% were used. Magnitude-based inference calculates probabilities that the true effect could be clinically harmful (negative), trivial, or beneficial (positive), with; < 1%, meaning almost certainly not; 1 – 5%, meaning very unlikely; 5 – 25%, meaning unlikely or probably not; 25 – 75%, meaning possibly or may be; 75 – 95%, meaning likely or probably; 95 – 99%, meaning very likely; > 99%, meaning almost certainly. Depending on the size of each of the probabilities, the conclusion for the effect can then be: most likely beneficial, likely beneficial, possibly beneficial, unclear, very likely unclear, likely unclear, possibly harmful, very likely harmful, most likely harmful (Batterham & Hopkins, 2006).

4 Results

4.1 Reliability

Intra-class correlation analysis revealed moderate to good reliability for the static single-leg balance test with eyes opened (left foot, ICC = 0.69, $p < 0.01$; right foot, ICC = 0.85, $p < 0.01$) and

eyes closed (left foot, ICC = 0.62, $p < 0.01$; right foot, ICC = 0.85, $p < 0.01$). Excellent reliability was shown for the squat jump test (ICC = 0.95, $p < 0.01$) and the countermovement jump test (ICC = 0.98, $p < 0.01$). For Bosco's 30-second jump test in this study the intra-class correlation analysis showed excellent reliability (ICC = 0.97, $p < 0.01$). The reliability analysis has indicated excellent reliability (ICC = 0.97, $p < 0.01$) for the 20 m shuttle-run test in this study.

4.2 The Effects of Self-Induced Multi-Bar Massage Rolling on Balance

Table 1 shows the differences between the control and the experimental conditions for the static single-leg balance test (eyes closed only). For mean center of pressure distance on the left foot, the results of the analysis revealed that 5-, 10-, and 15-minute massage with the mechanical self-induced multi-bar massage roller had a small positive effect (d = 0.2, d = 0.4, and 0.4, respectively). For sway velocity the positive effects of 5-, 10-, and 15-minute massage protocols were larger (d = 0.8, d = 0.6, and 0.5, respectively). For sway area, 5-, 10-, and 15-minute massage protocols had a small to moderate positive effect (d = 0.4, d = 0.4, and 0.5, respectively). For the right foot, 5-, 10-, and 15-minute massage protocols had a small positive effect ($d \leq 0.3$) on all the parameters. However, none of the differences for the static single-leg balance test were statistically significant ($p > 0.05$).

Table 1. Differences between the control and experimental conditions for the static single-leg balance test (eyes closed only).

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Left foot					
Mean COP dist. (mm)					
Control	15.3 (5.4)				
Total massage time 5 min.	13.8 (4.5)	-1.5 (1.8)	-3.9 to 7	0.84	0.2
Total massage time 10 min.	13.3 (3.3)	-1.9 (1.5)	-2.5 to 6.4	0.58	0.4
Total massage time 15 min.	13.1 (3.6)	-2.2 (1.3)	-1.8 to 6.3	0.41	0.4

Table 1. (Continued) Differences between the control and experimental conditions for the static single-leg balance test (eyes closed only).

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Sway velocity (mm/s)					
Control	131.4 (40.3)				
Total massage time 5 min.	100.9 (31.4)	-30.4 (12)	-5.3 to 66.3	0.1	0.8
Total massage time 10 min.	106.4 (38.5)	-25 (9)	-1.6 to 51.7	0.06	0.6
Total massage time 15 min.	109.3 (41.3)	-22 (8.5)	-3.1 to 47.3	0.09	0.5
Sway area (mm^2)					
Control	1236 (936.1)				
Total massage time 5 min.	899.8 (464.4)	-335.9 (268.5)	-461.3 to 1133	0.6	0.4
Total massage time 10 min.	868.8 (471.8)	-366.9 (245.6)	-362.2 to 1096	0.47	0.4
Total massage time 15 min.	838.9 (471.1)	-396.8 (199.5)	-195.5 to 989.1	0.24	0.5
Right foot					
Mean COP dist. (mm)					
Control	15.1 (4.3)				
Total massage time 5 min.	14.4 (3)	-0.7 (1.4)	-3.6 to 5	0.96	0.1
Total massage time 10 min.	14 (4.3)	-1.1 (1.4)	-3.3 to 5.5	0.87	0.2
Total massage time 15 min.	15.2 (9.2)	0.08 (2.7)	-8.1 to 7.9	0.99	-0.01
Sway velocity (mm/s)					
Control	123.3 (59.1)				
Total massage time 5 min.	107.3 (37.7)	-15.9 (18.7)	-39.5 to 71.4	0.82	0.3
Total massage time 10 min.	106.6 (45.7)	-16.6 (18.5)	-38.4 to 71.8	0.8	0.3
Total massage time 15 min.	108.8 (59.5)	-14.4 (21.2)	-48.5 to 77.5	0.9	0.2

Table 1. (Continued) Differences between the control and experimental conditions for the static single-leg balance test (eyes closed only).

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Sway area (mm^2)					
Control	1268 (934.9)				
Total massage time 5 min.	1047 (499.4)	-221.6 (275.3)	-595.6 to 1039	0.85	0.2
Total massage time 10 min.	1044 (680.2)	-224.4 (259.8)	-546.8 to 995.5	0.82	0.2
Total massage time 15 min.	1107 (1043)	-161 (387)	-987.9 to 1310	0.97	0.1

SD = standard deviation; SEM = standard error of the mean; CI = confidence intervals; COP dist. = center of pressure distance.

Figure 24 shows the results of magnitude-based inferences analysis. For all parameters, except sway velocity on the left foot, the results showed that the effects of 5-, 10-, and 15-minute massage protocols were unclear. Only for the sway velocity on the left foot did the results show that the effects of 5-, 10-, and 15-minute massage with the mechanical self-induced multi-bar massage roller were likely beneficial (88.8%, 90%, 86.4%, respectively).

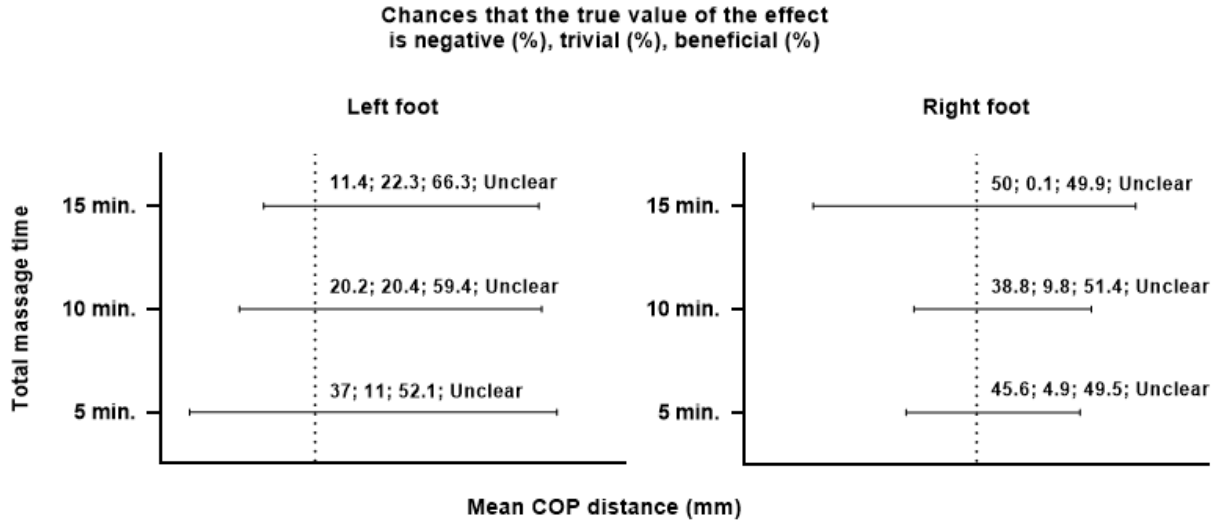

Figure 24. The results of the magnitude-based inference analysis for the static single-leg balance test (eyes closed only). COP dist. = center of pressure distance.

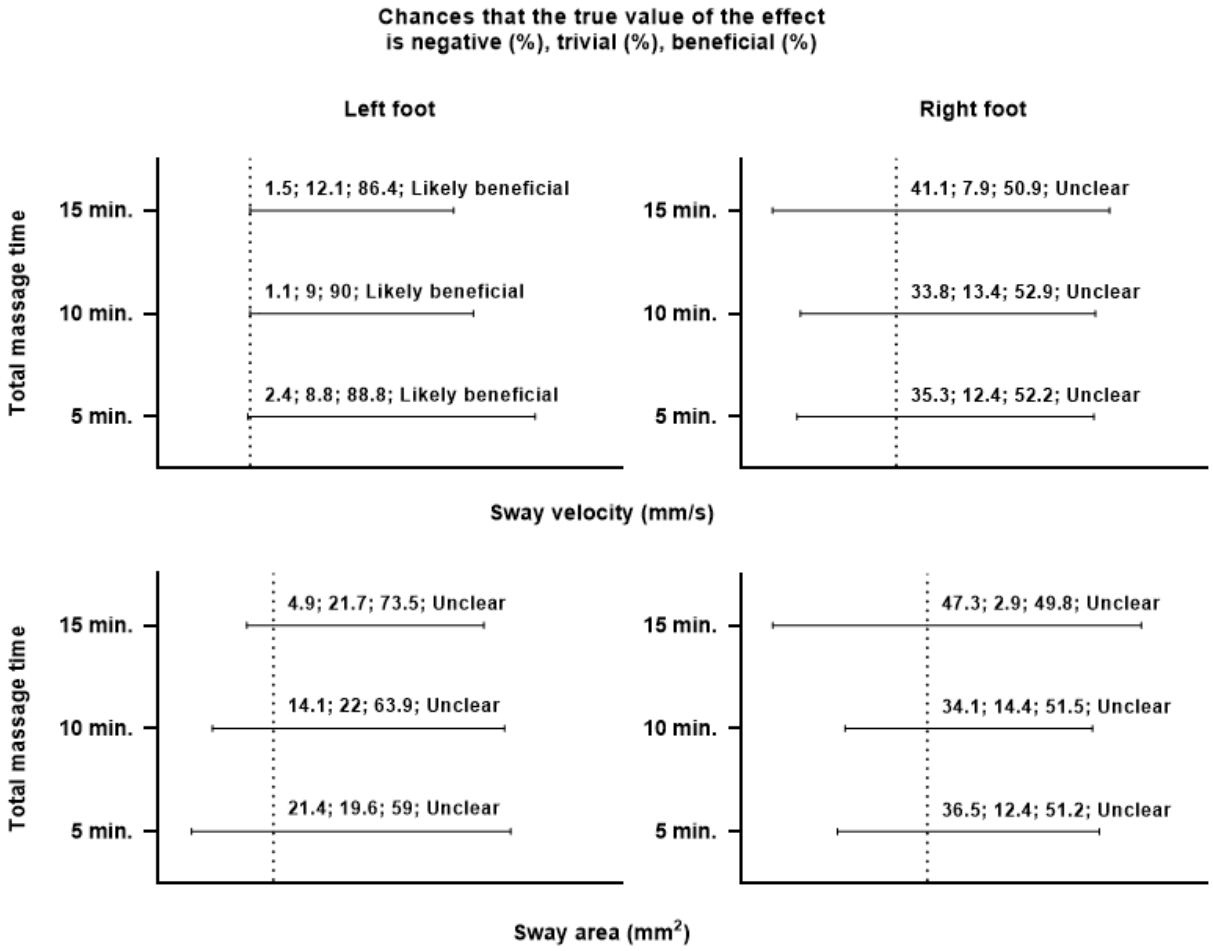

Figure 24. (Continued) The results of the magnitude-based inference analysis for the static single-leg balance test (eyes closed only). COP dist. = center of pressure distance.

4.3 The Effects of Self-Induced Multi-Bar Massage Rolling on Anaerobic Power and Anaerobic Capacity

The differences between the control and the experimental conditions for the squat jump test are shown in Table 2. The 5-, 10-, and 15-minute massage with mechanical self-induced multi-bar massage roller had a trivial effect (d = -0.09, d = -0.03, and -0.05, respectively) on squat jump height. The differences in squat jump height between the control and experimental conditions were not statistically significant ($p > 0.05$).

Table 2. Differences between the control and experimental conditions for the squat jump test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Squat jump height (cm)					
Control	37.5 (5)				
Total massage time 5 min.	36.9 (6.7)	-0.5 (1)	-2.6 to 3.8	0.95	-0.09
Total massage time 10 min.	37.3 (5.5)	-0.1 (0.8)	-2.2 to 2.6	0.99	-0.03
Total massage time 15 min.	37.2 (5.9)	-0.3 (0.7)	-2 to 2.6	0.97	-0.05

SD = standard deviation; SEM = standard error of the mean; CI = confidence intervals.

The results of the magnitude-based inference analysis showed that the effects of 5-, 10-, and 15-minute massage protocols on squat jump height were unclear (Figure 25).

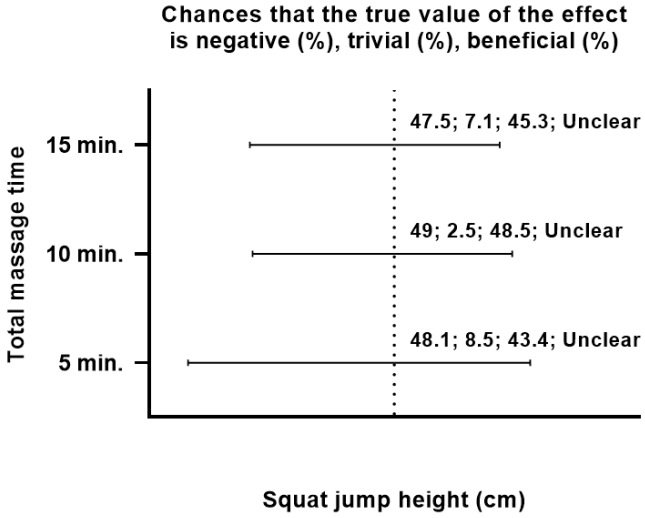

Figure 25. The results of the magnitude-based inference analysis for the static squat jump test.

Table 3 shows the differences between the control and the experimental conditions for Bosco's 30-second jump test. Results showed that the 5-, 10-, and 15-minute massage protocols had trivial effects (d = 0.01 d = -0.05, and d = 0.06, respectively) on peak power at 15 seconds.

Table 3. Differences between the control and experimental conditions for Bosco's 30-second jump test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
PP at 15 s. ($W \cdot kg^{-1}$)					
Control	6.9 (1.8)				
Total massage time 5 min.	7.1 (2)	0.1 (0.3)	-1.1 to 0.7	0.91	0.1
Total massage time 10 min.	6.8 (2.2)	-0.1 (0.3)	-0.8 to 1	0.98	-0.05
Total massage time 15 min.	7 (1.8)	0.1 (0.2)	-0.7 to 0.5	0.94	0.06
MP at 30 s. ($W \cdot kg^{-1}$)					
Control	6.2 (1.3)				
Total massage time 5 min.	6.3 (1.5)	0.1 (0.2)	-0.9 to 0.6	0.95	0.09
Total massage time 10 min.	6.1 (1.7)	-0.02 (0.2)	-0.7 to 0.7	0.99	-0.01
Total massage time 15 min.	6.4 (1.4)	0.2 (0.1)	-0.8 to 0.4	0.74	0.1
Fatigue index (%)					
Control	20.5 (8.9)				
Total massage time 5 min.	20.6 (10.1)	0.1 (2)	-6.2 to 6	0.99	-0.01
Total massage time 10 min.	17.6 (10.35)	-2.8 (2.2)	-3.9 to 9.6	0.58	0.2
Total massage time 15 min.	18.2 (10.6)	-2.3 (2.1)	-4.1 to 8.7	0.70	0.2
NVJ at 15 s.					
Control	12.6 (1.1)				
Total massage time 5 min.	11.4 (2.2)	-1.1 (0.6)	-0.9 to 3.3	0.37	-0.6
Total massage time 10 min.	11.9 (2.8)	-0.7 (0.8)	-1.9 to 3.4	0.83	-0.3
Total massage time 15 min.	12.1 (1.6)	-0.4 (0.4)	-1 to 1.9	0.79	-0.3

Table 3. (Continued) Differences between the control and experimental conditions for Bosco's 30-second jump test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
NVJ at 30 s.					
Control	24.7 (2.2)				
Total massage time 5 min.	23.8 (3.7)	-0.9 (0.9)	-1.9 to 3.8	0.77	-0.2
Total massage time 10 min.	23.8 (4.6)	-0.9 (1.1)	-2.5 to 4.3	0.85	-0.2
Total massage time 15 min.	24.2 (3.2)	-0.4 (0.6)	-1.6 to 2.5	0.91	-0.1
Reactive strength index					
Control	0.317 (0.06)				
Total massage time 5 min.	0.322 (0.08)	0.005 (0.01)	-0.04 to 0.03	0.97	0.07
Total massage time 10 min.	0.315 (0.08)	-0.001 (0.01)	-0.03 to 0.04	0.99	-0.02
Total massage time 15 min.	0.327 (0.07)	0.01 (0.01)	-0.04 to 0.02	0.78	0.1
Stiffness (kN/m)					
Control	2,77 (0,5)				
Total massage time 5 min.	2.83 (0.9)	0.06 (0.2)	-0.6 to 0.5	0.98	0.08
Total massage time 10 min.	2.76 (0.9)	-0.002 (0.2)	-0.6 to 0.6	0.99	0.003
Total massage time 15 min.	2.80 (0.7)	0.03 (0.1)	-0.4 to 0.3	0.99	0.04
Heart rate (bpm)					
Control	159.7 (6.9)				
Total massage time 5 min.	158.6 (5.7)	-1 (2.2)	-5.9 to 8	0.96	-0.1
Total massage time 10 min.	157.5 (7.9)	-2.1 (1.8)	-3.3 to 7.7	0.63	-0.2
Total massage time 15 min.	160.9 (8.2)	1.1 (2.6)	-9.1 to 6.7	0.96	0.1

Table 3. (Continued) Differences between the control and experimental conditions for Bosco's 30-second jump test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Blood lactate (mmol/l)					
Control	4.02 (1.9)				
Total massage time 5 min.	4.2 (2)	0.1 (0.6)	-2 to 1.6	0.99	0.09
Total massage time 10 min.	3.63 (1.6)	-0.3 (0.8)	-2.2 to 3	0.96	-0.2
Total massage time 15 min.	3.5 (1.6)	-0.5 (0.7)	-1.6 to 2.7	0.88	-0.2

SD = standard deviation; SEM = standard error of the mean; CI = confidence intervals; PP = peak power; MP = mean power; NVJ = number of vertical jumps.

The 5-, 10-, and 15-minute massage protocols had a trivial effect (d = 0.09, d = -0.01, and d = 0.1, respectively) on mean power at 30 seconds. When compared to the control (20.5 ± 8.9%), the fatigue index was slightly higher after the 5-minute massage protocol (20.6 ± 10.1%; d = -0.01) and lower after 10-minute (17.6 ± 10.35%; d = 0.2) and 15-minute (18.2 ± 10.6%; d = 0.2) massage protocols. Massage with the mechanical self-induced multi-bar massage roller had an overall negative effect on the number of vertical jumps at 15 seconds, with the effect of the 5-, 10-, and 15-minute protocols being small to moderate (d = -0.6, d = -0.3, and d = -0.3, respectively). Results showed that the massage protocols had an overall negative effect on the number of vertical jumps at 30 seconds as well; however, the effects of the 5-, 10-, and 15-minute protocols were smaller (d = -0.2, d = -0.2, and d = -0.1, respectively). For the reactive strength index, results showed a trivial effect of d = 0.07, d = 0.02, and d = 0.1 after the 5-, 10-, and 15-minute massage protocols, respectively. Regarding stiffness, results also showed trivial effects of d = 0.08, d = 0.003, and d = 0.04 after the 5-, 10-, and 15-minute massage protocols, respectively. When compared to control, the 5- and 10-minute massage protocols had a small negative effect (d = -0.1 and d = -0.2, respectively), while the 15-minute massage protocol had a trivial effect (d = 0.1) on heart rate. Blood lactate concentration was higher after the 5-minute massage protocol (4.2 ± 2 mmol/l; d = 0.09) and lower after the 10-minute (3.63 ± 1.6 mmol/l; d = -0.2) and 15-minute (3.5 ± 1.6 mmol/l; d = -0.2) massage protocols. None of the differences for all the parameters of Bosco's 30-second

jump test were statistically significant ($p > 0.05$).

Figure 26 shows the results of the magnitude-based inferences analysis for Bosco's 30-

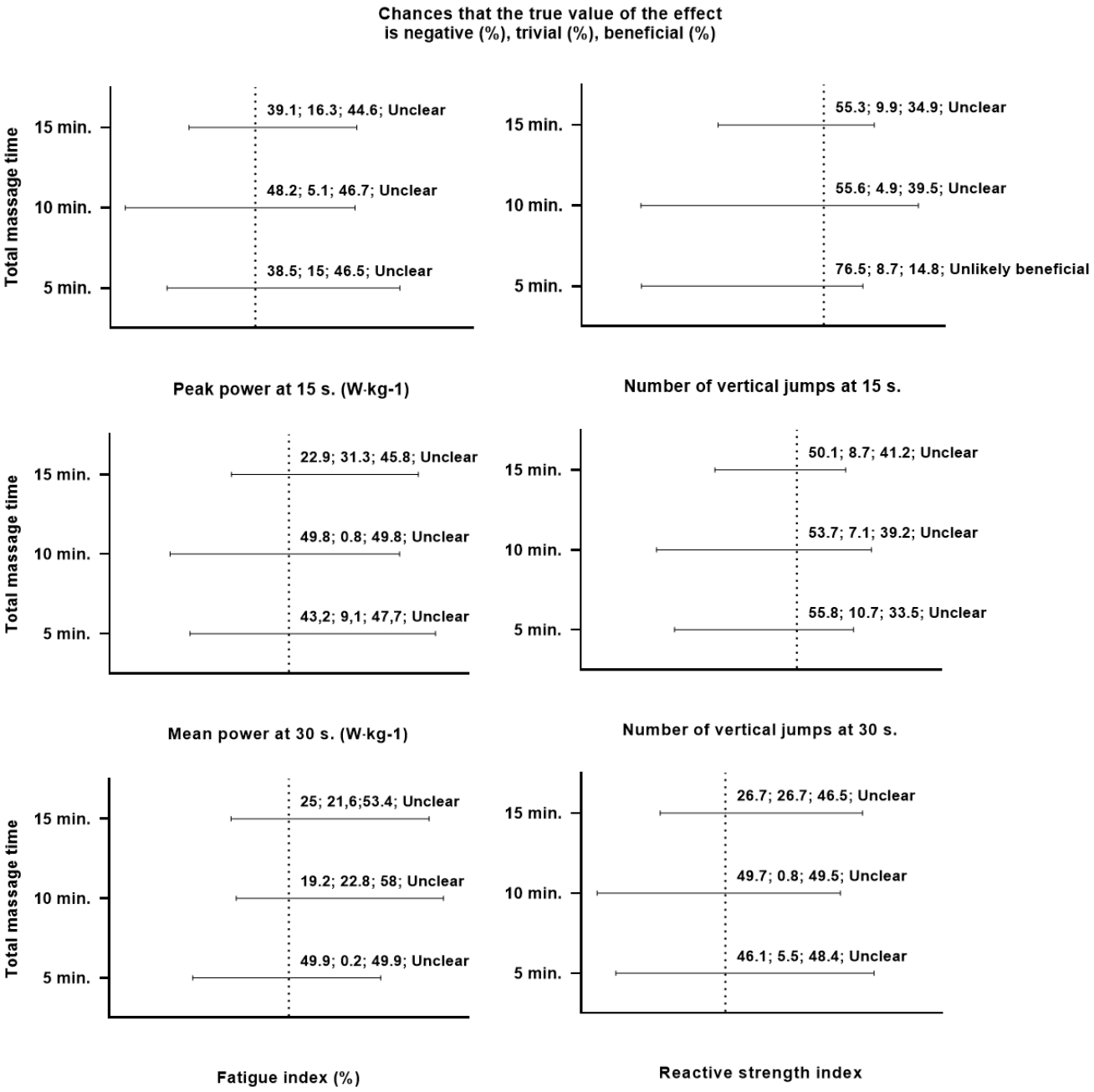

Figure 26. The results of the magnitude-based inference analysis for Bosco's 30-second jump test.

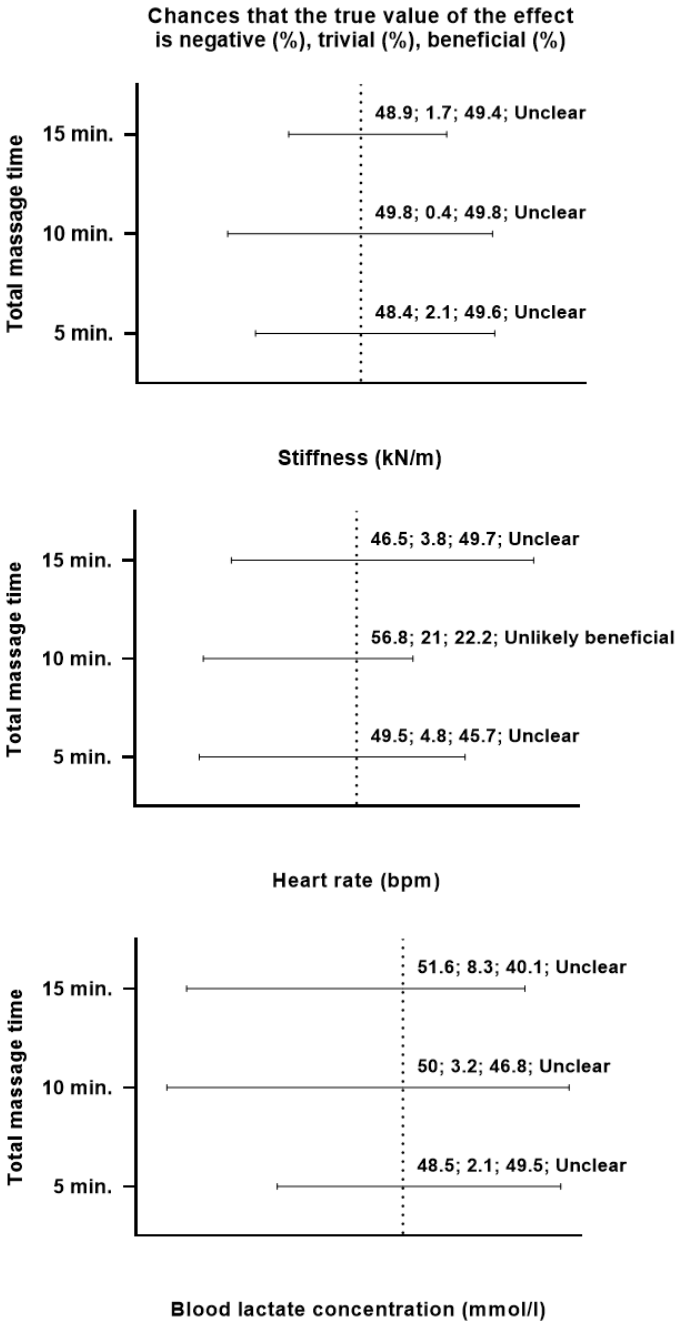

Figure 26. (Continued) The results of the magnitude-based inference analysis for Bosco's 30-second jump test.

second jump test. The results of the analysis showed that the effects of the 5-, 10-, and 15- minute massage protocols were unclear for all except two parameters, the number of vertical jumps at 15 seconds after the 5-minute massage protocol and heart rate after the 10-minute massage protocol; for these two parameters, the results showed that the effects were unlikely to be beneficial, with probabilities of 76.5% and 56.8%, respectively.

4.4 The Effects of Self-Induced Multi-Bar Massage Rolling on Aerobic Capacity

Table 4 shows the results for the 20 m shuttle-run test. Results of the analysis showed that the 5-, 10-, and 15-minute massage protocols had a trivial effect on total running distance (d = 0.1). The 5-, 10- and 15-minute massage protocols had trivial effects (d = -0.03, d = 0.04, and d = 0.09, respectively) on heart rate. The 5-, 10, and 15-minute massage protocols had trivial effects (d = 0.01, d = -0.005, and d = 0.1, respectively) on blood lactate concentration. There were no statistically significant ($p > 0.05$) differences between the control and experimental conditions for all the parameters of the 20 m shuttle-run test.

Table 4. Differences between the control and experimental conditions for the 20 m shuttle-run test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Total running distance (m)					
Control	1511 (325.4)				
Total massage time 5 min.	1551 (394.9)	40 (41.8)	-164.3 to 84.3	0.77	0.1
Total massage time 10 min.	1554 (328.4)	43 (37.6)	-154.9 to 68.7	0.67	0.1
Total massage time 15 min.	1566 (394.8)	55,3 (43.6)	-185.1 to 74.3	0.59	0.1
Heart rate (bpm)					
Control	192.7 (9.2)				
Total massage time 5 min.	192.4 (6)	-0.3 (1.2)	-3.4 to 4	0.99	-0.03
Total massage time 10 min.	193.1 (7.3)	0.3 (1.3)	-4.2 to 3.5	0.99	0.04
Total massage time 15 min.	193.5 (6.6)	0.7 (1.3)	-4.7 to 3.2	0.93	0.09

Table 4. (Continued) Differences between the control and experimental conditions for the 20 m shuttle-run test.

	Mean (SD)	Difference (SEM)	95% CI	*p* value	Cohen's *d*
Blood lactate (mmol/l)					
Control	11.34 (3.2)				
Total massage time 5 min.	11.38 (2.1)	0.04 (0.4)	-1.4 to 1.3	0.99	0.01
Total massage time 10 min.	11.32 (4.1)	-0.02 (0.7)	-2.2 to 2.3	0.99	-0.005
Total massage time 15 min.	11.73 (3.5)	0.3 (0.8)	-2.9 to 2.1	0.96	0.1

SD = standard deviation; SEM = standard error of the mean; CI = confidence intervals.

The results of the magnitude-based inference analysis for the 20 m shuttle-run test are shown in Figure 27. The results of the analysis showed that the effects of 5-, 10-, and 15-minute massage on total running distance, heart rate, and blood lactate concentration were unclear.

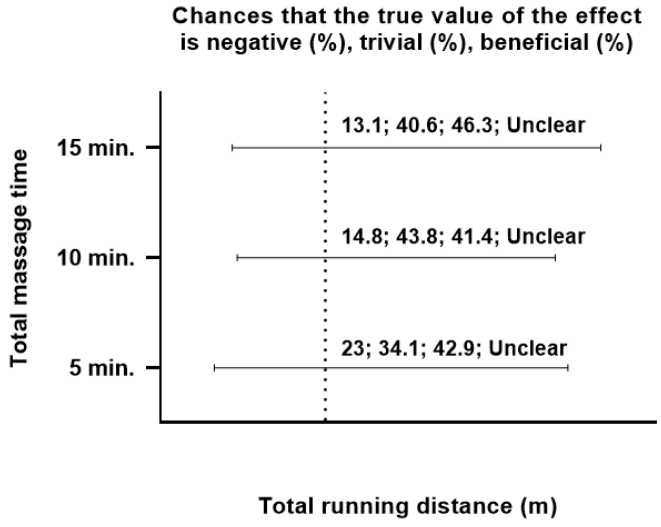

Figure 27. The results of the magnitude-based inference analysis for the 20 m shuttle-run test.

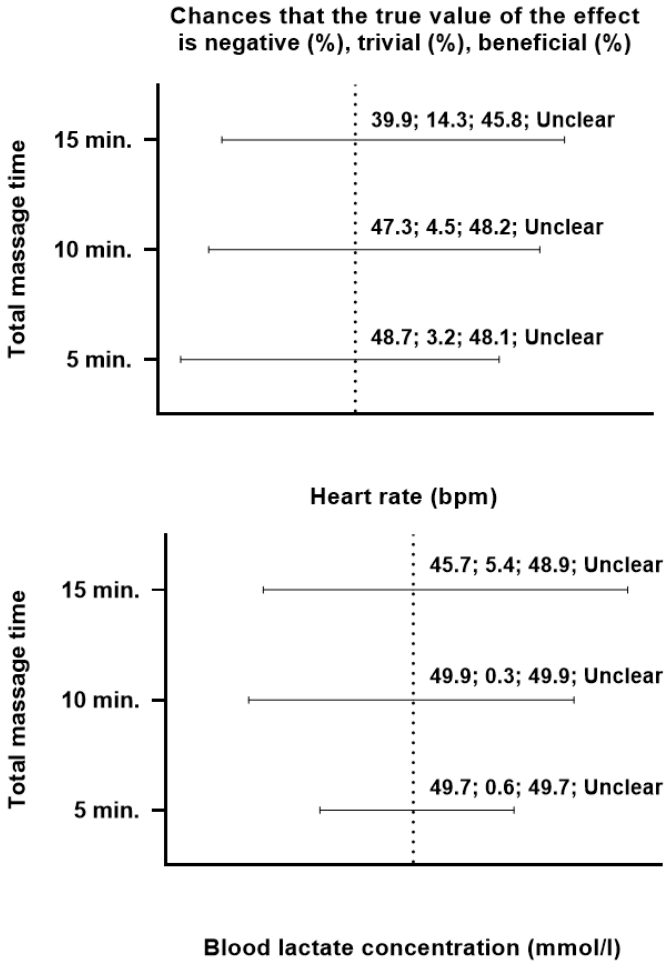

Figure 27. (Continued) The results of the magnitude-based inference analysis for the 20 m shuttle-run test.

5 Discussion

The purpose of this study was to examine the effects of 5-, 10-, and 15-minute massage with a mechanical self-induced multi-bar massage roller on static single-leg balance, anaerobic power, and anaerobic and aerobic capacity. It was hypothesized that the massage will increase balance, anaerobic power, and anaerobic and aerobic capacity, and that the effects would be massage length dependent. The findings indicated that effects were not massage length dependent. The one-way ANOVA showed that none of the differences between the control and the massage protocols for all tests were statistically significant ($p > 0.05$). The magnitude-based inference analysis showed that the effects of the massage protocols, for all but 5 performance parameters, were unclear, meaning more data is needed to decide if there is an effect and if it's harmful or beneficial for those performance parameters. The magnitude-based inference showed that the effects of 5-, 10-,

and 15-minute massage protocols were likely beneficial (88.8%, 90%, and 86.4%, respectively; Figure 24) for sway velocity on left foot. For Bosco's 30-second jump test, the magnitude-based inference analysis showed that the effects of the 5-, and 10-minute massage protocols were unlikely beneficial for the number of vertical jumps at 15 seconds (76.5%; Figure 26) and heart rate (56.8%; Figure 26), respectively.

5.1 Reliability

The static single-leg balance test, through the use of a computerized force plate, has been shown to be a valid test for measuring the ability of the human body to retain a specific posture (Yim-Chiplis & Talbot, 2000; Panjan & Sarabon, 2010; Flanagan, 2012). Intra-class correlation analysis revealed moderate to good reliability for the static single-leg balance test with eyes opened (left foot, ICC = 0.69, $p < 0.01$; right foot, ICC = 0.85, $p < 0.01$) and eyes closed (left foot, ICC = 0.62, $p < 0.01$; right foot, ICC = 0.85, $p < 0.01$). These results are in line with previous research which also shows moderate to good reliability (ICC = 0.52 to 0.62) for the static single-leg balance test (Lafond, Corriveau, Hébert, & Prince, 2004).

The squat jump test and countermovement jump test, through the use of a computerized force plate, have been shown to be valid measurements of anaerobic power (Markovic et al., 2004). The force plate is considered to be the Golden Standard of measurement methods for the squat jump test and countermovement jump test (Chamari, Chaouachi, & Racinais, 2010). The intra-class correlation analysis in this study showed excellent reliability for the squat jump test (ICC = 0.95, $p < 0.01$) and the countermovement jump (ICC = 0.98, $p < 0.01$) test. These results are in line with those of Markovic et al. (2004), which also showed excellent reliability for the squat jump test (ICC = 0.97, $p < 0.01$) and countermovement jump test (ICC = 0.98, $p < 0.01$). When it comes to measuring anaerobic capacity through jumping, Bosco's 30-second jump test is a valid measurement method when compared to the Wingate anaerobic test (Chamari et al., 2010). Bosco's 30-second jump has shown excellent reliability in this study, as demonstrated by high intra-class correlation values (ICC = 0.97, $p < 0.01$). These results are similar to results from other studies which also found excellent reliability (ICC = 0.98, $p < 0.01$) of Bosco's 30-second jump test when compared to the Wingate anaerobic test (Theodorou & Cooke, 1998; Dal Pupo et al., 2014; Čular et al., 2018). The instrument by which blood lactate concentration was measured (Lactate Scout+ analyzer, EKF Diagnostics, Cardiff, Great Britain) has been shown to give reliable results when compared to a blood analyzer (model ABL90, Radiometer, Copenhagen, Denmark),

with low levels of bias (Bonaventura et al., 2015).

The 20 m shuttle-run test which was used in this study, has been shown to be a valid method for measuring aerobic capacity (Leger et al., 1988). The reliability analysis has indicated excellent reliability (ICC = 0.97, $p < 0.01$) for the 20 m shuttle-run test in this study. These results are in line with those of Leger et al. (1988), who also found excellent test-retest reliability (ICC = 0.95, $p > 0.05$) for the 20 m shuttle-run test. The 20 m shuttle-run test also showed moderate reliability (ICC = 0.61, $p < 0.05$) when compared to the maximal oxygen uptake (VO_2max) test (O'Gorman, Hunter, McDonnacha, & Kirawan, 2000), which is considered to be the Golden Standard of measuring aerobic capacity (Saltin & Astrand, 1967).

5.2 The Effects of Self-Induced Multi-Bar Massage Rolling on Balance

The findings in this study showed that massage had an overall positive effect on performance, with only mean center of pressure distance on right foot after 15-minute massage protocol being affected slightly negatively (d = -0.01; Table 1). The positive effect sizes for the static single-leg balance test ranged from trivial to large (d = 0.1 – 0.8; Table 1). To the researcher's knowledge, this was the first study to examine the effects of 5-, 10-, and 15-minute massage with the mechanical self-induced multi-bar massage roller on static single-leg balance. The researcher was thus unable to find other studies which conducted similar experiments. Nevertheless, there are studies which have examined the effects of different forms of massage therapy on balance performance in other various sample groups. A study by Cieślik et al. (2017) examined the effects of a tensegrity-based massage protocol on static balance in healthy female university students. Study results showed that the tensegrity-based massage positively affected postural control, particularly in the anterior-posterior center of pressure direction where statistically significant ($p < 0.05$) differences were observed (Cieślik et al., 2017).

Exactly how massage induces these positive effects in balance performance is still unclear (Chatchawan, Eungpinichpong, Plandee, & Yamauchi, 2015). However, researchers have made suggestions of the possible massage mechanisms which could have contributed to the increase in balance performance (Park & Hwang, 2016; Cieślik et al., 2017; Tütün Yümin, Şimşek, Sertel, Ankaralı, & Yumin, 2017). Because balance, from a biomechanical perspective, is a complex process that depends on constant relay and processing of sensory information from the neural, muscular, visual, and vestibular components (Riemann & Lephart, 2002), any change in these components might affect the overall balance performance (Cieślik et al., 2017). This includes

changes in muscular and fascial tension. Excessive muscular and fascial tension may restrict and affect the relaying and processing of sensory information (Chaitow, 2010). It is possible that massage alleviates the tension in the muscle and fascia by loosening them up, thereby enhancing proprioception (Arroyo-Morales et al., 2008; Cieślik et al., 2017). This notion can be supported by findings from other studies as well.

Park and Hwang (2016) found a statistically significant decrease in the timed "up and go" test ($p = 0.034$) and a statistically significant increase in the Berg Balance Scale scores in chronic stroke patients ($p = 0.001$) after 8 weeks (3 sessions per week) of myofascial release through the use of a tennis ball. Similarly, Vaillant et al. (2009) found an improvement in the Lateral Reach test and statistically significant ($p < 0.05$) improvements in the static single-leg balance test and the timed "up and go" test in elderly people after a manual massage and mobilization protocol (Vaillant et al., 2009). These increases in balance performance could also be explained by enhanced mechanoreceptor activity. It has been shown that massage can stimulate the mechanoreceptors, which play an important role in postural control (Schleip, 2003; Taylor, Menz, & Keenan, 2004; Tütün Yümin et al., 2017).

The findings from the magnitude-based inference analysis for the static single-leg balance test (Figure 24) showed that the effects of 5-, 10-, and 15-minute massage were unclear. However, sway velocity on the left foot is the only parameter for which the effects were close to reaching statistical significance; for this parameter the results showed that the effects of 5-, 10-, and 15-minute massage protocols were 88.8%, 90%, 86.4% likely beneficial, respectively (Figure 24). It is known that postural control decreases by age, especially if the individual has a condition which further impedes balance (Marsh & Geel, 2000; Lacour, Bernard-Demanze, & Dumitrescu, 2008; Kitabayashi, Uchiyama, Demura, Kawabata, & Demura, 2011). Because of these reasons, the risk of falling and injury is higher in older individuals, which is why studies investigating effects of massage therapy on balance performance usually involve older participants (Halvarsson et al., 2013). It is also known that participation in sports and physical activity can improve the individual's balance, which is why athletes and physically active individuals tend to have better balance ability compared to individuals who aren't physically active (Hrysomallis, 2011). The participants in this group were all healthy and physically active young to middle-aged adults. This could possibly explain why the balance performance increases in this study did not reach statistical significance and why most of the other studies (with physically inactive or older participants with

medical conditions) reported statistically significant increases in balance performance after massage (Park & Hwang, 2016; Cieślik et al., 2017; Tütün Yümin et al., 2017).

5.3 The Effects of Self-Induced Multi-Bar Massage Rolling on Anaerobic Power and Anaerobic Capacity

The findings in this study show that, compared to control, the massage had an overall trivial effect ($d < -0.1$; Table 2) on anaerobic power as evident by the slight drop in squat jump height. Furthermore, the results of the magnitude-based inference analysis showed that the effects of 5-, 10-, and 15-minute massage protocols on squat jump performance were unclear (Figure 25). This isn't the only study which examined the effects of massage, specifically myofascial release massage, on anaerobic power and capacity in collegiate level athletes. When it comes to effects of pre-exercise massage on athletic performance, research has mostly focused on the power development and anaerobic capacity aspects (Schroeder & Best, 2015; Kalichman & David, 2017; Mine et al., 2018). There are therefore numerous studies which have examined the effects of various massage therapy methods on power development and anaerobic capacity in various athlete groups (Janot et al., 2013; Healey et al., 2014; Bradbury-Squires et al., 2015). More specifically, the findings for the squat jump test in this study are in similar to the results of previous studies that examined the effects of massage therapy on anaerobic power (Healey et al., 2014; Behara & Jacobson, 2017).

Healey et al. (2014) examined the effects of foam rolling on vertical jump height and power, agility, and isometric force in healthy college-aged individuals. No statistically significant difference was observed in vertical jump height and power, agility, and isometric force after 30 seconds of foam rolling (Healey et al., 2014). Behara and Jacobson (2017) examined the effects of foam rolling on hip joint range of motion, power, velocity, and knee flexion and extension torque in National College Athletic Association (NCAA) Division 1 football linemen. Compared to baseline, no statistically significant differences were observed in power, velocity, and knee flexion and extension torque after foam rolling and a statistically significant difference ($p < 0.0001$) was observed in hip joint range of motion (Behara & Jacobson, 2017). Statistically non-significant differences in vertical jump, maximum voluntary contraction, and sprint performance after massage were also observed in several other studies (Mine et al., 2018).

The way massage affects power development is similar to the way static stretching affects power development. Statistically significant power decrements have been observed after bouts of

static stretching (Power, Behm, Cahill, Carroll, & Young, 2004; Holt & Lambourne, 2008; Kay & Blazevich, 2012). These power decrements are mainly explained by the reductions in muscle tension, increase in muscle length, and reduction in neural activation of the muscle (Kay & Blazevich, 2012). It has been suggested that massage can also affect muscle tension, increase muscle-tendon compliance, and decrease neuromuscular excitability (Weerapong et al., 2005; Cheatham et al., 2015). Earlier studies of the effects of massage on the human muscle also show that massage can cause H-reflex inhibition, which is an indirect measure of the α-motor neuron excitability (Sullivan, Williams, Seaborne, & Morelli, 1991; Goldberg, Sullivan, & Seaborne, 1992; Morelli, Chapman, & Sullivan, 1999). Put together, these mechanisms could reduce power development (Cheatham et al., 2015). However, it appears that the effect that myofascial release has on power development is less significant than the effect of static stretching. This notion can be supported by several studies (Sullivan et al., 2013; Bradbury-Squires et al., 2015; Grabow et al., 2018).

Sullivan et al. (2013) examined the effects of a mechanical roller massager on joint range of motion, muscle activation using electromyography, and maximum voluntary contraction in college individuals. Results showed no statistically significant difference in muscular activation and maximum voluntary contraction force after roller massaging; however, a statistically significant improvement ($p < 0.0001$) was observed in joint range of motion (Sullivan et al., 2013). Bradbury-Squires et al. (2015) examined the effects of the same mechanical roller-massager on knee-joint range of motion and neuromuscular efficiency during a lunge in recreationally active males. The results showed a 10% and 16% increase in knee-joint range of motion after the 20- and 60-second massage conditions, respectively ($p < 0.05$). The results also showed a decrease in electromyographic activity during the lunge (Bradbury-Squires et al., 2015). In a recent study, Grabow et al. (2018) examined the effects of different forces of roller-massaging on pain perception, knee-joint range of motion, single-leg drop jump performance, and maximum voluntary contraction. The results showed a statistically significant increase ($p < 0.001$) in active and passive knee-joint range of motion regardless of roller-massage force. No statistically significant differences were observed in drop jump performance and maximum voluntary contraction (Grabow et al., 2018).

For Bosco's 30-second jump test, adverse results were observed when comparing the control protocol to the massage protocols, with some parameters being affected negatively and

some positively. However, the overall sizes of the negative and positive effects ranged from moderate to trivial ($d \geq$ -0.6, $d = \leq 0.2$, respectively; Table 3). The magnitude-based inference analysis of Bosco's 30-second jump test also revealed that the effects of 5-, 10-, and 15-minute massage protocols were unclear for most parameters; for the number of vertical jumps at 15 seconds after the 5-minute massage protocol and heart rate after the 10-minute massage protocol the effects were shown to be unlikely beneficial (76.5% and 56.8%, respectively; Figure 26). These findings for Bosco's 30-second jump test are somewhat similar to the results of Janot et al. (2013).

Janot and colleagues (2013) were amongst first to examine and compare the effects of self-myofascial release and static stretching on anaerobic capacity in healthy young adults. The results of the study were adverse, showing no statistically significant difference in peak power output and statistically significant ($p < 0.05$) decrease in percent power drop (fatigue index) in female participants, and a statistically significant ($p < 0.05$) increase in peak power output and percent power drop in male participants (Janot et al., 2013). Conversely, the results from this study showed a slight increase in peak power at 15 seconds after the 5- and 15-minute massage protocols and a slight decrease after the 10-minute protocol, while the fatigue index was slightly higher after the 5-minute massage protocol and lower after the 10- and 15-minute massage protocols. It is unclear why these results are this adverse. However, the aforementioned findings and theories about the effects of massage on anaerobic power, from a biomechanical and neurological perspective, could also help explain why there was no statistically significant change in performance for Bosco's 30-second jump test (Weerapong et al., 2005; Schroeder & Best, 2015; Mine et al., 2018).

Compared to control (2.77 ± 0.5 kN/m), a slight increase in leg stiffness has been observed after the 5-, 10-, and 15-minute massage protocols (2.83 ± 0.9 kN/m, 2.76 ± 0.9 kN/m, and 2.80 ± 0.7 kN/m, respectively). Leg stiffness depends on a combination of various musculoskeletal properties such joint stiffness and the tension and length of the musculotendinous units which act about that joint (Ferris & Farley, 1997; Farley, Houdijk, Van Strien, & Louie, 1998). If massage would lead to an increase in muscle-tendon compliance, then a slight decrease in leg stiffness would be expected. It is difficult to discuss these results given that the researcher was unable to find any studies which have examined the effects of massage on this specific parameter. However, what is known is that humans can adjust their leg stiffness depending on the physical task which is performed (i.e., walking, running, or jumping) and other various factors (i.e., surface stiffness) (Farley et al., 1998; Kuitunen, Kyröläinen, Avela, & Komi, 2007; Hobara et al., 2010).

Furthermore, stiffness has been shown to be a parameter that is very little variable (Struzik & Zawadzki, 2013). Thus, there is a possibility that these results show the adjusted leg stiffness for the physical task of repeated jumping and that the slight changes in stiffness between the massage protocols could just be attributed to normal variation.

5.4 The Effects of Self-Induced Multi-Bar Massage Rolling on Aerobic Capacity

To the researcher's knowledge, this was the first study to examine the effects of 5-, 10-, and 15-minute massage with the mechanical self-induced multi-bar massage roller on aerobic capacity in collegiate level athletes. There is a lack of research examining the effects of various massage therapies on subsequent aerobic capacity. Research in this area has mostly focused on the recovery effects of various post-exercise massage therapies compared to other recovery methods (Cafarelli & Flint, 1992; Schroeder & Best, 2015; Poppendieck et al., 2016). Thus, because massage in this study was performed pre-exercise, it is difficult to compare the results from this study with results from other studies. Nevertheless, the results in terms of the effects of massage on total running distance, heart rate, and blood lactate concentration can be discussed in light of previous research (Martin, Zoeller, Robertson, & Lephart, 1998; Hinds et al., 2004; Micklewright, Sellens, Gladwell, & Beneke, 2006).

The findings from this study indicated massage had an overall trivial effect ($d = 0.1$; Table 4) on total running distance in the 20 m shuttle-run test. However, the magnitude-based inference analysis showed that the effects of 5-, 10-, and 15-minute massage protocols on total running distance were unclear. The small increase in total running distance during the 20 m shuttle-run test in this study could be justified by an increase in running economy. There are many factors which can affect running economy, flexibility being one of them. Increased joint range of motion can have a positive effect on running economy (Saunders, Pyne, Telford, & Hawley, 2004). Godges et al. (1989) found statistically significant increases in hip-joint range of motion ($p < 0.01$) and in running economy ($p < 0.05$) in moderately trained athletic college students after a static stretching and proprioceptive neuromuscular facilitation stretching protocol. However, other studies have found that increases in flexibility could affect running economy negatively (Craib et al., 1996; Kyröläinen, Belli, & Komi, 2001; Jones, 2002). Saunders et al. (2004) suggested therefore that an optimal level of flexibility is required to increase running economy. Thus, the massage could have provided the participants in this study with a more optimal level of lower limb flexibility. Because the 20 m shuttle-run test consists of participants running back and forth on a length of 20 m with

a gradually increasing pace, this slight improvement in lower limb flexibility could have been beneficial for the later stages of the 20 m shuttle-run test when the participant would be required to run and change directions faster.

The results for heart rate and blood lactate concentration were somewhat adverse, with the 5-, 10- and 15-minute massage protocols having trivial effects (d = -0.03, d = 0.04, and d = 0.09, respectively; Table 4) on heart rate, and on blood lactate concentration (d = 0.01, d = -0.005, and d = 0.1, respectively; Table 4). The magnitude-based inference analysis showed that the effects of 5-, 10-, and 15-minute massage protocols on heart rate, and blood lactate concentration were unclear as well (Figure 27). Regarding blood lactate concentration, it has been suggested that massage could increase muscle blood flow, which could increase the shuttling rate of substances necessary for the energy metabolism, such as oxygen and blood lactate, which would increase aerobic capacity (Cafarelli & Flint, 1992). This is one of the most prominent notions amongst coaches and athletes who utilize massage in athletic pre-exercise settings in hopes of increasing performance (Weerapong et al., 2005; Cheatham et al., 2015). Several earlier studies have reported increases in blood flow after a bout of massage therapy (Bell, 1964; T. I. Hansen & Kristensen, 1973; Hovind & Nielsen, 1974). However, these studies also had design limitations such as small sample sizes, no reported statistical analysis, and no control group, which made it difficult to tell if the changes were due to massage or normal variation (Weerapong et al., 2005). Several studies have not found any statistically significant increase in blood flow and blood lactate clearance after massage (Martin et al., 1998; Hinds et al., 2004; Micklewright et al., 2006).

Martin et al. (1998) compared the effects of sports massage with active and passive recovery on blood lactate clearance after maximal anaerobic leg exercise. The results showed no statistically significant difference in blood lactate clearance after sports massage and passive recovery when compared to active recovery (Martin et al., 1998). Hinds et al. (2004) examined the effects of deep effleurage and petrissage massage after a bout of dynamic exercise on blood flow, blood lactate concentration, skin and muscle temperature, and heart rate. When compared to the control condition, no statistically significant differences were observed for blood flow, blood lactate concentration, skin and muscle temperature, and heart rate after two 6-minute bouts of massage (Hinds et al., 2004). Micklewright et al. (2006) examined the effects of various recovery strategies on blood lactate concentration after the 30-second Wingate anaerobic test. Statistically significant ($p < 0.05$) reductions in blood lactate concentration were observed after active recovery

and the combined massage-active recovery, but no statistically significant difference was observed after leg massage alone (Micklewright et al., 2006). In a recent study, D'Amico and Paolone (2017) examined the effects of foam rolling on performance and blood lactate levels between two 800 m runs. When compared to the control condition, results showed no statistically significant difference in running performance and blood lactate concentration between the two 800 m runs (D'Amico & Paolone, 2017).

All these findings (Cafarelli & Flint, 1992; Hinds et al., 2004; Weerapong et al., 2005) could also explain why there was almost no change in blood lactate concentration and heart rate between the control and experimental conditions during Bosco's 30-second jump test. Thus, it appears that pre-exercise massage therapy doesn't increase muscle blood flow or promote blood lactate clearance, or at least not to an extent where it would have any real impact on athletic performance (Cafarelli & Flint, 1992; Weerapong et al., 2005). This is mainly because the effects of massage on muscle blood flow only appear to be lasting as long as the pressure is applied, with some researchers suggesting that for there to be a more significant change, either much larger pressure needs to be applied or that it be applied for much longer amounts of time (Cafarelli & Flint, 1992; Schleip, 2003; Weerapong et al., 2005).

5.5 Strengths and Limitations of the Study

One of the study's strengths lies in is its originality. To the researcher's knowledge, this is the first study to utilize this kind of a mechanical self-induced multi-bar massage roller device and examine its pre-exercise effects on several physical performance parameters, not just one. Thus, the study was provided with extensive data which could say something about the effects of this mechanical self-induced multi-bar massage roller on overall performance, and not just one aspect of it. Another strength of the study is its design. The use of the crossover design enables each participant to act as their own control. This increases statistical power, while reducing the number of participants needed, and reduces variability of measurements related to the differences between the participants (Salkind, 2010, p. 309; Lui, 2016, p. 1).

However, this study also has some limitations which should be addressed. While the crossover design has its strengths, it also has a weakness, which is also this study's main limitation, and that is the high risk of participant dropout (Senn & Lee, 2004). Because the design required participants to complete the test battery 4 times, it resulted in many participants dropping out from the study. While 25 participants signed the informed consent and agreed to participate, only 13

actually completed the study, which is a dropout rate of 48%. Thus, the lack of participants in this study also limits it in generalizing the results. A greater number of participants, from varying sports, might have provided data which could show if the self-induced multi-bar massage rolling affected athletes differently depending on the sport. Some limitations were also imposed by the lack of research literature on certain topics. Very little research has been conducted on the effects of pre-exercise massage on balance in athletes, and almost no research has been conducted on the effects of pre-exercise massage on aerobic capacity. Further research should therefore focus on the effects of self-induced multi-bar massage rolling on more physical performance parameters than just one. Further research should also be examining how self-induced multi-bar massage rolling, regularly over longer periods of time, affects various aspects of performance in athletes.

6 Conclusion

The findings from this study indicated that the effects of the massage were not length dependent. Furthermore, the self-induced multi-bar massage rolling affected physical performance in various ways although none of the differences reached statistical significance ($p > 0.05$). Specifically, trivial to large ($d = 0.1 – 0.8$; Table 1) positive effects were observed for the static single-leg balance test, with only mean center of pressure distance on right foot after the 15-minute massage protocol being affected slightly negatively ($d = -0.01$; Table 1). For the squat jump test, an overall trivial effect ($d < -0.1$; Table 2) was observed after the massage protocols. For Bosco's 30-second jump test, adverse results were observed after the massage protocols, with moderate to trivial ($d \geq -0.6 – d = \leq 0.2$; Table 3) negative and positive effects. For the 20 m shuttle-run test, with the massage protocols having an overall trivial effect on total running distance ($d = 0.1$; Table 4), heart rate ($d \leq 0.09$, Table 4), and blood lactate concentration ($d \leq 0.1$; Table 4).

Additionally the magnitude-based inference analysis showed that the effects of the massage protocols were unclear for most of the physical performance parameters, meaning more data is needed to decide if the effects would be harmful, trivial, or beneficial. However, for sway velocity on left foot the magnitude-based inference analysis showed the effects of 5-, 10-, and 15-minute massage protocols were likely beneficial (88.8%, 90%, and 86.4%, respectively; Figure 24). During Bosco's 30-second jump test, for the number of vertical jumps at 15 seconds after the 5-minute massage protocol and heart rate after the 10-minute massage protocol the results showed that the effects were unlikely beneficial (76.5% and 56.8%, respectively; Figure 26).

Altogether, the findings support the alternative hypothesis partially. The findings from the static single-leg balance test provide support for the alternative hypothesis that massage will increase balance performance. However, the findings from the squat jump test and Bosco's 30-second jump test do not provide support for the alternative hypothesis that massage will increase anaerobic power and capacity. Likewise, the findings from the 20 m shuttle-run test do not provide support for the alternative hypothesis that massage will increase aerobic capacity.

The massage may have caused these changes in physical performance through various biomechanical (Schleip, 2003), physiological (Schleip & Müller, 2013), or neurological (Tozzi, 2012) mechanisms, although concluding directly on which of these mechanisms, is not possible in this study. Due to the small sample size, is not possible to generalize the results from this study. The uniqueness of this study combined with the lack of research in certain areas also made it difficult for some of the findings to be compared with other findings. Future research should therefore focus on the effects of self-induced multi-bar massage rolling on more physical performance parameters than just one, with larger sample sizes. Future research should also focus on how self-induced multi-bar massage rolling, regularly over longer periods of time, would affect these various aspects of performance in athletes from various sports.

Based on the findings from this study and previous studies which have examined the effects of massage on various performance aspects (Beardsley & Škarabot, 2015; Cheatham et al., 2015; Mine et al., 2018), a conclusion can still be made. While pre-exercise massage, specifically self-induced multi-bar massage rolling, may have some positive effects on balance performance, its effects on anaerobic power and anaerobic and aerobic capacity in male collegiate level athletes appear to be trivial. In other words, while pre-exercise self-induced multi-bar massage rolling doesn't appear to increase anaerobic power and anaerobic and aerobic capacity, it doesn't appear to decrease anaerobic power and anaerobic and aerobic capacity either. However, practitioners who are seeking to implement self-induced multi-bar massage rolling into their strength and conditioning programs should always consider the goal of the exercise, individual differences, and athlete's background.

7 References

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8 Appendix 1: Norwegian Center for Research Data Project Approval

Shaher Shalfawi

4036 STAVANGER

Vår dato: 21.02.2018	Vår ref: 58950 / 3 / LT	Deres dato:	Deres ref:

Vurdering fra NSD Personvernombudet for forskning § 31

Personvernombudet for forskning viser til meldeskjema mottatt 04.02.2018 for prosjektet:

58950	*The effect of automated muscle tissue rolling on physical performance and Lactate Acid buffering time during restitution.*
Behandlingsansvarlig	*Universitetet i Stavanger, ved institusjonens øverste leder*
Daglig ansvarlig	*Shaher Shalfawi*
Student	*Milos Popovic*

Vurdering

Etter gjennomgang av opplysningene i meldeskjemaet og øvrig dokumentasjon finner vi at prosjektet er meldepliktig og at personopplysningene som blir samlet inn i dette prosjektet er regulert av personopplysningsloven § 31. På den neste siden er vår vurdering av prosjektopplegget slik det er meldt til oss. Du kan nå gå i gang med å behandle personopplysninger.

Vilkår for vår anbefaling

Vår anbefaling forutsetter at du gjennomfører prosjektet i tråd med:

- opplysningene gitt i meldeskjemaet og øvrig dokumentasjon
- vår prosjektvurdering, se side 2
- eventuell korrespondanse med oss

Vi forutsetter at du ikke innhenter sensitive personopplysninger.

Meld fra hvis du gjør vesentlige endringer i prosjektet

Dersom prosjektet endrer seg, kan det være nødvendig å sende inn endringsmelding. På våre nettsider finner du svar på hvilke endringer du må melde, samt endringsskjema.

Opplysninger om prosjektet blir lagt ut på våre nettsider og i Meldingsarkivet

Vi har lagt ut opplysninger om prosjektet på nettsidene våre. Alle våre institusjoner har også tilgang til egne prosjekter i Meldingsarkivet.

Vi tar kontakt om status for behandling av personopplysninger ved prosjektslutt

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

NSD – Norsk senter for forskningsdata AS | Harald Hårfagres gate 29 | Tel: +47-55 58 21 17 | nsd@nsd.no | Org.nr. 985 321 884
NSD – Norwegian Centre for Research Data | NO-5007 Bergen, NORWAY | Faks: +47-55 58 96 50 | www.nsd.no

Ved prosjektslutt 01.02.2025 vil vi ta kontakt for å avklare status for behandlingen av personopplysninger.

Se våre nettsider eller ta kontakt dersom du har spørsmål. Vi ønsker lykke til med prosjektet!

Dag Kiberg

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77 / lis.tenold@nsd.no

Vedlegg: Prosjektvurdering
Kopi: Milos Popovic, m.popovic@stud.uis.no

9 Appendix 2: Informed consent (Norwegian version)

Forespørsel om deltakelse i forskningsprosjektet

"The effect of different volumes of automated muscle tissue rolling on physical performance."

Bakgrunn og formål

Self-myofascial release (SMR) er en velkjent og populær metode som blir brukt av utøvere og trenere for å øke bevegelighet, redusere restitusjonstid og øke prestasjon. Self-myofascial release utføres ofte ved bruk av en foam roller, men det kan også utføres ved bruk av en automatisert roller. Flere studier har undersøkt effektene som ulike doser med foam rolling kan ha på prestasjon; hvor noen studier brukte 30 sekund, mens noen studier brukte 5 til 10 minutt. Det finnes derimot ingen konsensus på hvilken dose med foam rolling gir mest prestasjonsøkning. Til dags dato finnes det heller ikke studier som undersøker effekten av ulike doser med automatisert rolling på prestasjon. Derfor er hensikten med denne studien å undersøke effekter av automatisert rolling i 5, 10, og 15 minutt på prestasjon. Dette prosjektet er en del av instituttet for grunnskolelærerutdanning, idrett og spesialpedagogikk, Universitetet i Stavanger.

For å kunne belyse temaet av dette prosjektet, etterlyses deltakere som deltar aktivt i organisert idrett. Dette samtykkeskjemaet deles ut til alle deltakere med hensikten å informere om studiens bakgrunn og formål, prosedyre, og ytterligere informasjon om studiet.

Hva innebærer deltakelse i studien?

Følgende kriterier er avgjørende for å være i stand til å gjennomføre studien:

1. Måling av kroppshøyde og vekt.
2. Måling av balanse med og uten rolling protokollen.
3. Måling av spenst (Squat jump, countermovement jump, og Bosco repetitive vertical jump) med og uten rolling protokollen.
4. Testing av utholdenhet med og uten rolling protokollen.
5. Puls måling under utholdenhets testen.
6. Laktatmåling rett etter spensttesten og utholdenhetstesten.

For å kunne gjennomføre testene **må** deltakerne også ha med seg treningstøy og innendørs sko. Testing vil foregå i laboratoriet og gymsalen på Hagbard Line-huset, Universitetet i Stavanger. Testbatteriet vil ta omtrent én time å gjennomføre.

Hva skjer med informasjonen om deg?

All personlig informasjon vil bli behandlet konfidensielt. I tillegg til studieresultater, er det bare beskrivende informasjon som nivå, høyde, vekt og alder som blir rapportert i den endelige rapporten, i form av gjennomsnitt av alle deltakere. Ingen navn eller noen identifiserbar informasjon vil bli brukt under og etter at studien er avsluttet. Denne studien er en del av et større prosjekt og data fra denne studien skal bli brukt i en masteroppgave. Innsamlede opplysninger vil bli anonymisert og det skriftlig samtykke slettet senest 01.02.2025. Ingen personer vil kunne gjenkjennes i den endelige publikasjonen.

Frivillig deltakelse:

Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn.

Dersom du trekker deg, vil alle opplysninger om deg bli slettet.

Dersom du ønsker å delta eller har spørsmål om studien, ta kontakt med prosjektleder Shaher Shalfawi (45660660 eller shaher.shalfawi@uis.no) eller Milos Popovic (97897733 eller m.popovic@stud.uis.no).

Studien er meldt til Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste AS.

Samtykke til deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta

---

(Signert av prosjektdeltaker, dato)

Mvh

Prosjektleder

Shaher Shalfawi

Universitet i Stavanger

10 Appendix 3: Informed consent (English version)

Informed consent

"The effect of different volumes of automated muscle tissue rolling on physical performance."

Background and purpose

Self-myofascial release (SMR) is a well known and popular method which is used by athletes and coaches to increase flexibility, reduce the recovery time, and increase performance. Although self-myofascial release is often performed with the use of a foam roller, an automated roller can also be used. Several studies have examined the effects of different foam rolling doses on performance; with some studies using 30 seconds, and other studies using 5 to 10 minutes. However, no consensus has been reached regarding the optimal foam rolling dosage for maximal increase in performance. Furthermore, no studies to this date have examined the effects of different doses of automated rolling on performance. Therefore, the purpose of this study is to examine the effects of 5, 10, and 15 minutes of automated rolling on performance. This study is a part of the institute of Education and Sports Science at the University of Stavanger.

To be able to shed light on the subject of this study, we are seeking participants that are actively participating in organized sports. This informed consent is handed out to all the participants with the intension of informing the participants about the background, purpose and procedure of the study.

What would it mean to participate in the study?

The following criteria are essential for completion of the study:

1. Measuring body weight and height.
2. Measuring balance, with and without the rolling protocol.
3. Measuring power (Squat jump, countermovement jump, and Bosco repetitive vertical jump), with and without the rolling protocol.
4. Testing of endurance, with and without the rolling protocol.
5. Measuring heart rate during the endurance test.
6. Blood lactate measurements right after power and endurance tests.

To be able to complete the test the participants **must** have sports clothing and indoor shoes. Testing will take place in the laboratory and gymnasium in Hagbard Line building, University of Stavanger. The test battery will take approximately an hour to complete.

What will happen with information about you?

All personal information will be handled confidentially. In addition to the results of the study, only descriptive information such as: gender, age, height, and weight shall be reported in the final report in the form of means of all the participants. No personally identifiable information such as: name or address shall be used during or after the study. This study is a part of a bigger project, and data from this study shall be used in a master's thesis. Data collecting is scheduled to end in autumn 2023. The project is scheduled to end in 2025. Your written consent shall be deleted at the end of the project. Raw data shall be kept in anonymous form after the project ends and no persons shall be recognizable in the publication or raw data.

Voluntary participation:

Participation in the study is voluntary and you can withdraw your consent at any given time without providing any reason.

If you withdraw from the study all the information about you shall be deleted.

If you wish to participate or have further questions about the study, contact the project leader Shaher Shalfawi (45660660 or shaher.shalfawi@uis.no) or Milos Popovic (97897733 or m.popovic@stud.uis.no).

This study has been reported to the Norwegian Centre for Research Data.

Consent for participation in the study

I have received the information about the study and I am willing to participate

---

(Signed by participant, date)

Sincerely

Project leader

Shaher Shalfawi

University of Stavanger