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The Effect of Knee Extension Angle on Knee Joint Position Sense Between Genders

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THE EFFECT OF KNEE EXTENSION ANGLE ON KNEE JOINT POSITION SENSE BETWEEN GENDERS

By

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Accepted in Partial Completion of the Requirements for the Degree Master of Science

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THE EFFECT OF KNEE EXTENSION ANGLE ON KNEE JOINT POSITION SENSE BETWEEN GENDERS

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment Of
the Requirements for the Degree
Master of Science

by Samuel Lyons
May, 2017
Abstract

The purpose of this study was to examine the differences in knee JPS between males and females at both 30 and 60 degrees of knee extension in the dominant leg of healthy young adults. 46 subjects (22 males, 24 females) participated in the study; aged 19-25 years old, average height 172.7±8.4 cm, and average mass 71.2±12.9 kg. The data collection consisted of three position reproduction tasks with two different target angles for a total of six trials. When subjects arrived for testing, they were taken through a standard warm-up consisting of five minutes on a cycle ergometer. Immediately after the warm-up, subjects were seated on a massage table with shank hanging off, resting at 90 degrees of knee flexion. Subjects were then taken through six randomized trials of their position reproduction task. Specifically, three trials to 30 degrees of knee extension and three trials to 60 degrees of knee extension. The difference in reproduction angle was recorded and the data was then analyzed as an absolute error between position and reposition. A 2x2 mixed analysis of variance (ANOVA) was used to analyze the difference between genders as well as knee extension angle. The mixed ANOVA revealed that the 30 degree position had a significantly greater absolute reposition error than the 60 degree position (p = 0.007). There was no significant difference in JPS between males and females (p = 0.225). Furthermore, there was no presence of an interaction effect between main effects and therefore there was no need to perform post-hoc tests. These results indicate that there is no difference in JPS between genders at positions within the knee’s mid-range of motion. For both males and females, the 30 degree position had greater accuracy than the 60 degree position. The results indicate that there is no difference in JPS between males and females at positions within the knees mid-range of motion. Different results may have been seen at a position closer to maximum extension where more tension is placed onto the ACL.
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Chapter I

Research Problem

Introduction

Lower extremity coordination is critically important to factors surrounding locomotion. If an individual has poor joint coordination, then his or her ability to move efficiently may be compromised. Similarly, if individuals are unable to move efficiently, due to injury or disease, then their respective joint coordination may suffer. This phenomenon is commonly seen in individuals with osteoarthritis in their respective knee joint (Sharma, Pai, Holtkamp, & Rymer, 1997). One predominant factor affecting joint coordination is joint proprioception (Sainburg, Poizner, & Ghez, 1993)

Joint proprioception is the awareness of where the joint is in space with regards to both body and mobile segment. Accurate proprioception is critical for proper muscle contraction, limb movement, stability and injury prevention (Ageberg, 2005; Mandelbaum, 2005; Suprak, Osternig, Van Donkelaar, & Karduna, 2006). Proprioception is usually looked at in two ways: joint position sense and the ability to detect joint and limb movement. However, both are essential for fluid muscle contraction, movement and injury prevention.

The knee joint is vitally important to functional movement of the lower extremity. Therefore, accurate proprioception around the knee is crucial. Currently, much is already known about proprioception about the knee. Specifically, as the knee is subjected to conditions in which increased torque is placed upon the joint, proprioceptive acuity will increase (Bullock-Saxton, Wong, & Hogan, 2001). Furthermore, as the knee gets closer to its end range of motion proprioceptive awareness will increase (Bottoni, Herten, Kofler, Hasler,
& Nachbauer, 2013). These factors may be important when examining knee proprioception across a variety of movements.

In humans, fluid movement of the lower extremity consists of both open and closed chain movements. Open chain movement consists of movement where the distal end of a segment is free, moving in space (Firoozkoohi Moghadam, Ebrahimi Atri, & Hashemi Javaheri, 2016). Closed chain movement refers to movement where the distal segments apply forces to the ground, or rigid surface, that relay forces and motion to the rest of the body (Adouni, & Shirazi-Adl, 2009; Firoozkoohi Moghadam, et al., 2016). For example, human gait consists of rapid cycle between both open and closed chain actions, which correspond to differences in individual kinematics and muscle activation. Specifically, open chain gait kinematics will require more maximum knee flexion than that of closed chain gait kinematics (Ferber, McClay Davis, & Williams III, 2003; Kadaba, Ramakrishnan, & Wootten, 1990; Sasaki & Neptune, 2006). Furthermore, depending on the speed of the gait cycle, the maximum range of motion about the knee will change (Kadaba et al., 1990; Novacheck, 1998; Sasaki & Neptune, 2006). When assessing accurate knee joint coordination, it is important to test accuracy of proprioception across this variable range of motion.

Furthermore, the difference in joint proprioception between genders is important to consider. Differences between muscle activation patterns, as well as anthropometric and anatomical characteristics are well noted and hypothesized to illicit changes in injury risk and motor control between the two sexes (Bencke & Zebis, 2011; Nagai, Sell, Abt, & Lephart, 2012). Specifically, females have significantly less pre-activation of their hamstring than males during cutting maneuvers which may contribute to decreased joint stability (Bencke & Zebis, 2011). Furthermore, females have also been shown to exhibit less cartilage
surrounding their knee when compared to males as well as differences to their intercondylar notch structure (Cicuttini, Forbes, Morris, Darling, Bailey, & Stuckey, 1999; Tillman, Smith, Bauer, Cauraugh, Falsetti, & Pattishall, 2002). These differences may have a profound effect on individual knee joint proprioception. It has been documented that there is a difference in the ability to detect passive movement between males and females (Koralewicz & Engh, 2002; Nagai et al., 2012). However, the presence of this difference is not always expressed when examining the ability to detect passive movement (Pincivero, Bachmeier, & Coelho, 2001). Examining the difference in joint position sense (JPS) between the two genders may provide more information on their proprioceptive differences.

Normally JPS is assessed by a test termed method of adjustment (Han, Waddington, Adams, Anson, & Liu, 2016). In general, the method of adjustment, or the method of average error, presents the subject with a reference stimulus. Then the subject will be required to adjust the level of the stimulus to recreate and match that of the reference stimulus. The error between the reference stimulus and the adjustable references is recorded (Han et al., 2016). In this study, the method of adjustment was utilized to test differences between genders and position angles. The two knee joint positions correspond to positions achieved during different portion of a gait cycle (Ferber et al., 2003; Novacheck, 1998). However, due to the nature of the test, the two positions will also be affected differently by gravitational torque, and therefore may exhibit differences in muscle activation and proprioception (Worringham, & Stelmach, 1985). Furthermore, the different positions will affect the internal structures of the knee differently. Therefore, examining the differences in the two positions between both males and females may shed light on the effect of muscle activation, knee angle position, and gender on knee JPS.
Purpose of the Study

The purpose of this study was to examine the differences between 30 and 60 degrees of knee extension on knee joint position sense as well as to examine the differences in knee joint position sense between males and females in the dominant leg of healthy young adults.

Hypothesis

In this study, the following hypotheses were tested: there will be a significantly greater absolute JPS error in females when compared to males. Furthermore, there will be significantly less error in joint position sense within the 60 degree position when compared to the 30 degree position.

Significance of the Study

Accuracy of proprioception and knee joint position sense is very important with regards to proper movement of the lower extremity and injury risk around the knee. However, there are still biological and physical factors that remain unexplored. Furthermore, there are many differences between biological genders that have the potential to cause a difference in proprioceptive acuity. Specifically, males and females exhibit differences in the structural anatomy of their knee and differ with regards to muscle activation patterns. These differences have a potential impact on the function and rate of injury around the knee joint. Furthermore, because different velocities of human gait correspond to differences in maximum knee angle, testing proprioceptive accuracy at different angles will possibly shed light on variability in coordination during different gait velocities. In addition, because the different angular positions will correspond to difference in gravitational torque placed on the knee, the positions will exhibit differences in muscle activation. Therefore, a better understanding of the effects of gender and knee extension angle on knee joint position sense
will help provide more information on proprioceptive variability between genders and across a knee joints range of motion and thus allow for a possible explanation to differences in motor control and injury rate.

**Limitation**

1. The age range, 18-25 year olds, of the participants has the possibility to limit the findings to other populations.

2. Subjects had no prior injuries to their knees; therefore, the findings may only be specific to non-injured individuals.

3. Subjects of varying body size and body type may exhibit different testing effects.

4. Subjects with prior, varying levels of muscular coordination or proprioception may cause a threat to internal validity.

5. Though tests were randomized to reduce testing bias, they were not specifically blind, allowing for a treatment expectancy bias on both the subjects and testers.

6. The testing protocol only consisted of testing the subjects respective dominant leg. Therefore, the results found only apply to that of the dominant leg.

7. This study only examined two different angles of knee flexion. Therefore, different angles of knee flexion may see different results.

**Definition of Terms**

Proprioception –

Conscious perception of the limb in space, consisting of joint awareness and limb movement (referred to as kinesthesia) (Patrella, 1998).
Intrafusal muscle fiber –

Muscle fibers within a muscle strand that relates primarily to sensory information; consists mainly of a muscle spindle and other collagen and nerve tissue (Bessou, Emonet-Dénand, & Laporte, 1965) - often used synonymously with muscle spindle.

Extr autofusal muscle fiber –

Primary muscles stimulated by motor neurons with the purpose of producing forces (Bessou et al., 1965)

Musculotendinous Mechanoreceptor –

Mechanoreceptors that relay sensory information to the brain, which originate in the muscles and tendons- specifically, the muscle spindle and the Golgi tendon organ (Myers & Lephart, 2000).

Capsuloligamentous Mechanoreceptor –

Mechanoreceptors that relay sensory information to the brain, which originate in the joint capsules and ligaments (Myers & Lephart, 2000).

Open Chain Movement –

of movement where the distal and of a segment is free moving in space and forces are transferred through the rest of the segment (Firoozkoohi Moghadam et al., 2016).

Closed Chain Movement –

movement where the segments apply forces to the ground, or rigid surface, that relay forces and motion to the rest of the body (Adouni, & Shirazi-Adl, 2009).

Autogenic Inhibition –

A reflex arch in the body that inhibits muscles that are producing dangerously high forces (Chalmers, 2002)
Agonist –

A muscle directly responsible for producing or controlling a specific motion of the body and/or segment (Hamill, Knutzen, & Derrick, 2015).

Antagonist –

A muscle which opposes that of the muscle directly producing or controlling the movement of a body and/or segment (Hamill et al., 2015).

Gait –

An individual’s manner of walking, running, and other types of ambulation (Hamill et al., 2015).

Range Effect –

The tendency for individuals to make compensatory movements away when they feel their target is too close and compensatory movements towards when they feel their target is too far (Poulton, 1975).
Chapter II

Review of the Literature

Introduction

Proprioception refers to a person’s ability to sense where they are in space. Specifically, proprioceptive feedback is relayed back to the brain from three major systems, the vestibular, the somatosensory and the visual. Visual system provides individuals with sensory information from the surrounding environment as well as information in segment and body orientation (Grace Gaerlan, Alpert, Cross, Louis, & Kowalski, 2012). The vestibular system mainly relies around sensory feedback from the inner ear and the semicircular canals to provide information on postural orientation, balance, and spatial awareness with respect to gravity (Agrawal, Carey, Santina, Schubert, & Minor, 2009; Yang & Hullar, 2007). Lastly the somatosensory system provides sensory feedback from the appendages to allow for sensation of position and motion.

The somatosensory system provides feedback specifically from the muscles, tendons, ligaments, fascia, and skin in order to accurately gauge both limb position and movement (Lephart, Pincivero, Giraido, & Fu, 1997). The appreciation of limb position is usually referred to as joint position sense (JPS), whereas the appreciation of limb movement is usually referred to as kinesthesia (Lephart et al., 1997). JPS is specifically the ability to sense, either passively or actively, the position of a given joint and thus segment (Lephart et al., 1997; Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2009). Kinesthesia specifically refers to the conscious awareness of body and segment motion (Konradsen, 2002). While both measures are important to proper muscle coordination, JPS is predominantly examined to test individual proprioceptive acuity. However, much about JPS is still being researched.
The purpose of this chapter is to review the literature surrounding JPS as well as implications of gender variation and kinematic variation. Specifically, the review will be broken down in six major sections. Within these sections basic anatomy and terms will be defined. First, an overview to joint position sense and proprioception will be discussed with regards to anatomy and properties. Next, proprioception with regards to how it is usually tested and what limiting factors are seen, leading into current knowledge on knee proprioception and information that is already known. Next, a section describing the gait kinematics and its relevance to joint position sense will be covered. The last section will cover biomechanical and neurological difference between males and females that may play a role in proprioceptive acuity.

**Joint position sense and proprioception mechanics**

Joint position sense and proprioception are critical for fluid muscle and limb movement, maintenance, and injury prevention. Specifically, proprioception is the perception of both joint and body movement with regard to position of body and segment (Hiemstra, Lo & Fowler, 2001). In most cases this is examined in two parts, JPS and kinesthesia. Both of these are regulated by certain mechanics within the muscles and tendons of the respective joint.

One of the specific factors in regulating proprioception is the muscle spindle (Roll & Vedel, 1982). The muscle spindle is a sensory structure within the intrafusal fiber that responds to lengthening of the muscle (Prochazka, 1980; Roll & Vedel, 1982). The intrafusal fiber is entwined in a type 1a afferent motor neuron, which responds to length. As the intrafusal fiber is lengthened a signal is sent to the brain, via type 1a afferent, which then will lead to activation of the extrafusal muscle fiber via an alpha motor neuron (Nicol et al.,
At the same time the alpha motor neuron is activating extrafusal muscle fibers, the gamma motor neuron is activating the intrafusal muscle fibers, which help maintain sensitivity of the 1a afferent neuron through changes in range of motion (Durbaba, Taylor, Ellaway, & Rawlinson, 2001). This muscle activation is dependent on velocity and distance of lengthening (Hiemstra et al., 2001). With increased velocity and/or increased distance, the level of signal activation will be increased. This reaction to muscle lengthening is what makes the muscle spindles important to proprioception.

Many obstructions have the ability to affect muscle spindle sensitivity and decrease proprioceptive acuity. In a study by Hurley, Rees & Newham, (1998), researchers found an increase in age can reduce the functional performance and proprioception of the quadriceps muscle. This increase in age affects the main peripheral proprioceptor in the muscle, namely the muscle spindle to reduce joint position sense. Repeated active muscle contraction increases fusimotor drive, which thus increases afferent sensitivity, gamma motor sensitivity and thus muscle spindle sensitivity and proprioception (Hurley et al., 1998; Suprak et al., 2006). Therefore, with an increase in age and a decrease in muscle activation, muscle spindle sensitivity and joint position sense are decreased.

Further studies show the importance of muscle activation with regard to the muscle spindle. A study by Suprak et al. (2007) shows that an increase in muscle activation level will increase JPS accuracy. The increase in muscle activation leads to an increase in gamma motor firing frequency, which may have enhanced the sensitivity of the muscle spindle to a certain degree of change in muscle length (Suprak et al., 2007). However, this change in muscle activation may have also effected the Golgi tendon organ and thus increasing JPS accuracy.
Similarly to the muscle spindle, the Golgi tendon organ is another mechanoreceptor that provides a great deal with regard to joint position sense. The Golgi tendon organ (GTO) is a mechanoreceptor that is located in the tendon of skeletal muscles and is highly associated with proprioception (Chalmers, 2004; Houk, & Henneman, 1967; Jami, 1992). Where the muscle spindle relays information with regards to muscle length, the GTO relays information with regards to muscle tension (Houk, & Henneman, 1967). The Ib afferent neuron is linked to the GTO to increase firing rate in response to muscle contraction or tension (Gregory, Brockett, Morgan, Whitehead, & Proske, 2002). Therefore, with an increase in load we see an increase in Ib afferent stimulation and an increase JPS accuracy.

Along with musculotendinous mechanoreceptors like the muscle spindle and the GTO, capsuloligamentous mechanoreceptors also play a role in joint proprioception (Suprak et al., 2006). Capsuloligamentous mechanoreceptors consist of afferent neuron pathways within the joint capsules and ligaments (Myers & Lephart, 2000). These are primarily seen as either Ruffini receptors or as Pacinian corpuscles (Myers & Lephart, 2000; Schutte, Dabezies, Zimny, & Happel, 1987). The Ruffini afferents predominantly act to provide sensory feedback when the ligament is reaching an extreme end range of motion in response to tensile force, whereas the Pacinian afferents provide feedback at extreme end range of motion to both tensile and compressive forces (Myers & Lephart, 2000). Therefore, these capsuloligamentous mechanoreceptors influence the joint primarily at the end ranges of movement with maximal deformation.

At movements that range through a variety of a given muscles range of motion, passive properties of the muscle play a role on JPS and proprioception along with mechanoreceptors. As actin and myosin detach, roughly one percent of these binding sites
form new non-force producing attachments that lead to the muscles thixotropic properties (Proske, Tsay & Allen, 2014). This leads to a passive stiffness within the muscle. This passive stiffness can affect both intrafusal and extrafusal fibers and adversely affect JPS (Tsay, Savage, Allen & Proske, 2014). If the stiffness of intrafusal fiber is heightened due to decreased movement, the contraction of the extrafusal muscle fiber can overtake that of the intrafusal fiber causing it to fall slack and become desensitized to stretch (Tsay et al., 2014). When the intrafusal muscle fiber becomes desensitized to stretch it causes the muscle spindle to inaccurately gauge muscle length and adversely affects proprioceptive awareness.

Accurate proprioception and joint position sense are critical with regards to limb movement, force production, and proper movement mechanics. The human body has numerous built in mechanics in order for it to maintain perfect control of our joints and limbs for this reason. Whether it is mechanoreceptors or the muscles own passive properties, the tools used to know where the body is in space greatly effect human movement.

**Proprioception Protocols and Current knowledge**

Proprioception is usually described in two aspects, joint position sense and kinesthesia, or sense of movement. JPS is usually examined using the method of adjustment (Han et al., 2016). Specific to joints, this method involves bringing a joint and segment to a reference position using a stimulus. The subject then recreates this reference position without any stimulus and the error between the reference position and manual position is recorded (Han et al., 2016). With regards to external stimuli, many aspects can affect a person’s internal joint position sense. Therefore, testing for proprioceptive acuity needs to correctly control for external stimuli that may provide unwanted proprioceptive feedback to an individual.
In an article by Tsay et al. (2014), proprioception was measured by examining JPS. Specifically, by testing the difference in elbow angle between multiple joint movements. The researchers looked at the effect of a contraction-conditioning program on the influence of joint position sense with the control being the dominant arm of the subject and the experimental test undergone on the non-dominant arm of the subject in order to test muscle thixotropy on proprioception. They found that when comparing the two limbs, the brain tries to mimic the afferent pathway of one limb in order to apply it to the other which leads to muscle thixotropy to play a major role in causing joint position error (Tsay et al., 2014).

When tests are performed on joint position sense within a single limb there are still factors, in which we already know, about how they affect the mechanoreceptors. Suprak et al. (2007) conducted a study in which they examined the effect of adding an external load on joint position sense. Researchers instructed subjects to reach a target position with the help of visual feedback after which they were asked to replicate the position without the aid of the visual stimulus. Subjects did this protocol for both a control condition and a condition with an external load. Suprak et al., (2007) found that if the external load is added in the direction of the recumbent movement used for testing, proprioception accuracy is increased.

Bullock-Saxton et al., (2001), found similar results with regards to the effect of increased weight on joint position sense, however their study also had the added effect of age. The subjects were separated into three groups of young, middle aged, and elderly. Within the groups all subjects underwent two closed chain movement protocol, one being with full body weight, and one with partial body weight. Bullock-Saxton et al. (2001) found that with an increase in age, we see a decrease in joint position sense of the knee, however in all subjects’ joint position sense was better in full body weight movement.
Because an increase in external load has the potential to increase proprioceptive acuity, it is important to understand how gravitational torque can effect the external load during a given test. Worringham and Stelmach (1985) examined proprioceptive acuity of the elbow joints with varying degrees of external force placed upon the limbs. It was reported that gravitational torque plays an accessory role in joint position sense accuracy. This is further supported by Suprak et al., (2006) who examined elevation angle and shoulder joint position sense. The researchers found that as the shoulder joint reached a position where the torque increased, joint reposition error decreased. At 90 degrees, the theoretical moment arm of the arm segment about the shoulder is greatest. As the shoulder angle moves below 90 degrees, the theoretical moment arm shortens and therefore the gravitational torque demand decreases and joint reposition error increases (Suprak et al., 2006).

In summary, when testing for joint position sense, the protocol revolves around testing the error in recurrent movement with and without the presence of stimulus. We know that when testing a variable unrelated to difference in limbs, testing should be done within a single limb to limit error from difference in muscle thixotropy. Furthermore, most stimuli that increase the external load on a limb, whether from added weight or gravitational torque, have a high potential to increase proprioceptive accuracy. It is important to note that visual stimuli can adversely affect the results of a study because it plays a major role in providing proprioceptive feedback (Grace Gaerlan et al., 2012)

**Knee Proprioception**

Proprioception is primarily determined by input from capsuloligamentous mechanoreceptors, originating in joints, and musculotendinous mechanoreceptors, originating in the muscle (Patrella, 1998; Schutte et al., 1987). Specifically, the
capsuloligamentous mechanoreceptors in the knee joint are classified as the Ruffini endings and pacinian corpuscles in the ligaments and menisci, and the musculotendinous receptors are the muscle spindle and the Golgi tendon organ (Patrella, 1998; Schutte et al., 1987). Furthermore, the factors leading to the sensitivity of the mechanoreceptors consist of the external load on the joint, its joint position, movement type, and the condition of the joint (Bottoni et al., 2013). Therefore, changes in knee proprioception may depend on these manipulations of the mechanoreceptors.

When examining the effect of added weight on joint position sense of the knee, there is an increase in joint position awareness (Bullock-Saxton et al., 2001). This response makes sense with regards to musculotendinous mechanoreceptors. With increased activation of the muscles surrounding the knee joint there will also be an increase in gamma motor firing rate, and thus an increase in sensitivity of the intrafusal muscle fibers surrounding the knee (Hurley et al., 1998; Suprak et al., 2006; Suprak et al., 2007). Additionally, the increased weight will lead to increased tension on the muscle tendon, which will cause an increase to joint position sensitivity from the Golgi tendon organs (Gregory et al., 2002). Bullock-Saxton et al. (2001) demonstrates this specifically in the knee with their study on full body weight vs. partial body weight on knee joint position sense.

Furthermore, the effects of joint movement and position on proprioceptive awareness of the knee, Bottoni et al. (2013) reported that there was a significant effect of joint position and passive movement on joint position sense. Specifically, when the knee was starting at 60 degrees of flexion moving towards extension, there was a decrease in joint awareness (Bottoni et al., 2013). As the leg starts at 60 degrees of flexion, a position within mid-range of motion, the leg receives sensory information primarily from the musculotendinous
mechanoreceptors (Myers & Lephart, 2000; Janwantanakul, Magarey, Jones, & Dansie, 2001). As the leg moves passively the muscle spindle will not gain increased sensitivity from the muscle activation, nor will the GTO receive much benefit from the contracting muscle. Therefore, as the leg moves farther from its nearest end range (moving towards extension), there will be less response from other mechanoreceptors. Specifically, the capsuloligamentous mechanoreceptors that show increased activation at end range of motion (Myers & Lephart, 2000, Janwantanakul et al., 2001). Therefore, if the motion led closer to an end range of motion, greater activation of the Ruffini receptors and pacinian corpuscles may have the potential to increase joint position sense in the knee (Janwantanakul, et al., 2001).

Additionally, in knee joints that have suffered an injury there can be deficits to knee proprioception (Beard, Kyberd, Fergusson, & Dodd, 1993). In knee joint injuries, there are problems within the joint capsule, surrounding ligaments, and/or the menisci. Thus, with injury to the knee ligaments, there will be deficits in capsuloligamentous mechanoreceptors within the injured ligament (Beard et al., 1993). Specifically, Beard et al. (1993) tested proprioception of the knee by assessing reflex latency in the hamstring of both healthy and anterior cruciate ligament (ACL) deficient knees. Though the application of inducing the reflex was to the muscle and therefore directly affecting the musculotendinous mechanoreceptors, the deficiency within the ACL, and thus the capsuloligamentous mechanoreceptors, are likely to cause a decrease in joint proprioception (Beard et al., 1993). Therefore, though Ruffini receptors and Pacinian corpuscles primarily act at end range of motion, deficiencies in said capsuloligamentous mechanoreceptors may still cause problems in joint position sense across a wide range of motion.
When assessing the joint position sense about the knee, the primary receptors are the musculotendinous and capsuloligamentous mechanoreceptors. Though this joint may exhibit less range of motion relative to the shoulder, the knee is more prone to heavy weight bearing activity. Thus, the knee requires high synergy between any given movement’s agonist and antagonist muscles, tendons, and ligaments. Therefore, any benefit or deficiency applied to the muscles, tendons, and/or ligaments surrounding the knee will cause a change in joint position sense of the knee, thereby affecting stability, and force production of the segment.

**Human Knee Kinematics**

The knee joint of a human will undergo a variety of different motions and positions based on the desired holistic movement outcome. In a general sense, the knee predominantly moves in sagittal plane in flexion or extension, however also minimally moves in external and internal rotation as well as varus or valgus (Kadaba et al., 1990). When examining proprioceptive accuracy at the knee joint it is important to keep in mind the different movement patterns and kinematics. Specifically, the kinematics of the knee joint during gait are of extreme importance to both functional and performance outcomes.

In a normal human gait cycle, there are two general types of movement seen, open chain movement and closed chain movement. Open chain movement refers to movements where the distal end of a limb segment is free, non-weight baring to the rest of the body and is thus open, moving in space, for example swing phase (Firoozkoohi Moghadam, Ebrahimi Atri, & Hashemi Javaheri, 2016). Whereas closed chain movement refers directly to movements where the distal end of a limb segment is firmly on a surface and not moving, however relaying force production to the rest of the body, for example stance phase. (Adouni, & Shirazi-Adl, 2009; Firoozkoohi Moghadam, et al., 2016). Therefore, when
discussing movement and variables of the knee, synergy between both open and closed chain movement is imperative in order to assess functional performance.

Furthermore, during functional movement the knee will undergo a variety of changes to knee angle. This is partially determined on gait velocity as an increase in gait turn-over will elicit a different power response to certain muscles causing a greater or lesser change in knee joint range of motion (Novacheck, 1998; Sasaki and Neptune, 2006). Walking requires less power than that of running and will elicit less maximum knee flexion in both swing and stance phase of gait (Ferber et al., 2003; Kadaba et al., 1990; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Novacheck, 1998; Sasaki and Neptune, 2006). Specifically, Kadaba et al., (1990) found that walking generally required a maximum change of 60 degrees of knee flexion during swing phase. Whereas when running is examined it exhibits a maximum change of 80 to 110 degrees of knee flexion during swing phase (Novacheck, 1998). This makes sense as if an individual wants to increase his/her thigh flexion velocity, increasing knee flexion angle will minimize the moment arm for the thigh and help decrease the overall torque demand required to move the whole segment. With regards to stance phase of gait, walking will generally produce 20 degrees of knee flexion whereas running may elicit up to 45 degrees of knee flexion. (Ferber et al., 2003; Novacheck, 1998).

When assessing knee proprioception, it is important to keep in mind the joints kinematics, in that, the joint will be placed in a variety of different positions as well as both open kinetic chain and closed kinetic chain. Closed kinetic chain will generally have better proprioceptive acuity due to the movements interaction with multiple joints as well as the high load on the joint from the body (Herrington, 2005). Open kinetic chain movement may give a better representation on a single joints proprioceptive acuity because one can easily
isolate a specific single joint. At the knee, it is important to test a variety of different positions because the given kinematics of the knee vary greatly during functional tasks.

**Differences in Biomechanics and Neuromuscular Control Between Males and Females**

It is well documented that there are many contributing factors within the environment, as well as within human anatomy that lead to proprioceptive accuracy. However, these factors may affect an individual differently based on their gender. Males and Females have many differences in the underlying anatomy and physiology that can influence their biomechanics and neuromuscular control (Bencke & Zebis, 2011; Hewett et al., 2005; Tillman, Smith, Bauer, Cauraugh, Falsetti, & Pattishall, 2002). Specifically, this can be in the form of differences in muscle activation patterns, boney structures, and cartilage surrounding the knee.

If individual’s express differences in their muscle activation patterns, they may respond differently to internal and external stimuli. In a study by Bencke and Zebris (2011), researchers examined the neuromuscular control of muscles surrounding the knee during side cutting maneuvers. Specifically, they examined pre-activity of the hamstrings and quadriceps during a side cut by using electromyography. They found that females had significantly lower hamstring pre-activation prior to planting while having no difference to males with respect to quadriceps pre-activation (Bencke & Zebris, 2011). This difference could possibly result in decreased hamstring contraction force and decreased knee stability during the specific movement (Benecke & Zebris, 2011). This imbalance between muscle groups may result in problems around the knee. Specifically, if an individual has such an imbalance that causes their kinematics to change and increase their knee valgus loading, they may be at an increased risk for anterior cruciate ligament injury (Hewett at al., 2005). Furthermore,
anatomical differences in the knee between genders may also play a large role with respect to
their biomechanics and motor control.

Within the knee, there may be differences between genders with respect to bony and
cartilaginous structures that can affect an individual’s biomechanics. In a study by Cicuttini
et al., (1999) researchers examined the volume of cartilage in the knee between males and
females. Specifically, they examined differences between femoral, tibial, and patellar
cartilage. They found that males have significantly more tibial and femoral cartilage than
females even when normalizing for body and bone size. Furthermore, males also possess
more patellar cartilage than females at older ages (Cicuttini et al., 1999; Ding, Cicuttini,
Scott, Glisson, & Jones, 2003). The differences in cartilage may lead to increased problems
such as knee pain, a decrease in knee function, and increase in risk for osteoarthritis (Hunter,
March, & Sambrook, 2003).

Furthermore, males and females can also exhibit differences in the boney structures
of their knee. Specifically, the intercondylar notch of the femur is the space in-between the
condyles of the femur and this structure differs between males and females (Tillman et al.,
2002). The intercondylar notch is the space that is occupied by the anterior cruciate ligament
(ACL) and the posterior cruciate ligament (PCL). In females, the notch is less round and may
not permit normal function of the ACL (Tillman et al., 2002). Specifically, as the knee
approaches full extension, the internal ligaments become taut and will fill the space of the
intercondylar notch. Because the female intercondylar notch shape is less round it may
inhibit normal ligament function (Tillman et al., 2002). Furthermore, it is well known that
one of the normal functions of ligaments is to provide proprioceptive feedback (Myers &
Lephart, 2000; Vangsness, Ennis, Taylor, & Atkinson, 1995). Therefore, because male and
female ligaments are effected differently by their intercondylar notch, their respective proprioceptive acuity may be effected.

In a study by Nagai, Sell, Abt & Lephart (2012), researchers examined the gender difference of proprioception between knee internal and external rotation. Specifically, time to detect passive movement was measured in two positions, one near external rotation end range, and internal rotation end range. The passive movement tested was both towards internal rotation and towards external rotation. Nagai et al., (2012) found that when moving into internal rotation, from either a position of external or internal rotation, females had a significantly greater time to detect passive movement. Moving into internal rotation, especially while in extension, puts strain on the ACL and the lack of neuromuscular control could predispose females to an ACL injury (Barrack, Skinner, & Buckley, 1989; Nagai et al., 2012).

Koralewicz and Engh (2002) supported this finding when they examined the difference in proprioception between arthritic knees of females and males. Specifically, their test examined passive movement detection of either knee flexion or knee extension between males and females with arthritic knees. They found that women had significantly greater time to detection then that of males when moving both in flexion and extension. However, extension yielded more prominent results (Koralewicz & Engh, 2002).

Proprioceptive deficits in the knee between genders are not always present however. Pincivero, Bachmeier, & Coelho, (2001) also examined knee proprioception by testing movement detection starting from different knee angles, moving into flexion and extension. The researchers found no difference between the two genders across all their conditions (Pincivero et al., 2001). Therefore, there may be a specific testing condition that needs to be
met in order to illicit a proprioceptive difference between males and females. Further research is still needed to exactly understand the difference in knee proprioception between males and females.

**Summary**

Proprioceptive acuity of the knee is a very important factor with regards to functional movement and coordination. Feedback that helps provide this acuity primarily come from structures that are within, and surround, the joint. Specifically, these structures come in the form of mechanoreceptors within the muscles, tendons, ligaments, and fascia (Lephart et al., 1997). These mechanoreceptors can be influenced in a number of ways that can either heighten or diminish one’s ability to perceive accurate JPS. At the knee, accurate JPS is extremely important because the joint is extremely involved in locomotion (Ferber et al., 2003; Kadaba et al., 1990).

Furthermore, it is well documented that there are differences in the internal structure of the knee between females and males. These different structures cause the two genders to exhibit differences in their biomechanics and motor control, which, may also provide one explanation to their difference in proprioceptive acuity (Koralewicz & Engh, 2002; Nagai et al., 2012; Tillman et al., 2002). However, there are still many inconsistencies when examining JPS between the two genders (Pincivero et al., 2001). Therefore, comparing active JPS at different knee angles, between males and females may help provide more information and explanation on the differences in proprioceptive acuity between the two genders.
Chapter III

Methods and Procedures

Introduction

The purpose of this study was to test the effects of gender as well as to examine the differences between 30 and 60 degrees of knee extension on knee joint position sense (JPS). Specifically, an Apple iPod containing a preloaded customized application software to measures knee JPS was utilized to examine the absolute error in a position reproduction task. The iPod has been previously validated to be an accurate tool to measure knee JPS (Lyons, Cordell, Gossage, Suprak, & San Juan, 2016). The position reproduction task consisted of multiple randomized trials at two different knee extension angles in order to quantify JPS errors across positions.

The purpose of this section is to thoroughly describe the methods and procedures used within this experiment. Specifically, this section will contain a description of the subjects followed by the design of the study, instrumentation used, collection procedures, and data analysis.

Description of Subjects

The study consisted of a total of 46 subjects, 24 females and 22 males, between the ages of 19 – 25 years old. The subjects had an average height of 172.7 ± 8.4 cm and average mass of 71.2 ± 12.9 kg. All subjects were recruited from the campus of Western Washington University within the Health and Human Development department. All subjects were free of lower extremity injury. The study was reviewed by the university’s Human Subjects Committee prior to recruitment and all of the subjects gave their written informed consent prior to testing.
Design of the Study

A multiple participant, between-within subjects design was conducted. Prior to testing, subjects underwent a basic warm-up consisting of five minutes on a cycle ergometer at a self-selected pace. Subjects were instructed to refrain from high intensity exercise prior to testing. Furthermore, they were also instructed to wear tight clothing for testing in order to minimize stimulation of the cutaneous receptors in the skin.

Data Collection Procedures

Instrumentation. Subjects’ height and weight were measured on a Stadiometer (Detecto, Webb City, MO, USA). Prior to testing, all subjects underwent their warm-up on a Spinner cycle ergometer (Star Trac, Lake Forest, CA, USA). Subjects then were seated on a standard massage table to undergo their testing. An iPod Touch, 5th generation, Model PE643LL/A (Apple, Cupertino, CA, USA) was preloaded with a custom JPS software and served as our experimental data collection device. A neoprene armband (Tune Belt, Cincinnati, OH, USA), model #AB87 was utilized to place the iPod on the subject’s shank, in line with the fibula just above the lateral malleolus. A NFC Bluetooth speaker (Leesentec, Loggang District, China) was paired to the iPod in order to ensure subjects audible understanding of the commands given by the iPod.

Measurement techniques and procedures. Prior to testing, all subjects were informed of the testing protocol, as well as time commitment required. Subjects were also provided an informed consent document to further add to their understanding of the test. After all of the details had been discussed, measurements of the respective subject height and weight were taken. Additionally, leg dominance and history of injury were also determined. If any subject had a history of leg injury, they were excluded from the study. Leg dominance
was self-reported by the subject unless it was unknown. If leg dominance was unknown, subjects were prompted to kick a soccer ball on the ground and dominance was determined by the leg that performed the kicking motion.

Subjects began their 5-minute warm-up on a cycle ergometer. They were instructed to remain on a ‘comfortable’ resistance level throughout the duration of the warm-up. After their warm-up, subjects removed their shoes and socks as to not interfere with the iPod or neoprene sleeve. They then were seated onto a massage table and outfitted with the iPod. The seated position consisted of subjects sitting upright on a massage table, with the shank hanging off the table at approximately 90 degrees of knee flexion. The iPod touch was attached to the dominant leg, via neoprene sleeve, approximately 20 mm above the right lateral malleolus, in line with fibula. There was approximately 2.54 cm of space between the edge of the table and the popliteal surface of the knee as to avoid putting unwanted pressure on the gastrocnemius.

Once all the equipment was attached, the subject was given a practice trial with the JPS iPod application (JPS app) software in order to get familiar with the test. The practice trial consisted of three position reproduction tasks to 45 degrees knee flexion. 45 degrees of knee extension was selected in order to minimize any effect on the testing trials from the range effect, since the practice position was equidistant from the testing positions. During the practice, they could ask questions and were allowed to keep their eyes open. Once the official testing began, the subjects were instructed to keep their eyes closed and focus entirely on the position reproduction task. The official testing consisted of six trials in a randomized order, three trials moving to an angle of 30 degrees of knee extension, and three trials moving to an angle of 60 degrees of knee flexion. Because the initial position of the knee was at 90 degrees
of flexion at the start of data collection, the JPS iPod app considered this as 0 degrees or starting position. As a result, 30 degrees of knee extension on the JPS app corresponds to an actual knee angle of 120 degrees, whereas 60 degrees of knee extension corresponds to an actual knee angle of 150 degrees (Figure 1).

The JPS app takes the subject through a randomly assigned position reproduction task comprised of six total trials. Specifically, the software provides an auditory cue to signal the subject to extend their shank. Once they get to the target angle, the auditory cue stops and they hold the position for two to three seconds within a range of ±2.5 degrees of the set target angle. If the subject overshoots the desired angle, the software emits a high pitch auditory sound, indicating to the subject that they must lower, or flex, their shank back to the desired angle. Again, the desired angle is signified by the absence of any auditory cue. Once the subject reached the target and held the position for the allotted time, an auditory cue from the JPS app prompted the subject to return their shank to the starting position. After returning to the starting position for three seconds, an auditory cue from the JPS app prompted the subject to find the target angle, however this time without any auditory feedback. When subjects believed they had replicated the target position, they held the position until again, prompted by an audible cue from the JPS app to relax. Both the guided and unguided angles of extension were then internally saved in the iPod for later processing the repositioning errors. Errors were calculated as absolute errors by taking the difference between the unguided angle and the guided angle for each trial at both 30 and 60 degrees of knee extension. Next, the three trials at each angle were averaged to obtain an average reposition error at both 30 and 60 degrees for each individual subject. Lastly, the absolute value for each subjects reposition error was taken in order to quantify absolute error for both extension angles.
Data Analysis

Descriptive statistics of height, weight, and leg dominance were determined for each subject. SPSS version 21 (IBM Corp., Armonk, New York, USA) was used to perform the statistical analysis. A 2x2 mixed analysis of variance (ANOVA) was used to analyze the difference between gender as well as knee extension angle. The dependent variable consisted of absolute joint reposition error after the position reproduction task. In the case of a significant interaction effect, simple effect analyses were performed to specifically analyze the different levels. Significance was defined as a p-value less than 0.05.

Figure 1. Pictures depicting resting position (A), the 30 degree position (B), and the 60 degree position (C)
Chapter IV

Results and Discussion

Introduction

This study tested the hypothesis that females would have significantly greater joint position sense (JPS) error when compared to males, and that the 60 degree position will have significantly less JPS error when compared to the 30 degree position. The independent variables examined consisted of gender and knee extension angle. The dependent variable consisted of absolute error from the position reproduction task. A 2x2 mixed analysis of variance (ANOVA) was utilized to analyze the difference between the two position between both males and females. In the case of a significant interaction effect, post-hoc tests were utilized to further analyze the two extension angles between genders.

Results

Mauchly’s test of sphericity indicated that sphericity was not assumed for both gender and knee extension angle position. Therefore, the Greenhouse-Geisser correction was utilized. There was no significant interaction effect between genders and knee extension position ($F[1, 44] = 3.183, p = 0.081, \eta_p^2 = 0.067$). There was no main effect of gender on knee JPS ($F[1, 44] = 1.513, p = 0.225, \eta_p^2 = 0.033$) (Figure 2). However, there was a main effect of extension angle on knee JPS ($F[1, 44] = 8.015, p = 0.007, \eta_p^2 = 0.154$) (Figure 2). Specifically, the 30 degree position had an error of 3.44 degrees whereas the 60 degree position had an error of 2.18 degrees. Values for joint reposition error are reported in Table 1.
Figure 2. The difference in mean absolute reposition error at the 30 degree knee extension position and 60 degree knee extension position.

<table>
<thead>
<tr>
<th>Gender</th>
<th>30 degrees</th>
<th>60 degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2.73 ± 2.64</td>
<td>2.28 ± 1.59</td>
</tr>
<tr>
<td>Female</td>
<td>4.08 ± 2.40</td>
<td>2.09 ± 1.62</td>
</tr>
</tbody>
</table>

Table 1. Means and standard deviations of absolute joint reposition error for males and females across both 30 and 60 degree positions

Discussion

Joint position sense (JPS) assesses of proprioception be specifically examining an individual’s ability to sense where a certain joint is in space. Accuracy of this sense is important to complex movements and proper muscle activations. Though there is a
substantial body of research examining proprioception of the knee, there is limited research
which examines the differences in JPS between genders at varying degrees of knee extension.
Therefore, the aim of this study was to specifically test the differences in JPS between males
and females at positions of 30 degrees of knee extension and 60 degrees of knee extension.
We hypothesized that males would have less absolute reposition error than females and that
the 60 degree position would be more accurate than the 30 degree position.

The hypothesis that males would have a more accurate absolute reposition error than
females was rejected. According to the results there were no significant differences between
the error of males and females during their position reproduction test. Therefore, there may
be no difference in proprioceptive acuity of the knee between genders at these positions.
These results are in accordance with Pincivero et al., (2001) that examined the difference in
proprioception of the knee between males and females at different knee angles. Specifically,
they examined the time to detect passive movement at three different starting position,
corresponding to 15, 30 and 60 degrees of knee flexion. Across all positions there was no
difference between males and females.

However, to contrast, Nagai et al., (2012) also examined time to detect passive
movement at the knee between genders with motions of internal or external rotation. They
found that when moving towards internal rotation, females had a significantly greater time to
detect passive movement. It was theorized that this difference was caused by the anterior
cruciate ligament (ACL) or surrounding structures (Nagai et al., 2012). When the knee is
rotated into internal rotation, the ACL acts as a secondary restraint. The ligament will stretch
and take on a large amount of tension. During this stretch, the change in length and the
tension placed on the ligament will cause the capsuloligamentous mechanoreceptors within
the ligament to fire and provide proprioceptive feedback (Myers & Lephart, 2000; Schutte et al., 1987). It is for this reason that Nagai et al., may have found a significant difference between genders. The presented study may not have found any difference in proprioception because our trials may not have affected the parts of the knee that differ between males and females.

Tillman et al., (2002) indicated that the intercondylar notch of the femur in females is less round than in males. When the shank goes into extension the ACL and posterior cruciate ligament (PCL) fill the intercondylar notch of the femur. Therefore, difference in notch shape may affect the normal function of the ligaments when the knee is extended and consequently affect motor function and proprioception. The inconsistencies in knee proprioception between genders could possibly be attributed to the difference in knee anatomy between the two genders. However, the results found in the present study and in the study by Pincivero et al., (2001) indicate that the difference in notch shape may not play a role in proprioceptive function when performing only flexion or extension of the knee.

With regards to the differences in JPS at different positions of knee extension, the hypothesis that the 60 degree position would elicit a more accurate reposition error than that of the 30 degree position was accepted. According to the results, the 60 degree position had a significantly less absolute reposition error than that of the 30 degree position. Therefore, this study found that as the shank approaches a more extended position, an individual’s JPS will improve. This increase in proprioceptive acuity may be explained by a number of different reasons.

There are two main difference between the 30 and 60 degree positions tested in this study. Because the starting position of the position-reproduction task is roughly 90 degrees of
knee flexion, the 30 degree position corresponds to a knee angle of 120 degrees and the 60 degree position corresponds to a knee angle of 150 degrees. Roach and Miles (1991), indicate that the maximum knee range of motion is about 130 degrees of flexion. Therefore, the 30 degree position lies within the knee’s mid range of motion and the 60 degree position lies much closer to the knees extended end range of motion. Firstly, the different positions will put different strains on the internal structure of the knee and secondly, the different positions will be affected differently by gravitational torque and thus require different levels of muscle activation to maintain (Fuss, 1989).

In our test, as the knee became more extended, the moment arm of the shank increased and thus the overall torque demand increased. Therefore, the 60 degree position required a greater torque demand than that of the 30 degree position. It is well documented that as the torque demand on a joint increases there will be a potential increase in proprioceptive acuity at that specific joint (Bullock-Saxton et al., 2001; Suprak et al., 2007). The increase in torque demand will require an increase in muscle activation. With an increase in muscle activation there will be an increase in alpha and gamma motor neuron firing frequencies, which will maintain the sensitivity of the muscle spindles during the movement (Durbaba et al., 2001). Furthermore, the increase in torque demand will also increase the tension placed on the surrounding muscles. This increased tension may cause increased sensitivity of the Golgi tendon organs in the muscles which relay proprioceptive feedback (Houk, & Henneman, 1967). Therefore, a potential reason that our study exhibited more accurate JPS at the 60 degree position when compared to the 30 degree position could be due to the increased muscle activation caused by the increase in gravitational torque demanded by the given position.
Studies that have examined the shoulder joint have seen comparable results with regards joint position sense and gravitational torque. In a study by Suprak et al., (2006), shoulder joint position sense was examined at different degrees of elevation. Specifically, the different elevation angles were 30, 50, 70, 90, and 110 degrees. It was found that there was a linear decrease in reposition error as shoulder elevation angle increased. The smallest error was observed at the 90 degree position. As shoulder angle increased, the horizontal moment arm between the arms center of mass and the axis of rotation also increased. The increase in moment arm will cause an increase in gravitational torque placed on the joint. Furthermore, with an increase in gravitational torque, there will be a presumed increase in surrounding muscle activity and muscle tension, which was suggested to play a large role in proprioceptive feedback (Suprak et al., 2006). Our study found very similar results being that as the extension angle increased, the gravitational torque was greater, thus increasing proprioceptive acuity.

Specifically comparing to the knee, Bullock-Saxton et al., (2001) examined knee JPS between a full body weight and a partial body weight joint reposition test. It was found that the full body weight test had a significantly less reposition error than the partial body weight test. This study further supports the claim that tasks which place a greater torque demand on the knee joint will elicit a more accurate JPS. In addition, in the 20-35-year-old age group, the full body weight test had a reposition error of about 1.8 degrees where the partial body weight test had an error of about 2.2 degrees (Bullock-Saxton et al., 2001). These values are similar to ones found in this study, however our reposition errors are slightly less accurate (Table 1). It is possible that our values are less accurate because the overall torque demand required of our test came predominantly from gravity acting only on the shank. The torque
required during Bullock-Saxton and colleagues test was much greater because their test involved a closed kinetic-chain movement where the subject’s knee accepted body weight. It is theorized that if we tested JPS of the knee at a more extended position, where more gravitational torque is acting on the joint, reposition error would be more accurate and perhaps more comparable to Bullock-Saxton et al. However, the difference we found in our study between positions could also be attributed to the effect of these positions on the internal structures of the knee joint.

As discussed previously, the 30 degree position corresponds roughly to the knees mid-range of motion whereas the 60 degree position corresponds closer to the knees extended end range of motion. Another explanation of the results is that at the extension end range of motion, the ACL will become taut and therefore may provide proprioceptive feedback from mechanoreceptors which respond to tension (Fuss, 1989; Myers & Lephart, 2000). Therefore, the difference this study exhibited between positions could possibly be due to the increased tension on the ACL within the 60 degree position. Conversely, when the knee is close to its flexion end range of motion the PCL becomes taut and similar results may be seen with regards to heightened proprioceptive acuity.

Pincivero et al., (2001) also examined knee time to detect passive movement at different starting positions of knee flexion. Specifically, subjects laid prone with their shank hanging off of a table. The different position consisted of varying degrees of knee flexion while laying prone. Subjects were passively brought to the three starting positions and instructed to catch their shank when they sensed it start to extend. The positions coincided with 15 degrees of flexion, 30 degrees of flexion, and 60 degrees of flexion. They found that the most extended position, 15 degrees of flexion, had the most accurate time to detection
when compared to the 30 and 60 degree starting position. Furthermore, there was no difference in detection time between the 30 and 60 degree starting position. It was presumed that the tautness of the hamstrings and ligaments within the knee were greater at the 15 degree position, and therefore proprioceptive feedback was greater. This will cause proprioceptive acuity to be heightened at closer to terminal end range (Pincivero et al., 2001). When compared to our study, the 30 and 60 degree starting positions used by Pincivero and colleagues correspond to our 60 and 30 degree positions, respectively. It is possibly that because Pincivero et al., found no difference in time to detect passive motion between the positions, that our findings may be more attributed to the increased torque demand required from our protocol. However, the nature of the two tests is inherently different and therefore the true effect of position cannot be entirely confirmed with only the presented data.

This study provides valuable information on how gravitational torque and muscle activation can affect the proprioceptive acuity of the knee. However, in order to fully understand how JPS changes at different position within the range of motion of the knee, researchers will first need to accurately account for gravitational torque so that muscle activation does not determine the results. This study also further indicates that there is no difference in JPS between males and females at positions in varying degrees of knee extension in the dominant knees of healthy young adults during an unconstrained open-chain gross motor task.
Chapter V
Summary, Conclusion and Recommendation

Summary

Joint coordination of the knee is important to many variables surrounding locomotion. Though there are many parts of overall joint coordination, one predominant factor is joint proprioception (Sainburg et al., 1993). Accurate joint proprioception is imperative for complex movement and proper muscle activation (Ageberg, 2005; Mandelbaum, 2005). However, there are still many factors that remain unknown with regards to differences in knee joint position sense (JPS). One of these factors is how knee JPS is affected at different positions within the knee's range of motion.

During a normal gait cycle, the human knee will move through a portion of its range of motion. As gait velocity increases, the maximum knee angle will also increase (Kadaba et al., 1990; Novacheck, 1998; Sasaki & Neptune, 2006). Therefore, it is important to understand how JPS will change throughout this range. However, when joint position is held static it may experience a degree of gravitational torque. If the joint position changes, so too will the gravitational torque at that joint. Therefore, when testing JPS at the knee it is important to understand that different positions will correspond to different amounts of torque which may affect muscle activation surrounding the joint.

Furthermore, it has been documented that there are differences in proprioception with regards to males and females (Nagai et al., 2012). The difference exhibited could be due to the anthropometric or anatomical difference between the genders. However, the exact reason for these differences is uncertain as it has also been documented that there is no difference in proprioception between genders (Pincivero et al., 2001). A better understanding on the
difference in knee JPS between males and females at different positions may help researchers understand the proprioceptive difference between genders.

Therefore, this study examined the difference in knee JPS between males and females across 30 degrees and 60 degrees of knee extension. Specifically, this was done by examining the absolute reposition error after a position reproduction task. Furthermore, this was an unconstrained task performed by the dominant leg in healthy young adults. It was found that there was no significant difference between males and females in JPS. However, there was a significant difference between positions. The 60 degree position has a significantly more accurate JPS than the 30 degree position when both groups were combined.

**Conclusion**

The results indicate that there is no difference in knee JPS between the dominant knees of healthy males and females. Furthermore, the results indicate that there is a significant difference in knee JPS between position of 30 degrees of extension and 60 degrees of extension in the dominant knees of healthy young adults. Specifically, as the knee becomes more extended proprioceptive acuity was heightened. It is unclear whether this increase in proprioceptive acuity was derived from the increase in muscle activation due to increased gravitational torque or changes in internal anatomy of the knee between the two position. Therefore, future research is still needed to discern exactly whether the heightened proprioceptive acuity comes from the differences in gravitational torque or the differences in the anatomical structures of the knee between the two positions.
Recommendations

Proprioception and JPS are highly researched with regards to its effect on factors surrounding motor control. This study helps provide more information on how JPS differs between males and females. Furthermore, this study also provides valuable information on how JPS changes between a position within mid-range of knee motion and a position close to maximum knee extension. However, it is unknown whether our results directly correspond to the joint position or the amount of gravitational torque placed on the joint during the test. Future research should keep this in mind when examining JPS at the knee in healthy young adults.

Furthermore, because this study examined the JPS in young healthy adults, it may serve as a foundation for normative range in healthy knee JPS. 46 healthy young adults were tested for JPS in the knee of their dominant leg at positions of 30 and 60 degrees of extension, or knee angles of 120 and 150 degrees respectively.
References


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https://doi.org/10.1177/0363546504269591


https://doi.org/10.1016/S1063-4584(03)00160-2


https://doi.org/10.1053/apmr.2001.21865


Appendix A

Experimental Checklist

Protocol Checklist

<table>
<thead>
<tr>
<th>Subject ID:</th>
<th>Date: / /</th>
</tr>
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<tbody>
<tr>
<td>Informed consent signed: YES / NO</td>
<td></td>
</tr>
<tr>
<td>Informed consent understood, questions answered: YES / NO</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>Weight</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Does subject have a history of right lower extremity injury? YES* / NO</td>
<td></td>
</tr>
</tbody>
</table>

*if yes, subject must be excluded from the study

Discuss protocol:

1. We will demonstrate the leg movements necessary for this study
2. We will then notify the subject about the cuing noises on the JPS software that will let the subject know when they are at the target angle
3. The subject will then be instrumented with reflector nodes and an iPod with the JPS software via an iPod armband
4. We will make sure the thigh is level on the table using towels as support to prop the thigh up
5. The test will begin and the subject will find the target angles
6. 3 trials will be performed for each of the two angles and will be randomized

Test protocol explained to subject: YES / NO

Instrumentation completed on right side:

Reflector nodes:

- □ Greater trochanter of R. femur b.
- □ Lateral epicondyle of R. femur b.
- □ R. lateral malleolus b.

iPod:

- □ Armband applied to distal end of shank

YES / NO

NOTES:
Appendix B

Western Washington University
Consent to Take Part in a Research Study
Validity and Reliability of an iPod Touch in measuring knee joint position sense

You are invited to participate in a research study conducted by Jun San Juan, PhD, ATC, from the department of Health and Human Development at Western Washington University. The purpose of this investigation is to assess how valid the iPod touch in measuring your knee angle and if we can repeat this measurement in different days while giving us the same results. You were selected as a possible participant in this study because you have no history of pain or surgery to the knee.

If you decide to participate, you understand that the following things will be done to you. You will be asked to fill out a brief form to provide basic information such as age, height, weight and dominant leg. Non-invasive measurements will be made throughout the experiment. To perform motion measurements, reflective markers will be taped to your legs and an iPod Touch will be strapped by your ankle. You will be asked to move your leg based on the direction of the software application. First day of testing should take about 30 minutes. The second day of testing will take about 15 minutes.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help in understanding the validity and reliability of the iPod touch in measuring joint angles and ability to reposition the knee, and may guide decisions made in prescribing strengthening and injury rehabilitation exercise.

There are no potential risks involved in participating in the study, and you may discontinue participation at any time during testing.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data with subject numbers, rather than names.

Your participation is voluntary. Your decision whether to participate will not affect your relationship with Western Washington University. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

If you have any questions, please feel free to contact Jun San Juan, (360) 650-2336, Department of Health and Human Development, Western Washington University, Bellingham, WA, 98225. If you have questions regarding your rights as a research subject, contact, Western Washington University Human Protections Administration (HPA), (360) 650-3220. In the event that you suffered any research related injuries or adverse effects as a result of participation in the study, you should contact Jun San Juan and/or HPA. You have been offered a copy of this form to keep.

I have read the above description and agree to participate in this study.
Print Name_______________________________________________
Date____________________

Signature_________________________________________________

Note: Please sign both copies of the form and retain the copy circled “Participant Copy”

Research Copy                                               Participant Copy
## Appendix C

### Raw Data

| Females | | Males | | |
|-----------------|-----|-----------------|-----|
| Subject ID      | 30 deg | 60 deg | Subject ID | 30 deg | 60 deg |
| KJPSVR01        | 0.76  | 2.91          | KJPSVR03 | 3.58  | 6.35  |
| KJPSVR02        | 0.85  | 1.79          | KJPSVR06 | 10.13 | 1.79  |
| KJPSVR04        | 6.6   | 1.27          | KJPSVR08 | 2.52  | 2.91  |
| KJPSVR05        | 4.32  | 0.44          | KJPSVR11 | 2.85  | 3.03  |
| KJPSVR07        | 0.85  | 1.79          | KJPSVR15 | 1.13  | 0.67  |
| KJPSVR09        | 3.42  | 0.79          | KJPSVR16 | 1.21  | 0.95  |
| KJPSVR10        | 7.87  | 0.27          | KJPSVR18 | 2.88  | 5.41  |
| KJPSVR12        | 0.15  | 1.79          | KJPSVR22 | 5.58  | 0.29  |
| KJPSVR13        | 10.44 | 6.49          | KJPSVR26 | 0.26  | 1.01  |
| KJPSVR14        | 2.77  | 1.95          | KJPSVR29 | 1.24  | 0.81  |
| KJPSVR17        | 2.79  | 1.86          | KJPSVR31 | 0.98  | 1.4   |
| KJPSVR19        | 4.24  | 0.91          | KJPSVR34 | 4.3   | 1.13  |
| KJPSVR20        | 4.86  | 1.06          | KJPSVR35 | 1.37  | 4.07  |
| KJPSVR21        | 1.67  | 2.33          | KJPSVR36 | 2.18  | 1.2   |
| KJPSVR23        | 1.93  | 1.09          | KJPSVR37 | 1.13  | 3.48  |
| KJPSVR24        | 7.31  | 5.17          | KJPSVR38 | 7.77  | 0.29  |
| KJPSVR25        | 6.5   | 1.05          | KJPSVR39 | 0.16  | 3.21  |
| KJPSVR27        | 5.79  | 1.56          | KJPSVR42 | 3.2   | 3.1   |
| KJPSVR28        | 2.72  | 5.44          | KJPSVR43 | 3.2   | 3.1   |
| KJPSVR30        | 1.4   | 2.08          | KJPSVR44 | 2.64  | 1.37  |
| KJPSVR32        | 2.96  | 1.54          | KJPSVR45 | 0.88  | 1.1   |
| KJPSVR33        | 7.07  | 3.71          | KJPSVR46 | 0.93  | 3.52  |
| KJPSVR40        | 6.41  | 2.49          |              |      |      |
| KJPSVR41        | 4.26  | 0.4           |              |      |      |
Appendix D

Statistical Results

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